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A. MacS. Stalker

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ABSTRACT

The Kananaskis Research Forest-Marmot Creek Basin lies along the Kananaskis River within the front ranges of the Rocky Mountains, some fifty miles west of Calgary. The mapped area covers 54 square miles.

Four major glaciers are recorded, each smaller than the previous one. The first three advanced down Kananaskis Valley to join glaciers in Bow Valley, north of the area, but the fourth apparently terminated in the region of Barrier Lake, short of the Bow Valley. The first covered all but the highest points in the area but, as all the glaciers left very little drift in upland districts, bedrock is exposed over three-quarters of the area. Frost-produced rubble covers much of the unglaciated area.

The bulk of the surficial deposits are found in the valleys. They consist of: glacial deposits of outwash and valley fill; glacial and postglacial deposits laid down in streams and lakes during retreat of the last glacier, generally while Bow Valley ice blocked the north end of Kananaskis Valley; and postglacial stream, fan and mass wasting deposits. Ground moraine, fan deposits, and postglacial alluvium form most of the surficial cover, but outwash and lake sediment predominate in certain parts of the Research Forest.

The four glaciers probably span all Wisconsin, and perhaps some pre-Wisconsin, time. It is suggested that the last reached its maximum between 12,000 and 10,000 years ago, and that it corresponds to the Canmore advance in Bow Valley.

RÉSUMÉ

Le bassin du ruisseau Marmot et du projet forestier Kananaskis est situé le long de la rivière Kananaskis dans la chaîne Frontale des Rocheuses, à quelque cinquante milles à l'ouest de Calgary. La région cartographiée comprend 54 milles carrés.

L'auteur signale quatre principaux glaciers, chacun plus petit que le précédent. Les trois premiers descendaient dans la vallée de la Kananaskis pour rejoindre les glaciers de la vallée de la Bow. Le premier couvrait toute la région sauf les sommets mais, comme tous les glaciers, n'a laissé que très peu de moraine dans les hautes-terres, et la roche en place affleure sur les trois quarts de la région. De la blocaille produite par le froid couvre la plus grande partie des zones qui n'ont pas subi la glaciation.

La majeure partie des dépôts meubles se rencontre dans les vallées. Ils consistent en dépôts fluvio-glaciaires et de remplissage de vallée; de dépôts glaciaires et postglaciaires laissés dans des cours d'eau et des lacs pendant la retraite du dernier glacier, surtout à l'époque où la glace de la vallée de la Bow fermait l'extrémité nord de la vallée de la Kananaskis; et des cônes alluviaux et des accumulations de débris d'érosion postglaciaires. La moraine de fond, les cônes de déjection et les alluvions postglaciaires forment la plus grande partie de la couverture superficielle, mais les dépôts fluvio-glaciaires et les sédiments lacustres prédominent dans certaines parties du projet forestier Kananaskis.

La durée des quatre glaciers embrasse probablement tout le Wisconsin et peut-être un peu le pré-Wisconsin. L'auteur émet l'hypothèse que le dernier a atteint son apogée il y a environ entre 12,000 et 10,000 ans, ce qui correspond à l'avancée Canmore dans la vallée de la Bow.

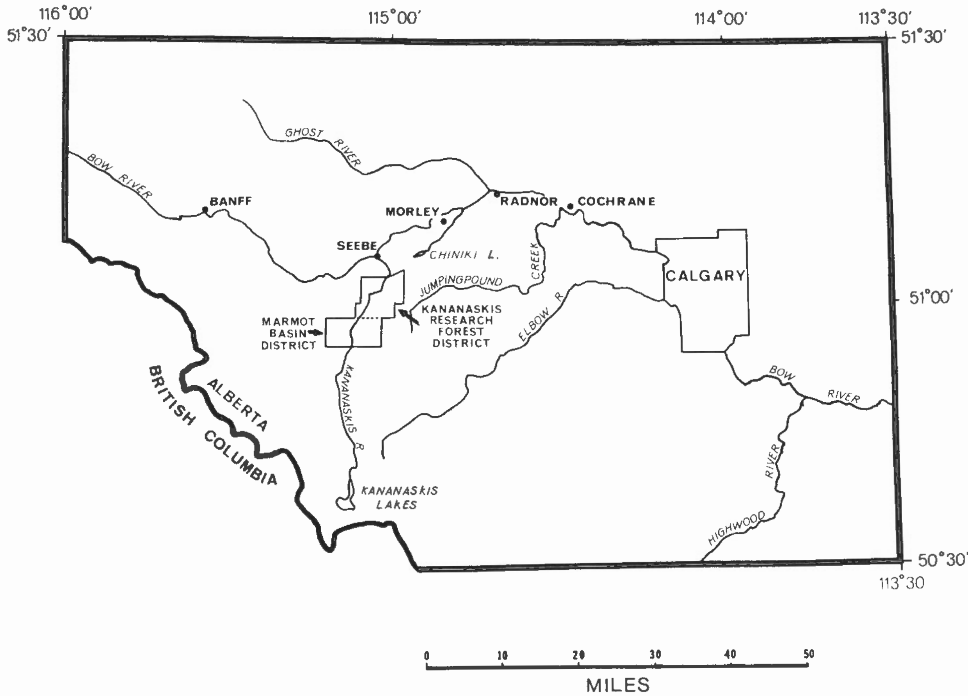

Figure 1. Index map.

SURFICIAL GEOLOGY OF THE KANANASKIS RESEARCH FOREST AND MARMOT CREEK BASIN REGION OF ALBERTA

INTRODUCTION

The Kananaskis Research Forest and Marmot Creek Basin region consists of two units (Fig. 1). The northern one, the Kananaskis Research Forest district, is found between 3 and 10 miles south of Seebe and 50 miles due west of Calgary. It lies within townships 23 and 24, range 8, west of the fifth meridian, Alberta, or within latitude 50° 58' to 51° 04'N., longitude 114° 59' to 115° 07'W. It includes the Kananaskis Research Forest of the Lands, Forest, and Wildlife Service, Department of the Environment, which for more than forty years has served as a permanent site for intensive studies in forest management and ecology and, more recently, for watershed management, insect disease, and physiology investigations. Since 1966, a University of Calgary Environmental Science Station has also used the site for studies in biology and ecology.

The second unit is entirely encompassed by the south two-thirds of tp. 23, rge. 9 and the west half of tp. 23, rge. 8, W. 5th mer. (lat. 50° 55' to 50° 58'N.; long. 115° 03' to 115° 12'W.), Alberta. It is named after Marmot Creek which empties into Kananaskis River from the west about 2 miles southwest of the Research Forest boundary, or some 7 miles southwest of the Forest headquarters. Its basin has been the scene of important studies by the Canadian Forestry Service into watershed characteristics and management.

Field work for the study was conducted during the summer of 1965. The report is intended to supply background information on surficial geology and history of glaciation which is necessary for proper understanding and evaluation of the other studies mentioned above. Unhappily, comprehension of local events during the Quaternary Period is still inadequate, and must remain so until more is known about events in nearby areas, and especially to the north in Bow Valley.

Topography and Climate

Topography is shown on Canada National Topographic Series sheets 82 O/3 east (Canmore) and 82 J/14 east (Evans Thomas Creek), which depict the area on a scale of 1:50,000 (approximately 1.25 inches to 1 mile), and with a contour interval of 100 feet. All elevations given are estimated from those maps.

The Research Forest-Marmot Basin region lies entirely within the rugged, southeast-striking, front ranges of the Rocky Mountains. Relief in the area ranges from 4,400 feet a.s.l. in the north, where Kananaskis River leaves the map-area, to more than 9,000 feet in sec. 21, tp. 8, rge. 24, W. 5th mer., in the southwest. The Kananaskis River, which flows north to enter Bow River at Seebe, a few miles north of the Research Forest, roughly bisects the area. Farther south this river follows a valley between two of these ranges but, within the map-area, it crosses several of them. The only flattish districts are near this river, which is paralleled by the Coleman-Seebe Forestry Trunk Road. This road is the best access route into the area.

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The Research Forest region receives an annual precipitation of between 20 and 25 inches, the larger part in summer, and the average annual temperature ranges between 33 degrees and 38 degrees F. Precipitation in Marmot Basin seems much greater, particularly at high altitudes. Obviously, in a mountainous area such as this, these figures can change greatly from place to place.

Previous Work

In his 1943 report on the Moose Mountain and Morley map-areas, Beach described the bedrock geology of the northern part of the area on a scale of 1 inch to 1 mile and Crockford (1949) did the same for that section of the southern part of the area lying west of Kananaskis River. Also in 1949, MacKay depicted the southern half of the area on a scale of 1 inch to 4 miles. This work by Crockford and MacKay was aimed largely at promoting development of coal resources in the Ribbon Creek district. The most comprehensive report on the whole Research Forest-Marmot Basin region is by Crossley (1951). Although basically a description of soils, his report also deals with topography and climate, portrays the bedrock geology on a scale of approximately 1 inch to 2 miles, and gives a brief description of both the bedrock and surficial geology. That report is still the best source of information on most of those topics. In addition, Beke and Pawluk (1971) made a detailed study of volcanic ashes and soil development in Marmot Creek Basin and Walker (1971) investigated the interaction of glaciers in the Kananaskis and Bow Valleys, mapping most of the present area and a larger area to the north in Bow Valley. His work included numerous till fabric and mechanical analysis studies of the various deposits in the area. His main conclusion that concerns us was that the last ice to occupy the stretch of the Kananaskis Valley within the present area came from the Bow Valley to the north, rather than from farther south in the Kananaskis Valley.

Acknowledgments

While mapping the area during the summer of 1965, the writer received the utmost co-operation and aid from everyone connected with the Research Forest. He extends his thanks to M. H. Drinkwater, then Regional Director of the Canadian Forestry Service, J. Krewaz, then superintendent of the Research Forest, and all the staff of the Research Forest for the facilities provided and the many kindnesses extended. P. J. B. Duffy of the Canadian Forestry Service gave freely of his time and valuable knowledge of the region he had accumulated during intensive forest site classification studies, and made many of the arrangements for this study. He also provided an unpublished report (Duffy and England, 1967) containing both a thorough forest land classification for the Research Forest and a detailed map of surficial materials on a scale of 4 inches to 1 mile. G. J. Beke, now with the Canadian Forestry Service, supplied much useful information on the Marmot Creek Basin. The enjoyment of the field work was greatly enhanced by the valuable services of Paul Johnson, assistant to the writer in 1965.

GENERAL GEOLOGY

Non-surficial Deposits

Preglacial Deposits

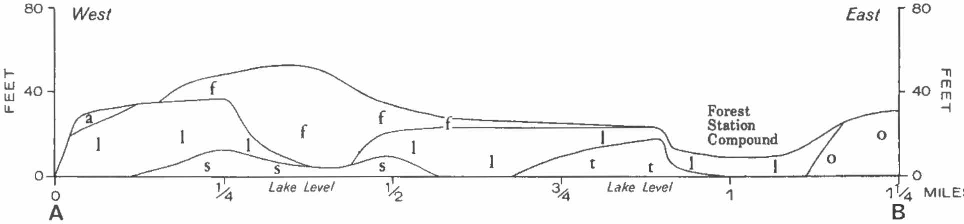
Bedrock. Bedrock is exposed throughout the high districts but, within the valleys, it is normally covered by drift, slide material or alluvium. Areas of outcrop are indicated on the surficial geology map (in pocket). Paleozoic formations of quartzite, limestone and dolomite underlie most of the area and determine its general character. Their more resistant beds form the rough hills and conspicuous, southeast-trending ridges. The Mesozoic formations found in the northeast and southwest, on the other hand, give smoother, gentler slopes and lack the sharp ridges, cliffs and hills seen in the older rocks. These Mesozoic formations consist mainly of shale and sandstone, with lesser amounts of limestone, conglomerate and coal. Apart from the gross features, the character of the exposed bedrock surface varies vastly in other ways. Where the bedrock has long been exposed to frost action, above the limits of glaciation (see surficial geology map, in pocket), large parts of the sandstone and shale formations are thinly covered with broken, angular rubble, and the upper part of the dolomite and limestone formations is strongly fissured and fractured, giving a surface generally covered by loose, angular blocks. These latter fragments are, in general, much larger than those found over the sandstone and shale formations. On the other hand, in the glaciated districts including those affected solely by the earlier glaciers, the ice removed most of the rubble and eroded and smoothed the bedrock surface, resulting in a marked contrast with those districts above the limit of the thickest glacier.

In many places the type of local bedrock strongly affected the composition and characteristics of the surficial materials seen directly above. This effect is well demonstrated in the tills, whose properties change markedly from one bedrock formation to another. The effect is less conspicuous in the stream and lake deposits of the main Kananaskis Valley, but the local bedrock plays a major role in determining the properties of the slide and solifluction deposits.

Surficial Deposits

The surficial geology map (in pocket) shows the areal extent of the various surficial deposits, and Figures 2, 3 and 4 show diagrammatic cross-sections through some of them. The deposits vary rapidly in the area, both horizontally and vertically, and in the mapping small changes generally had to be neglected. As a result, the map boundaries outline areas consisting principally of the material indicated without any attempt to show lesser amounts of other materials that might be present, whereas organic materials, such as bog deposits, are ignored. Deposits which help to explain the history of the area or which had important bearing on formation of soils or on tree growth, are emphasized.

The surface deposits tend to be thin and discontinuous in upland districts. Only in a few places are thicknesses known in the valleys, for the base of the fill is normally hidden and no borings have been made. They may



t: till

s: modern slump

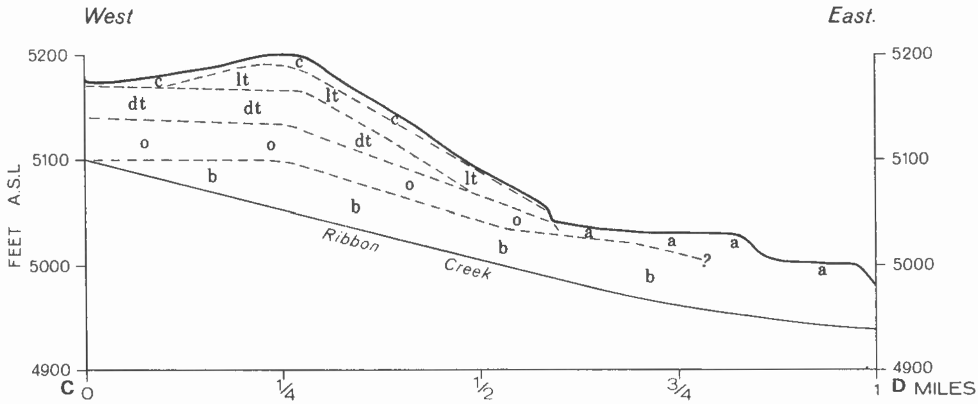
o: outwash sand and gravel

l: lake silt, sand, minor clay

f: fan deposits, mostly sand and subangular gravel

a: alluvial sand and gravel of Kananaskis River

Figure 2. AB: hypothetical cross-section through deposits on south side of Barrier Lake, between points AB as shown on surficial geology map.



b: dark shale bedrock

o: sand and gravel outwash

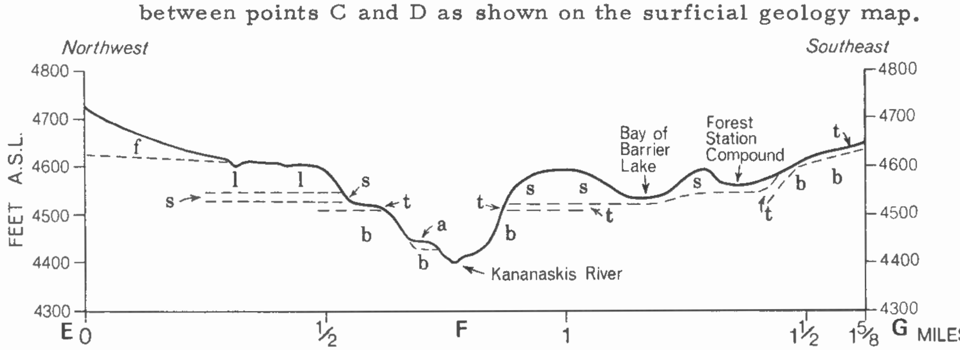
dt: dark till from Ribbon Valley

lt: light till from Kananaskis Valley

a: alluvial gravel and sand on terraces of Kananaskis Valley

c: covered by growth or slump

Figure 3. Hypothetical cross-section, on south side of Ribbon Creek, between points C and D as shown on the surficial geology map.



b: dark shale bedrock

t: buff, sandy till

s: fine lake sand and silt with scattered stones

l: lake silt, minor clay

a: alluvial sand and gravel of Kananaskis River

f: fan deposits, mostly sand and subangular gravel

Figure 4. Hypothetical cross-section, at northeast end of Barrier Lake, between points E, F and G as shown on the surficial geology map.

be substantial as exposures in terraces along Lusk Creek reveal depth of as much as 200 feet of surficial material, with bedrock still concealed. Equivalent or much greater thicknesses could well be present in parts of Kananaskis and Ribbon Creek valleys.

Four glaciations have been recognized in the area, and for convenience these are referred to, from oldest to youngest, as glaciers I, II, III, IV (see Historical Geology chapter, also Fig. 5). Surficial deposits of preglacial age have not been recognized and are not likely to be found. Intense erosion by the various Pleistocene glaciers and streams would have removed any such deposits from the valleys, whereas it is not likely that they were ever widespread in high districts. In addition, any such deposits that did survive in high areas would be so modified by frost action and mass movement processes, besides lacking diagnostic fossils or other features necessary for determination of their age, that they would be difficult to identify as old. As a consequence, the surficial deposits are divided into: early glacial, including those from the times of glaciers I, II, III combined; late glacial, or all those associated with the time spanned by the advance of glacier IV to, and subsequent retreat from, the middle or lower (northeast) end of Barrier Lake and perhaps including some left during the retreat of glacier III; glacial and postglacial; and postglacial. These terms are used solely as a convenience in this report, in a relative sense only. They do not have other time import.

In general, early glacial deposits are only found above the upper limits of glacier IV, and this is the chief means of distinguishing between them and the late glacial deposits. Thus, early glacial deposits are mapped only in the southwest (Marmot Basin) part of the area, where they lie above the limits of glacier IV. This criterion does not always hold, however, for that glacier terminated at Barrier Lake, but deposits contemporaneous with it are found over much of the northern part of the area, and undoubtedly some early glacial deposits are present in the high parts of the Research Forest district, farther northeast, that were not covered by the last glacier. In particular, the ground moraine area west of Lusk Creek, in tps. 23 and 24, rge. 8, may be early glacial in age. There is great difficulty in correlating the early glacial deposits of the southwest and the deposits in the high parts of the Research Forest district. However, because most of the deposits of the Research Forest district are associated with meltwater from glacier IV, or were deposited or modified under influence of glaciation in Bow Valley, and as the others are difficult to recognize, all the deposits exposed in the north half of the area are mapped as late glacial. In time it may be possible to classify some as early glacial.

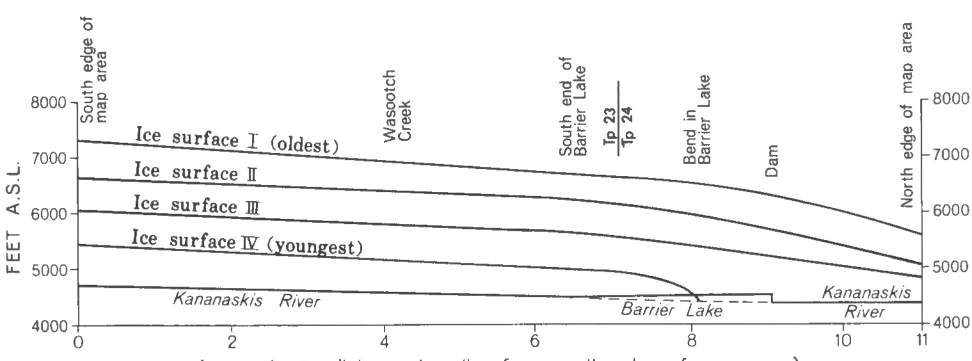


Figure 5. Approximate upper limits of the four glaciers recognized in Kananaskis Valley.

References to strength of soil development, such as well or poorly developed, relate to the general pattern found on surficial deposits solely in this area. All soils in the area would be considered as poorly developed in comparison to those found in many other regions. Similarly, statements about degree of forest growth refer to this area only, where the best tree growth present is much poorer than in many outside areas where the climate is more propitious.

Early Glacial Deposits

Ground moraine. Ground moraine from the earlier glaciers is widespread in the Marmot Basin district, although its continuity is commonly broken by bedrock outcrops or by burial under a thin mantle of colluvium or a thick mat of organic material. Its general thickness is probably about five feet, but it is much thicker where it fills basins in the underlying topography.

This early glacial ground moraine is composed typically of a stony, compact, dark brown to reddish brown, till. Its stones came directly from the fragmented bedrock surface rather than from previous stream gravels, and so tend to be angular; most are small, and many are striated. The compactness, clayiness, and dark colour of the till derive chiefly from its high content of the local, dark, Cretaceous shale. These traits may, however, be due in part to strong weathering and soil formation on this ground moraine, for the amount of weathering and thickness of soil do appear to be greater upslope in the areas of early glacial deposits. There is generally a marked change above the limits of glacier IV. This upward increase in weathering may result from both the longer exposure to the processes of weathering and soil formation in those upland areas, and the greater precipitation there.

The elongate hill, nearly a mile long, shown on the surficial geology map (in pocket) in sec. 23, tp. 23, rge. 9, W. 5th mer. has a characteristic drumlin shape. However, as this hill parallels the local bedrock strike, it is probably not composed fully of till but is rather a bedrock ridge that has been moulded and smoothed by overriding ice, with only a thin overlay of the till just described.

Most of the early glacial ground moraine carries a well-developed soil and is heavily forested. As it is generally found in high districts, severe climate may be the major factor in controlling plant growth on it.

Stream deposits. The only stream deposits or alluvium of possible early glacial age are in the spillway found in sec. 14, tp. 23, rge. 9, W. 5th mer. They are thin, sandy, and of small extent, and are thus of little use.

Late Glacial Deposits

The late glacial deposits include ground moraine, stream alluvium, and the various types of glaciofluvial deposits laid down by water in contact with, or flowing from, a glacier. These last deposits include the esker ridges built behind the ice front, and the kame terraces, various types of outwash, and some valley fill formed in front of the ice.

Ground moraine. Small areas of late-glacial ground moraine are exposed in Kananaskis Valley at low altitudes on the south side of Barrier Lake, near the former terminus of glacier IV, and in terraces along the valley. In addition, a small quantity of recent (Neoglacial?) till is found in cirques at high altitudes in the Marmot Basin region. Otherwise, the late-glacial ground moraine is a surface feature at intermediate altitudes, or those altitudes below continuous bedrock outcrop and below the early glacial deposits but above the districts that were strongly scoured by streams or covered by postglacial deposits. In addition, ground moraine is probably common beneath the lake deposits, outwash, and alluvium in Kananaskis Valley (see Figs. 2 and 4).

The late glacial ground moraine laid down by Kananaskis ice consists of two varieties, depending upon provenance. A light-coloured phase, found mostly in Kananaskis Valley, is buff or light grey in colour, stony, sandy and silty, weakly cemented with lime, and contains numerous large boulders, many of them striated. It owes these features mainly to a large content of Paleozoic quartzite, limestone and dolomite. The other phase, which in many respects resembles the early glacial ground moraine described previously, is a dark brown till found chiefly in areas of Cretaceous shale. The two phases are found together near the mouth of Ribbon Valley, where it meets the Kananaskis Valley. There the buff till overlies the dark one (Fig. 3) and, evidently, ice flowing down Ribbon Valley reached the confluence of the two valleys and laid down a thick deposit of the dark till before the Kananaskis glacier arrived. When that glacier did reach the area sometime later, it not only did not destroy the earlier till deposit, which was partly protected by being within the confines of Ribbon Valley, but superimposed its own layer of buff till.

The small patch of ground moraine in N. 1/2 of sec. 15, tp. 24, rge. 8, W. 5th mer. was deposited at much the same time as the rest of the late glacial ground moraine, but by Bow rather than Kananaskis ice.

Esker deposits. An esker ridge 5 to 15 feet high is mapped in sec. 11, tp. 23, rge. 9, W. 5th mer. It was formed by a stream that flowed north and slowly downslope along the side of Kananaskis Valley. It has supplied gravel for a local road crossing it, but as vast quantities of other gravel are present nearby, it has little economic importance. The other esker ridges in the area are smaller.

Outwash. Outwash is widespread in the Research Forest district, but it is a complex deposit, difficult to map, and its boundaries are commonly indefinite. On the map it is divided into coarse and fine. The coarse outwash is found chiefly on high ground, particularly in sec. 2, tp. 24, rge. 8, W. 5th mer. and, although it consists mostly of coarse, poorly sorted gravel, it also includes much sand and till. Its surface is generally rough and, on the basis of composition and morphology, its mapping as recessional or kame moraine could be justified. It was laid down by meltwater along a downhill-retreating ice margin.

The fine outwash lies mostly on low ground. It consists typically of sand and silt, although beds or lenses of medium gravel are common and scattered boulders to one foot in length are present. The stones are much better rounded than those in the coarse outwash. In many exposures it displays quiet water, ripple-marked, sediments. Most of the fine outwash deposit resembles a pitted plain type, not having the kame moraine aspect of the coarse outwash. The headquarters compound of the Research Forest lies in one of the larger pits or kettles, one that was later flooded by lake water. South of the compound the outwash is thin, and an underlying, pinkish buff till locally shows through.

The outwash was laid down in a sequence of closely spaced episodes as one of the ice sheets withdrew from the area; as the ice was retreating downhill the lower the outwash, the younger it is. Its time of deposition is not known, but it may have been during the retreat of glacier III. Its surface has been strongly modified by wind, especially near and east of the headquarters compound, and some low dunes are present. This modification most likely took place either immediately following retreat of the ice before vegetation was restored or else during the postglacial Altithermal episode when tree cover may have been much reduced.

The outwash is porous and so soaks up water readily, and in most places it has been stable long enough to develop a fairly good soil. These factors encourage dense tree growth. Most of the outwash also offers good foundation conditions.

Valley fill. Valley fill includes most of the material in the terraces along Lusk and Stony creeks. It is thick, thicknesses of 200 feet being common. On the map the deposit is divided into low and high terrace phases. The low terrace phase, which includes the lower one half to two thirds of the deposit, consists chiefly of sand with some silt and, in places, thin beds of gravel; locally, as in NW. 1/4 sec. 11, tp. 24, rge. 8, W. 5th mer. on the southwest side of Lusk Creek below the confluence of Stony Creek, it is mostly gravel, although even here the amount of sand does increase downward. The high terrace phase, or the upper one half to one third of the valley fill, consists chiefly of medium to coarse gravel and sandy gravel with subround to round stones. As a result, the high terrace along Lusk and Stony creeks, which lies entirely on the upper part of the deposit, contains much more gravel than the low terrace.

At the site just mentioned in sec. 11, tp. 24, rge. 8, limestone and dolomite form more than 70 per cent of the gravel, and the percentage is even higher amongst the smaller stones. About 10 per cent of the gravel is Cretaceous sandstone, another 10 per cent quartzite or very hard sandstone, and a few igneous stones of unknown origin, but probably from sills in the mountains, are present. Walker (1971, appendix C) obtained similar amounts of carbonates from his stone counts in that district, and most of the gravel in the valley fill probably has a somewhat analogous composition.

Originally, the valley fill probably spread right across Stony and Lusk valleys up to the present level of the highest terrace. Following its deposition, Stony and Lusk creeks incised deeply into it and formed the two main terraces. The upper terrace is best displayed on the north side of Stony Creek, the lower on the southwest side of Lusk Creek along the lower two miles of its course. Both terrace surfaces, but especially the upper, have been strongly altered by local stream erosion and gullying, locally abetted by slumping. This dissection is particularly noticeable in the angle between Lusk and Stony creeks, where most of the original, upper terrace surface has been destroyed leaving a complex mixture of ridges and valleys. Elsewhere fans have spread out over the terraces; once again the upper terrace has been affected most.

The valley fill is included with the late glacial deposits because, evidently, most of its upper part, and perhaps much of its lower part, were laid down while glacier IV was still active a short distance up Kananaskis Valley, and because the ice occupying Bow Valley at that time had great influence on its deposition, chiefly by raising the base levels of the various streams. The fill was deposited in valleys that had just previously been occupied by ice at least to the level of the highest terrace, and some of it may have originated as outwash from slowly melting ice lying in the upper stretches of Lusk and Stony valleys. The east-facing, apparently ice-front, scarps of the terraces in Lusk Valley, in SE. 1/4 sec. 13, tp. 24, rge. 8, W. 5th mer., indicate that ice still remained in the upper part of that valley at least during part of the time the terraces were being formed. The situation in Stony Valley is less clear. The terraces were formed much as follows. First, as the advancing Bow ice raised local base levels in Kananaskis Valley, Lusk and Stony creeks started to aggrade. Whether or not this aggradation first began during the penultimate glaciation (glacier III) is not known, but it is very likely that it did. It certainly continued and was important while glacier IV was near its greatest expanse. Then, as the Bow glacier corresponding to the Kananaskis glacier IV started to recede, the base levels in Kananaskis Valley lowered causing Lusk and Stony creeks to incise deeply into the newly formed deposits. A pause in retreat of the Bow glacier apparently halted the downcutting long enough to permit formation of the lower terrace. After that the streams resumed the downcutting that has continued to this day.

The porosity of the valley fill allows easy infiltration of water. This, along with good rooting conditions, encourages dense tree growth in some places. Elsewhere, however, the water seeps away so readily that there isn't enough left to support much tree growth. Areas near the terrace rises are subject to frequent slumping due to the steep slopes, general weakness and instability of the material and, in places, to stream undercutting along the base of the rises.

Glacial and Postglacial Deposits

Glacial and postglacial deposits include those whose deposition started towards the end of glaciation but while ice was still nearby and exerting strong influence, and whose deposition continued for a time after the ice had withdrawn completely. In many cases their deposition still continues, although at a lessened rate and over reduced areas, and consist chiefly of lake and stream sediments.

Lake deposits. Lake deposits cover only a small part of the area, and their total area of exposure is about one square mile. Some small patches, consisting mostly of sand, were laid down in front, or along the margins, of the last glacier as it lay near its maximum extent and therefore in areas not otherwise affected by that ice, or along the margins of the ice as it retreated. In some places those small patches of lake material have since been covered by, or mixed with, alluvium, colluvium, outwash, and organic material.

Most of the lake deposits, however, lie in the lower segment of Kananaskis Valley in the northeast part of the area. Lake deposits are probably extensive there, but they are generally buried under other material, chiefly fan and alluvial. They are exposed only on the north side of Barrier Lake, particularly near the power dam, and in a few cuts along the shores of the lake where they are as much as 80 feet thick. They consist mostly of silt, which is extremely stony in its basal part, that was deposited while the retreating Kananaskis glacier was still nearby. Upwards the silt becomes less stony and contains a lot more clay, and much of its upper part is varved.

This large-scale ponding in the lower part of Kananaskis Valley developed during the time of glacier IV, when Bow ice blocked the northern end of the valley. As the Bow ice thickened, the lake apparently expanded southwestward up valley until it reached the foot of the Kananaskis glacier. Later it spread even farther south as that glacier retreated from its terminal position at the north end or middle of the present Barrier Lake, and put down the lake deposits found along the margin of that lake. However, as Bow ice was probably now also receding, the lake level may have been dropping at the same time.

Modern Barrier Lake occupies the central part of a segment of the valley in which glacial lake deposits seem to be entirely absent, although they are found around its margins and across the full width of the valley farther down. Two explanations for this absence of lake deposits from the middle of the valley at that spot appear plausible. The first is that the water ponded in the vicinity of Barrier Lake did deposit sediment right across the valley to about the height of the sediments we now see in the terraces along the valley sides. Then, upon drainage of the lake, Kananaskis River started to cut its present valley through the centre of those sediments, removing all but the remnants we now see. However, before much incision had taken place, the river spread the thin mantle of gravelly alluvium now found over much of the lake sediment, which has vastly decreased the areal exposure of the lake sediment. The other possible explanation is that ice occupied the centre of the valley while lake sediments were being laid down in water ponded around its margins. Then, when the ice melted, the river started flowing through the low area in the centre of the valley, leaving the marginal lake sediments practically untouched. These form the remnants we now see around the shores of the present lake. The author believes this second explanation is the better, although it does not account for the widespread mantle of alluvial gravel found over much of the lake deposits, nor for the lack of stones in their upper part. Also, with such an origin, one would expect the terraces to contain kettle holes left upon melting of buried ice blocks, but kettles are rare except near the Research Forest headquarters.

As was the case with the glacial valley fill, deposition of the sediments in the large lake in Kananaskis Valley was controlled primarily by the ice lying in Bow Valley, which blocked the exits from Kananaskis Valley and so determined the lake level.

The surface exposures of lake deposits tend to have good soil and valuable timber stands.

Stream deposits. Glacial and postglacial stream deposits are found in a few small spillway valleys in the north half of the area. Some of those spillways are so small they can be shown only by symbol. In the larger spillways the deposits consist of gravel and sand, and in the smaller ones of silt and sand. Meltwater streams deposited most of them but, even after the ice had disappeared, small streams continued to supply some debris.

Postglacial Deposits

The postglacial deposits were laid down by lakes, streams, and the processes of mass wasting after the glaciers had retreated from the local area and after they had ceased to have any influence upon local features, either directly or through control of stream flow or lake levels. The term postglacial is thus used in a local sense only and has no absolute time connotation. Many types of these deposits, such as talus, colluvium and alluvium, are still being laid down.

Stream deposits. Postglacial stream deposits are an extensive and important surficial deposit, being exposed over 5 or 6 square miles. They include the alluvium along present and recent stream floodplains and the delta deposits or alluvial fans found where streams enter other bodies of water. Most are found in Kananaskis Valley and its tributaries, in places buried by fan or pond deposits. The only important alluvial fan is found where Ribbon Creek enters Kananaskis Valley, and the largest delta where Kananaskis River enters Barrier Lake.

The postglacial stream deposits range from silt to coarse gravel, gravel forming the largest component. In general, the valleys tributary to Kananaskis River that have a steep gradient, such as the valleys of Ribbon and Stony creeks, have coarse, poorly sorted and angular gravel. Along Kananankis River itself the gravel is better rounded and sorted than in its tributaries, and it tends to become finer downstream as the valley gradient lessens; the deltaic flats presently being built at the south end of Barrier Lake are chiefly medium to fine gravel. Most of the alluvial silt and sand is found on the floodplains, both past and present, of Kananaskis River and the lower part of Wasootch Creek. Undoubtedly much silt has settled on the bottom of Barrier Lake since it was formed by the power dam about 25 years ago. Although the writer understands that the rate of sedimentation in that lake has not been studied, the extent of delta building at the south end of the lake and the amount of debris being carried into the lake indicate that it should be high.

On the map the postglacial alluvium is divided into old and young phases. The two phases are similar in appearance, but the older was laid down between the departure of the ice and the time Kananaskis River and its tributaries had nearly reached their present grades, whereas the younger phase is found in the present floodplains and meander belts of the river and its tributaries. Unlike the younger phase, the older deposits are rarely, if ever, flooded by the present river. It is doubtful if Kananaskis River is degrading much at present, and the level of its modern floodplain appears fairly stable.

The porous nature of the stream deposits encourages dense and rapid tree growth. Trees on the younger alluvium, however, are always in danger of destruction from shifting of the river channel, spring floods, or floods caused by beaver dams. The forest on the older alluvium is more secure, and it contains some of the best timber stands in the area.

Fan deposits. Individual fans are delineated on the map. The fan deposits are the most spectacular, most interesting, and probably the most important surficial deposits in the area, even though they cover only three or four square miles, and they deserve much more study than has been given them.

More detail on the composition and construction of fans can be found in Ryder (1971). Most of the large fans of the area are in the Kananaskis Valley, and particularly on its northwest side. The thicknesses of very few are known, but some of the fans are probably well over 100 feet thick near their apex, though they thin rapidly towards their margins.

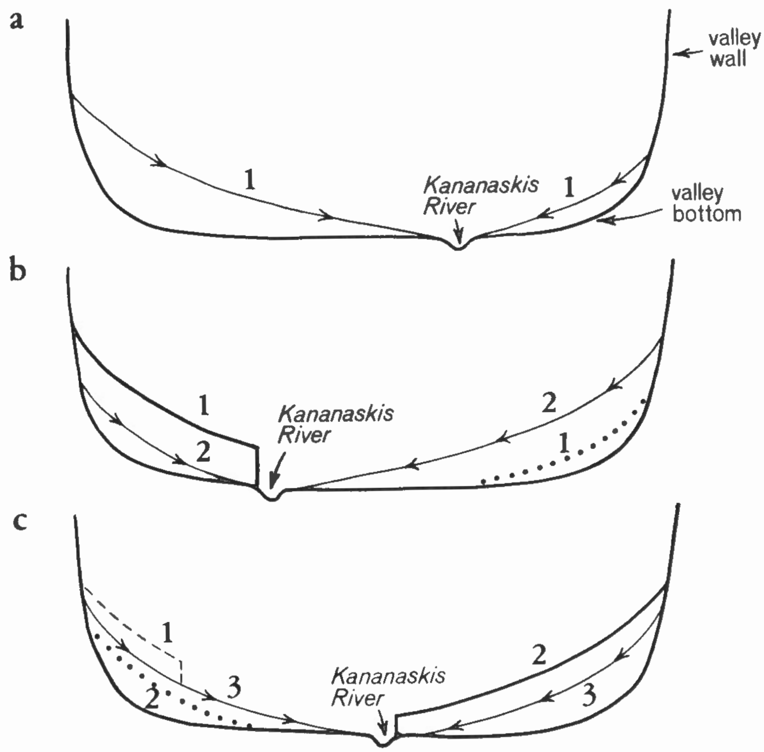
Composition of the fans ranges from coarse, angular gravel to silt, and the nature of the material within them is commonly reflected in the slope of the fan surface. Thus, a steep slope normally overlies coarse material, and a gentle one silt or sand. Unless they were originally picked up in a rounded condition, their stones are generally angular to subangular, reflecting their short distance of transport. Much of the material is poorly sorted and massive, particularly near the apex where bedding is only rudimentary. In general, the stones become better rounded, the bedding becomes more distinct, and the proportion of sand and silt increases away from the apex, with increasing distance of transport across the fan and lessening surface slope. At the outermost margins of large fans, where slopes are gentle, the material may resemble lake deposits. In the intermediate parts of the fans, where bedding is still poor but silt and sand content is increasing, the material commonly resembles till. The two are easily distinguished, however, for striated stones are abundant in the tills of the area but infrequent in the fan material.

In addition, the coarseness of the material changes vertically within a fan. For instance, if a fan increases in thickness it normally spreads outwards at the same time, and fine material being added to the fan is carried an even greater distance towards those margins. Also, with this thickening and expansion, its surface slope at any single point tends to steepen, with deposition of coarser debris there and removal of more of the fine material. As a result, the material in any part of a fan should coarsen upward, but the complicated history of most of the fans results in many deviations.

Neighbouring fans constantly interact, and their boundaries change rapidly and drastically. Normally, if undisturbed, a large fan expands at the expense of adjoining, smaller ones, but outside factors often interfere. In this area, for instance, a swing of the Kananaskis River towards the fan can cause the stream of a large fan to downcut drastically, permitting small adjoining fans to encroach. Also, small fans can grow on temporarily inactive parts of large ones, even if other parts of the large fans are still growing. The overall result is a very complex structure and size distribution of material.

The fans of the area are at many different stages of development, as indicated in Figure 6. In some, the fan streams are incising into their previous deposits whereas, in others, they are aggrading and enlarging the fan. Some fans display cliffs along the Kananaskis River, whereas others slope smoothly to the present river floodplain. All in all, perhaps more so than any other forms in the area, the fans should be regarded as animated, constantly changing features with a cyclical development. Some hypothetical stages in the cycle of one of the typical fans are shown in Figure 6.

As the last ice withdrew, the fans along the Kananaskis Valley started to form wherever an intermittent stream tumbled over the steep valley walls, and they have continued to develop ever since. With unchanging conditions, a fan grows until its surface reaches an equilibrium with the river level, after which any further material added to the fan by the fan stream will be approximately compensated for by material removed by the river along the fan margin (Fig. 6a).



a - fans grade to river on right side of valley

b - river shifts to left side of valley, fan streams grade to new river position form new fan set 2, bury former fan 1 on right side, incise into and remove fan 1 on left side; cliff forms where river encroaches on former fan 1.

c - River shifts towards centre of valley, fan streams now adjust to new river course, form fan set 3, bury fan 2 on left where part of fan set 1 still survives as terrace, incise into fan 2 on right where there is no longer any indication of fan set 1; cliff forms where river erodes into right fan 2.

Figure 6. Cycle in the development of fans in Kananaskis Valley 1, 2 and 3 - successive sets of fans

Even then, with general equilibrium reached, small changes still take place from year to year. For example, excessive spring run-off can bring in more coarse debris than normal and steepen the overall slope of the fan surface but, over several years, the size and shape of the fan remains relatively stable, any excess material being removed from its foot by the river. At this stage the fan can expand only if the river grade rises or if growth of the fan is sufficient to displace the river towards the far side of the valley.

If the climate of the area remains relatively constant, equilibrium will continue until the Kananaskis River either starts incising, which will decrease the volume of the fan, starts aggrading, with the opposite effect, or until the river merely shifts course while maintaining approximately the same grade (Fig. 6b). In this last case, if the river encroaches on the foot of the fan, perhaps due to a meander working its way downstream or due to a fast-growing fan on the far side deflecting the river, the fan stream downcuts and also erodes laterally as it seeks a new equilibrium, and the fan diminishes in size. If the river now maintains its new course long enough, a new equilibrium will be reached, and the fan will be greatly reduced in size (Fig. 6b), but parts of the old fan may survive for a time in the form of terraces rising above the new surface of the fan (Fig. 6c). At this time, adjoining fans have an opportunity to encroach upon its margins and, if there is a fan on the opposite side of the river, it will take this opportunity to expand until it reaches a new equilibrium. Finally, as the river again veers towards the far side of the valley (Fig. 6c), the first fan is rejuvenated and starts to grow anew, seeking a fresh equilibrium. In this manner a new cycle starts, but numerous interruptions and variations in the pattern are possible before such an equilibrium is reached.

Thus, the history of any of the large fans in Kananaskis Valley can be very complicated, and this is reflected by their complex structures and compositions. The cycles will repeat until either the valley walls retreat sufficiently to stop normal fan development or until the river starts to incise deeply or the valley becomes clogged with fill and the river grade rises, either of which will necessitate the fresh development of fans at a new level and cause the cycles to start anew. It is difficult to determine how many such cycles any single fan has undergone, but the last glaciation in Kananaskis Valley was probably too recent to have permitted very many. However, the cyclic phenomenon undoubtedly explains the many stages of development which the fans display. The slow downcutting by Kananaskis River, which now appears to be nearly stopped, probably has had only a negligible effect on the development of the fans.

The fans are well drained, seepage of water into them is rapid, they are composed of stable material, and they can generally support good tree growth. However, the fan surfaces are changed constantly as the fan stream veers from one part of the fan to another, or alternately degrades and aggrades. The changes are not sudden and drastic, such as those caused by landslides, but rather steady and continual modifications. Results of such changes are well depicted by the alternate washing out or burial of those portions of the road, on the northwest side of the Kananaskis Valley, that cross the fans. The apical area is most subject to change, but there is rarely time to develop a good soil on any part of a fan before it is buried or removed, and major construction or long-term vegetation studies on most of the fans are probably ill-advised.

Mass wasting debris. In a few places, mass wasting products formed by slow, downhill movement of material due to sheet wash, solifluction processes, or frost action, are found. Generally, the deposits are less than ten feet thick. In low areas they commonly are mixed with smaller amounts of stream or lake deposit, and they may incorporate other materials such as volcanic ash bands or soils. They consist mostly of poorly sorted silt, clay, sand, commonly with abundant organic debris, but in many places they are coarser, depending largely upon slope and mode of deposition.

The mass wasting debris is of little value. Much of it occupies low, poorly drained areas and so offers poor foundation conditions whereas, in higher areas and on steeper slopes, it tends to be unstable and its surface is in constant, slow movement.

Talus debris. Talus and mixed talus and colluvium cover small areas below some steep slopes. They differ from fan deposits chiefly by being at the angle of repose, by being formed of much larger, fresher, and more angular pieces of rock, by their situation at the base of very steep cliffs, and by being gravity deposits laid down without the aid of water or ice. Much of the talus, in fact, consists almost completely of large blocks derived directly from the bedrock; the colluvium is generally much finer and consists of whatever material was available for incorporation.

As with the fan material, deposition of the talus in any area started as soon as the glacier withdrew from that area - any earlier talus that fell on the ice was carried away by the glacier as drift - and its deposition continues. The present talus deposits started to form sooner in districts that were covered solely by the earlier and thicker glaciers than in those regions that were strongly scoured by the last glacier but, as formation of those deposits still continues, all the talus and colluvium is included with the postglacial deposits. The most extensive deposit, which is in the Marmot Basin district, grades from mostly talus at high altitudes to mostly colluvium at lower ones.

The talus and colluvium are in a state of constant change, due to continual addition of fresh material and to slow, downhill creep caused partly by freezing and thawing. These areas have only poor, if any, soil, they are rough, and are useless for most purposes. Obviously, no major projects should be undertaken on such unstable or even dangerous areas.

Volcanic ash. Volcanic ash is not shown on the surficial geology map because nowhere does it form the surface cover, but it is exposed in a few vertical cuts. Although the ash has a limited extent and its total volume is insignificant, it has much potential value for purposes of chronology and correlation. Beke and Pawluk (1971), while investigating soils in Marmot Basin, made the only detailed study of the ashes that is presently available, and they indicate the locations of some of the deposits. Interestingly, on their map showing sampling sites and volcanic ash distribution in Marmot Creek Basin, the lower limit of ash distribution is near the upper limit of the last Kananaskis glacier, which would seem to indicate that its deposition predated glacier IV. On pages 665-666 they state:

> "Layers of volcanic ash, commonly interbedded with colluvium (the mass wasting debris of this report), occur throughout most of the basin. The ash is of Mazama origin, and is dated at approximately 6700 B. P. Fragments of charcoal commonly occur as bands or admixed within the ash layers and the overlying colluvium. When banded, the charcoal probably reflects the chronology of colluvium deposition, whereas when admixed, it likely results from the burning of roots as well as from mass wasting processes."

Outside the area described by Beke and Pawluk (1971), a borrow pit on the southeast side of the forestry road in NW. 1/4 of sec. 22, tp. 23, rge. 8, W. 5th mer. shows a three inch band of slightly pinkish, white ash lying between sand and silt, whereas the east bank of Kananaskis River in LSD. 14, sec. 10, tp. 24, rge. 8, W. 5th mer., about 500 feet downstream from the dam and about 5 feet from the surface, displays a discontinuous ash band in weathered deposits of silt and stony silt. The enclosing material both there and at the borrow pit resembles that described by Beke and Pawluk for their ash bands. It contains several firebands, or evidence of past grass or forest fires, and consists partly of slump or colluvium. Neither of these ash exposures has been studied but they could very well be Mazama ash, like those described by Beke and Pawluk (1971). There is also no reason why they could not be from a younger ash fall.

HISTORICAL GEOLOGY

Introduction

Despite the comprehensive studies by Walker (1971) of the area near the confluence of Bow and Kananaskis valleys and of glaciation farther up the Bow Valley by Rutter (1972), deciphering of the Quaternary record in the Kananaskis Research Forest - Marmot Basin area is still handicapped by inadequate knowledge of related events in the general region. This lack of information is particularly acute for the sector of Kananaskis Valley extending south from the map-area, for not only did the glaciers that affected the present area have their source there, but that region also holds the key to the evolution of events following recession of the last glacier from the area. As a result, glaciation here can only be described in local terms, disassociated from events elsewhere.

The features of the area demonstrate a sequence of glaciers in Kananaskis Valley, each lower, less extensive, and shorter than the preceding one, until finally, it is assumed, they were restricted to the valley south of the map-area. Each glaciation of the valley was accompanied by glacier formation in the larger side valleys and most of those, during the more severe glaciations, joined and augmented the trunk glacier in Kananaskis Valley. Also, each Kananaskis glaciation was accompanied by nearly contemporaneous glaciation in Bow Valley, farther north. Between glaciations, streams cut notches into the bottoms of the glaciated valleys that enabled the next glacier to carve yet deeper, or else strewed alluvium over the valley floor. During large parts of those interglacial intervals the topography of the area must have closely resembled its present aspect.

Glaciation

The first glacier to leave a record was also the thickest. This does not mean that there were no glaciations in the area; undoubtedly there were. However, in an area subject to strong stream and ice scour, such as this one was, each glacier practically obliterated all trace of any preceding one in any area it covered. As a result, the thickest glacier was almost bound to be the first to leave any record that is still preserved, and that record is confined to high districts that were not overrun by later and lower glaciers. Similarly, following the first glacier recorded, there may have been glaciers of intermediate thickness whose traces have also been destroyed by thicker, succeeding ones. In other words, the glaciers for which we have evidence in this segment of Kananaskis Valley, four in number, are confined to those which, each in turn, exceeded the altitude obtained by any succeeding one, and whose record is preserved above or beyond the limits of those succeeding ones (<u>see</u> Fig. 5). For convenience, the four glaciers that have been recognized are numbered I to IV, from oldest to youngest. There is no way to determine how many other, unrecorded glaciations there were in Kananaskis Valley; probably there were many.

The area occupied by each of the four recognized glaciers is indicated on the surficial geology map, and their respective upper limits in the valley on Figure 5. At their maximum, glaciers I to III were tributary to glaciers occupying Bow Valley and, as long as they continued to be tributaries, the Bow ice controlled their thicknesses. As a result, the highest Kananaskis glacier did not necessarily have the largest ice discharge, even though it was the thickest, for its greater size may merely have reflected a greater thickness of the corresponding glacier in Bow Valley, to which it adjusted, and its movement may have been sluggish. However, as Bow and Kananaskis valleys are not far apart and are affected by similar weather patterns, glacial events in Kananaskis and Bow valleys probably corresponded closely, the largest glaciers being coincident, and their maxima nearly so.

It is thought that glaciers I, II, III, and IV were discrete events, separated from each other by full withdrawal of the ice from the area, although the situation with regard to the interval between glaciers III and IV is somewhat ambiguous. Several factors indicate such complete withdrawals. First, the subaerial deposits of the earlier glaciers, particularly in the Marmot Basin district but also east of Barrier Lake, are notably more weathered and modified those of the last glacier, indicating a significant age difference. Second, the shape and profile of certain side valleys tributary to the main Kananaskis Valley indicate an interval of stream erosion before advance of the last glacier. This is well illustrated in both Wasootch Valley and the unnamed valley directly north of it. In those, the U-shaped, cross-valley profile, characteristic of glaciated valleys and formed by the glacier IV advance, is lost a mile or two above the junction of those valleys with Kananaskis Valley. Also, below those termini, the basal part of the V-shaped profile inherited from earlier and larger glaciers has been destroyed by stream erosion, and the valley bottoms do not display any features indicating recent glaciation. The upper part of the V-shaped profile and other effects of those earlier and thicker glaciers can still be seen, however, higher up the valley walls. All in all, the downstream segments of those valleys indicate a long episode of uninterrupted stream erosion, which in turn implies that the interval between glacier III and the less extensive glacier IV was long, and also that the terminus of glacier IV in those valleys represented more than a mere standstill during a recession of the ice from more advanced positions. Third, Kananaskis Valley was sufficiently ice free during one interglacial interval to allow the glacier flowing down Ribbon Valley to deposit a sheet of till near its confluence with Kananaskis Valley. Evidently Ribbon Valley ice reached this point before the corresponding Kananaskis glacier arrived to deposit the overlying layer of till shown in Figure 3. For this to happen, Kananaskis Valley must have been ice free at least that far upvalley. This deposition is thought to have taken place during advance of glacier IV but, if glacier III did not recede that far upvalley before the advance of glacier IV, it may have occurred between glaciers II and III. These factors taken together suggest considerable, though undetermined, time lapses between the various glaciations.

The altitude of each of the four ice surfaces along much of Kananaskis Valley, as indicated approximately in Figure 5, is represented by discontinuities in the slope of the valley walls, by truncated spurs, and by hanging valleys and cirques. Each glacier must have remained near its maximum height for an extended time in order to produce such well-developed disconformities. Except with glacier IV, that height was controlled by the thickness of ice in Bow Valley, which must also, therefore, have maintained a stable thickness for a long time. Extrapolation of the three highest ice surfaces shown in Figure 5 northward to the south edge of Bow Valley indicates they were graded to glacier surfaces in the Bow Valley of approximately 5,100, 4,700, and 4,600 feet respectively. This, in turn, indicates that the corresponding Bow glaciers near the confluence of the two valleys had thicknesses of about 800, 400, and a meagre 300, feet. Obviously this 300-foot-thick Bow glacier did not extend much farther east. Rutter (1972) suggested that his Canmore advance descended the Bow Valley to about the 4,200-foot contour, which would be 2 or 3 miles east of the confluence of the Kananaskis Valley, and so this 300-foot-thick glacier (coeval with glacier III) would appear, at first glance, to be the Canmore advance. However, ice was apparently also present in that part of Bow Valley during the time of Kananaskis glacier IV, and it is more likely, as discussed later, that glacier IV corresponded to the Canmore. Possibly another, as yet unrecognized, ice advance of about the same magnitude as the Canmore advance took place in the Bow Valley between the Bow and Canmore advances and was the contemporary of Kananaskis glacier III. Indeed, Walker (1971, p. 42-44) found some indication of a previously unrecognized till in the nearby part of Bow Valley that might, possibly, represent such a glaciation.

If it were not for the moraine in sec. 15, tp. 24, rge. 8, the spillway directly west of it, and the lake deposits in the lower part of Kananaskis Valley, the possibility of ice-free conditions in that part of Bow Valley during advance of Kananaskis glaciers III and IV would have to be entertained. By itself, the surface gradient of glacier III would have allowed it to terminate a few miles inside Bow Valley, which is about five miles wide in that sector, and glacier IV did not, of course, reach Bow Valley. However the lake deposits dating from the time of Kananaskis glacier IV and found in the lower part of Kananaskis Valley were formed under influence of ice lying in Bow Valley, (the spillway valley was in use at that time) and Bow ice lay against the moraine. Hence the last Bow and Kananaskis glaciers in that region were partly, if not fully, contemporaneous, and ice certainly stretched down Bow Valley as far as Kananaskis Valley at that time. Glacier III was so much thicker than glacier IV, as shown by the relative altitudes of their surfaces, that it is logical to assume that the Bow glacier corresponding to it was at least as thick and reached equally far downvalley.

As shown on Figure 5, the surface gradients of the four Kananaskis glaciers increased greatly in the last few miles before their termini. Upvalley from the sector of higher gradient, the surfaces of the glaciers sloped downvalley at between 70 and 90 feet per mile, or about double the present stream valley gradient of some 40 feet per mile.

Glaciers I and II

The approximate limits of the areas covered by glaciers I and II are shown on the surficial geology map (in pocket), and the postulated maximum altitudes of those glaciers along Kananaskis Valley are shown in Figure 5. In general, the surface of glacier I was 400 to 600 feet higher than that of glacier II. Apart from their heights and approximate extents, little else is known about those glaciers, for subsequent glaciers destroyed most of the features they formed. No deposits are known from glacier I, but some from glacier II are exposed over a small part of Marmot Basin.

Glacier I covered the whole map-area, except for the top of Barrier Mountain in secs. 33 and 34, tp. 23, rge. 8; and in sec. 4, tp. 24, rge. 8 and the higher parts of the Marmot Basin district in secs. 9, 16, 21; tp. 23; rge. 9; W. 5th mer. The cirques in the southern half of the area were graded to the top of this glacier, and probably developed at that time. The previously mentioned change upward from a fairly smooth bedrock surface, which has seen the removal of most of its rubble, to a rubble-strewn, rough bedrock surface, takes place near the upper limits of this glacier.

During the maximum of glacier II, and also possibly during the maximum of glacier I, thick ice in Bow Valley diverted much of the Kananaskis meltwater east via Lusk and Stony valleys to Sibbald Creek (east of the map-area) and thence, perhaps by Jumpingpound Valley, into Bow Valley beyond the terminus of the Bow ice. The highest altitude on that route is about 5,000 feet a.s.l. Then, as glaciers I and II retreated, the meltwater used the lower route from the northeast corner of the map-area towards Lake Chiniki, whose present divide is about 4,425 feet a.s.l. During both glaciations, after separation of Bow and Kananaskis ice during their retreat, some of the drainage down Bow Valley may have spilled southeastward through the valley found in the north part of sec. 15, tp. 24, rge. 8 to reach and follow this Lake Chiniki spillway.

Glacier III

More is known about glacier III, chiefly because many of its features and deposits remain untouched in areas that the thinner and less extensive glacier IV failed to reach. It advanced down Kananaskis Valley as far as Bow Valley, overran the region of the Research Forest station, and evidently advanced a short distance up Lusk and Stony valleys to join any ice that had collected in those valleys and east of Barrier Mountain. It undoubtedly slowed the flow of that ice down those valleys causing it to pile up and, for a time, that district must have been thickly covered with nearly stagnant ice. Although its relationship with the Bow glacier is not known, it was probably strong enough to keep Bow ice from advancing up Kananaskis Valley. Much of its meltwater undoubtedly flowed eastward along the Lusk-Stony valley system until ice retreat uncovered the lower, Lake Chiniki, route.

Kananaskis glacier III received much ice from tributary glaciers in Ribbon, Wasootch, and other valleys, and also probably from cirques in the north half of the area that appear graded to its upper limits. It may even have received ice from Bow Valley across a divide northwest of sec. 23, tp. 23, rge. 9, as was suggested by Walker (1971, p. 60). The presence in that section of the elongate, drumlin-shaped hill, mentioned previously under Early Glacial Ground Moraine, would seem to corroborate this. The situation of that hill is peculiar, however. It lies just southeast of a small, weakly glaciated valley that could hardly have produced sufficient ice flow by itself to mould such a large feature, and so it would appear that the flow must have been augmented by ice from Bow Valley. In addition, the logical time for such diffluence from Bow Valley was during glacier III, for Kananaskis glaciers I and II were probably thick enough to prevent flow across the divide, while during glacier IV ice did not reach to the height of the divide. However, although this elongate hill may indicate that the Bow Valley did furnish ice at least once to a glacier in Kananaskis Valley, the amount must have been small, for its passage had remarkably little effect on the topography of the divide between the two valleys.

Glacier IV destroyed or buried with outwash and other materials many of the retreatal features left by glacier III. However, most such features found in the area east of the Research Forest headquarters evidently date from the time of glacier III. There glacier III retreated downslope and some of the small spillways or channels shown on the map mark its successive margins. It left behind small and thin patches of lake sediment, areas of till, and complex mixtures of outwash and recessional, or kame, moraine. Much of the fill in Lusk and Stony valleys may have originated then, although those creeks later added more and the final thickness of the fill and heights of the terraces carved in that fill were determined later, mainly by ice occupying Bow Valley during the time of glacier IV. Early during the withdrawal of glacier III, the ice in the upper reaches of Stony Valley, and perhaps also in Lusk Valley, apparently separated from the main body of the glacier, which was retreating downhill. Following the separation it stagnated and, while melting, spread outwash down the valleys and also formed the east-facing scarps found in the valley in SE. 1/4 of sec. 13, tp. 24, rge. 7.

Neither the extent of ice retreat before advent of glacier IV nor the length of that interval are known. If the basin now occupied by the north half of Barrier Lake and the nearby kettle holes represent depressions left by the melting of ice blocks remnant from glacier III, which were buried by lake sediment during the time of glacier IV, then the interval was short. If glacier IV originally advanced down valley past the limits indicated on the surficial geology map – a possibility discussed later – the ice blocks may have been remnants of that maximum advance left behind when it receded to the limits shown on the map, near the bend in Barrier Lake. This latter possibility is considered the more likely, and both the extent of ice retreat and length of the interval before advance of glacier IV were probably substantial.

Glacier IV

Glacier IV was much smaller than the other three glaciers, and its extent within the map-area was only about one quarter that of glacier I. It alone of the four glaciers failed to reach Bow Valley or to invade the districts north of Barrier Lake and near Lusk and Stony creeks. However, the limits of its maximum advance are hidden by lake water, lake sediment, and outwash. Very likely this glaciation had two phases. An early, short-lived phase may have seen the glacier occupy the whole basin of Barrier Lake as far as the present power dam, and some of the surrounding country, though the ice block depressions give the only support for glacier IV ever having advanced that far north; it has left no moraines nor indications on the valley walls there. In phase two, the part of the glacier lying in the northeastern half of the lake basin, or that part beyond the bend in the lake, stagnated, and the active part of the glacier terminated near the limits shown for glacier IV on the surficial geology map, about halfway down the lake. There the glacier made its main, and probably a long, stand during which the slowly melting; stagnant ice remnants farther down the basin were being buried beneath lake sediment and outwash. This is the simplest explanation for the formation and preservation of the depressions forming the present basin of Barrier Lake and the nearby kettles.

The difference in elevation between the surfaces of glacier IV and of the preceding glacier was less than that between glaciers I and II or II and III. Nevertheless, glacier IV was substantially lower than any of the other glaciers, although it actively eroded the valley walls, and its former surface is marked by a noticeable discontinuity in the slope and character of the valley walls.

The maxima of Kananaskis glacier IV and of the corresponding ice advance in Bow Valley were nearly synchronous, and Bow glacier controlled the development of many of the features that formed at that time in the lower part of Kananaskis Valley. The Bow glacier expanded to the north edge of the area where it built a moraine part way across Kananaskis Valley in the N. 1/2 of sec. 15, tp. 24, rge. 8. Originally that moraine was probably longer, but the postglacial Kananaskis River destroyed its eastern part. Some of the stream flow down Bow Valley was diverted, by the ice lying in Bow Valley, through the spillway found directly west of the moraine at about 4,600 feet a.s.l. and it built a delta in section 15 where it entered Kananaskis Valley. This water then followed the south edge of Bow glacier across Kananaskis Valley to join Kananaskis drainage flowing down Chiniki Valley toward Bow Valley a few miles farther northeast.

With Bow glacier sealing off its normal outlet to the north, the lower part of Kananaskis Valley was flooded to a height, determined by the level of Chiniki outlet and Bow ice farther down valley, of about 4,600 feet a.s.l. Most lake deposits in that region were laid down during that stage, including those burying the remnant, stagnant ice towards the north end of Barrier Lake and near the Research Forest compound. Most of this lake sediment came from heavily laden streams flowing from Kananaskis and Bow glaciers, but some originated in Lusk Valley. The upper terrace along Lusk and Stony creeks was graded to a level determined by the lake and the Chiniki outlet. The lower terrace formed later when base levels were lower. This may have happened after Chiniki outlet was abandoned and Kananaskis River had started to follow its present course along the lower part of the valley, though at a higher level than now.

Bow ice had only to retreat a short distance to withdraw fully from the map-area and to lose its influence there. When it did so, the spillways in sec. 5, tp. 24, rge. 8 and down Chiniki Valley were abandoned and most of the ponded water in the north half of the area disappeared. At the same time glacier IV was receding up Kananaskis Valley and, while doing so, spread a mantle of valley train down valley and formed the small eskers and spillways found in sec. 11, tp. 23, rge. 9. There is no indication of any halt in its retreat through the map-area after it abandoned its position halfway down Barrier Lake.

Chronology

Any chronology developed for the area must, at present, be highly speculative for, although some of the Quaternary events in the local area can be described, they cannot be correlated readily with events elsewhere in North America nor placed in their proper temporal perspective. For instance, it is not known whether the events described previously (glaciers I to IV) spanned a major part of the Quaternary Period, just the whole of the Wisconsin Glacial, or whether they were confined to Classical Wisconsin and later time. At a minimum they probably embraced most of the Wisconsin Glacial.

Rutter (1972) has recognized four glaciations in the upper part of Bow Valley and has tentatively correlated them with the Rocky Mountain glacial sequence developed in the United States. He names these glaciations, from oldest to youngest, the pre-Bow Valley, Bow Valley, Canmore, and Eisenhower Junction advances. Walker (1971) tied his sequence for the area near the confluence of Bow and Kananaskis valleys into Rutter's sequence. However, a general lack of material suitable for radiocarbon dating or of diagnostic fossils has prevented confirmation of the suggested correlations.

The third, or Canmore, advance of Rutter was the final one to reach the vicinity of Kananaskis Valley. Through long range comparison with events in the United States, he tentatively correlates this advance with the middle Pinedale Stade. Then, through comparison with dated deposits on the north side of North Saskatchewan River, west of Saskatchewan Crossing on the Banff-Jasper Highway in Banff National Park, he suggests that the Canmore advance ended before 9,300 years ago; how much before is difficult to determine. This reasoning implies that ice last occupied Bow Valley near Kananaskis River during middle Pinedale time, and more than 9,300 years ago. However, the absolute time of the middle Pinedale advance is still unkown, though Richmond (1965, p. 227) indicated it ended about 12,000 years ago.

Rutter (1972) suggested that the Canmore advance descended Bow Valley to an altitude of about 4,200 feet, or about two or three miles east of the confluence of Kananaskis Valley. That would place its terminus far enough east to block the end of that valley and to direct its drainage along the Chiniki Lake route, but not far enough downvalley to block the lower end of that route. As Kananaskis glacier IV reached its maximum during the last occupancy by ice of the nearby Bow Valley it should, at least in part, correspond to the Canmore advance in age, or middle Pinedale if the correlations are accepted.

Some terraces along Bow River at Cochrane (Fig. 1), about 25 miles east-northeast of the confluence of Bow and Kananaskis rivers, furnish additional information about time of glaciation. These terraces have yielded an interesting vertebrate fauna (Churcher, 1968) with an apparent age of slightly more than 11,000 years.[1] In discussing these terraces Stalker (1968, p. 1465) concludes:

> "The mid-time during deposition of the Bighill Creek Formation (the formation in which the terraces are cut) was about 11,000 years ago, and deposition of the whole formation probably continued throughout most of the period 12,000 to 10,000 years ago. Its deposition came about when glaciers in Bow Valley, and also probably in Kananaskis Valley, advanced considerable distances downvalley, and then stabilized for an extended time at their forward positions."

It would appear that the material in the Cochrane terraces was deposited between 12,000 and 10,000 years ago as Bow ice made its last extensive, or Canmore, advance and then retreated rapidly with the outpouring of vast quantities of meltwater. However, the terminus suggested by Rutter for the Canmore advance, at about 4,200 feet altitude, would be 25 miles upvalley from Cochrane, and the coarse gravel and large boulders found in much of the terrace deposit would seem to preclude a source that far away.

It is suggested here that the Canmore advance originally reached another 15 or so miles downvalley, to the vicinity of the present dam at Radnor

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[1]Radiocarbon dates GSC-612 (10,760 ± 160 B.P.); GSC-613 (11,370 ± 170 B.P.); GSC-989 (11,110 ± 160 B.P.).

near the confluence of Ghost River, east of the present map-area (see Fig. 1). It soon retreated, accompanied by a great outpouring of gravel and sand, and then made a prolonged stand at the terminus just below Kananaskis Valley, at about the point indicated by Rutter. This suggested sequence resembles the two-phase division propounded above for Kananaskis glacier IV, in which that glacier originally descended to the north end of Barrier Lake, soon followed by a retreat of two or three miles to its point of longest stand.

Rutter (1972, p. 41) states:

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

He further states (p. 16):

> "In the lower part of the Bow Valley, southeast of the east gate of Banff National Park, till of the Bow Valley advance cannot be distinguished from younger till deposited during the subsequent Canmore advance."

At present it cannot be determined whether or not Kananaskis glacier IV embraces both the Bow and Canmore advances of Rutter and also both the early and middle Pinedale of Richmond. However, considering the length of the interval between glaciers III and IV as indicated by the increase in surface weathering above the limits of glacier IV and by the change in valley character below its termini in Kananaskis and Wasootch valleys described earlier, it probably corresponds solely to the Canmore. If so, glacier III could then correspond in age to either the Bow advance or to an as yet unrecognized advance down Bow Valley that took place after the Bow advance but before the Canmore. The latter appears the more likely, because glacier III was graded to a Bow glacier similar in thickness to the Canmore advance but thinner than what would be expected for the Bow advance. The discovery by Walker (1971, p. 42-44), mentioned earlier, of a previously unrecognized till in the Bow Valley north of the Kananaskis lends some support to this reasoning. However, at present definite correlations cannot be made, and the main problem lies in determining the relation between the Bow and Canmore advances. In addition, too little is known about the age of early Pinedale to state whether glacier III might correspond to it. Richmond (1965, p. 227) does indicate that the early Pinedale started about 25,000 years ago; whether this would allow sufficient time between glaciers III and IV to develop the differences in weathering and changes in valley character beyond the limits of glacier IV is uncertain. At present all that can be said is that glacier IV appears to embrace the time of the Canmore advance, and that it may have been the contemporary of the middle Pinedale. If so, glaciers I and II would be pre-Pinedale and might correspond to the Bull Lake (Older Wisconsin) Glaciation.

Postglacial Events

Following retreat of glacier IV, the streams reverted to their normal processes of degradation and aggradation, whereas mass wasting processes have continued apace, and wind has intermittently modified the surface of parts of the area. The most striking feature of postglacial time, however, has been development of the numerous fans that border Kananaskis Valley right through the area, and deposition of talus in high districts. These deposits continue to form.

Coincident with formation of the fans, Kananaskis River has incised, in places, into the bottom of its U-shaped valley, though over most of its course it is still flowing largely on valley fill. The rate of downcutting appears to have been slow in most parts of the valley and may be decreasing, and the river is forming a well-developed floodplain. Large alluvial fans have developed where Wasootch, Ribbon, and other streams enter the main valley.

The freshness of the material in the high cirques (at about 7,500 to 8,000 feet a.s.l.) in the southwestern part of the area (in secs. 16 and 21 of tp. 23, rge. 9) indicates that those cirques were reoccupied by ice during the Neoglacial. The lower cirques found in the northern part of the area lack evidence of such reactivation.

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