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THE PHYSICAL BASIS OF THE ORCHARD INDUSTRY OF BRITISH COLUMBIA

*Ralph R. Krueger**

ABSTRACT: Since the mid-1800's commercial orchards have been established in a number of valleys in British Columbia. Of all the districts where fruit trees were planted, only the Okanagan Valley has become a major orchard region, and only in the southern part of the Okanagan Valley have soft fruits been planted extensively.

A number of physical characteristics have made the Okanagan suitable for the growth of the orchard industry. The climate and soils gave early promise that not only apples but also soft fruits including peaches and apricots would thrive. Broad terraces at some height above the valley floor provided orchard sites with excellent air drainage. The very dry climate made disease easier to control, and the large amount of summer sunshine and heat concentration helped to increase the size and heighten the color of the fruit. The presence of numerous creeks draining from the surrounding uplands made the irrigation problem easy to solve. A properly regulated water supply led to high orchard yields.

The Okanagan Valley also presents a number of physical handicaps for the orchard industry. Since 1900, orchards have suffered serious low-temperature injury in one out of every seven winters. In addition, a number of crop losses have occurred because of frost damage suffered by blossoms in the spring. In recent years orcharding has been declining in all the districts north of Kelowna because the frequent tree and crop losses have made the industry submarginal.

This paper presents an orchard-soil-capability classification for the Okanagan Valley. The acreage of good orchard soils is relatively small. Of the 23,000 irrigated acres suitable for orcharding in the Okanagan, only some 5,000 are suitable for all tree crops. The largest continuous area of the best soil for all crops is provided by the Penticton silt loam around the southern end of Okanagan Lake. The Summerland-Penticton-Naramata area also has the best climatic conditions for all the tree crops. Unfortunately, orchards are often planted where climate and soil are unfavorable.

Okanagan orchardists have a number of economic problems—the high cost of land, the high cost of operation (including irrigation), the distance of markets coupled with constantly rising transportation costs, and the rising cost of orchard and marketing operations in the face of declining prices.

Much credit for the moderate success of the Okanagan orchard industry must go to the central marketing agency, B.C. Tree Fruits, which has assisted immeasurably in stabilizing fruit prices and obtaining the maximum returns for growers in both poor and bumper-crop years.

If orchards in the future are planted only in the best orchard land, and if the economic problems can be solved, the Okanagan is likely to remain an important Canadian orchard region.

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RÉSUMÉ: La culture commerciale de fruits de verger dans bon nombre de vallées de la Colombie-Britannique se pratique depuis le milieu du XIX° siècle. Toutefois, parmi toutes les régions où l'on avait établi des vergers, seule la vallée de l'Okanagan demeure aujourd'hui une zone importante de production. De plus, ce n'est que dans sa partie sud que l'on se livre à la culture intensive des fruits charnus.

Certaines caractéristiques physiques ont favorisé l'exploitation fruitière dans la vallée de l'Okanagan. Au début de cette tentative de culture spécialisée, les conditions climatiques et le sol semblaient propices, non seulement à la culture des pommes, mais aussi à celle des fruits charnus tels que les abricots et les pêches. Les larges terrasses, sur les versants de la vallée, offraient d'excellentes conditions d'aération nécessaires à la culture des arbres fruitiers. Le climat très sec facilitait la maîtrise des maladies; le grand nombre de jours ensoleillés au cours de l'été ainsi que la grande somme de chaleur aidaient à augmenter le volume et à aviver la coloration des fruits. L'irrigation ne présentait pratiquement aucun problème grâce aux nombreux ruisseaux qui s'écoulaient des hautes terres. La réserve d'eau bien régularisée produisait d'abondantes récoltes.

Par contre, la culture des fruits est très aléatoire et elle dépend, pour une bonne part, des conditions météorologiques. Depuis 1900, les vergers de l'Okanagan ont subi des dégâts considérables dus à la basse température qui y a sévi à une fréquence moyenne d'un hiver sur sept. De plus, il y a eu de lourdes pertes causées par les gelées printanières au moment de la floraison. Depuis quelques années, la culture des vergers a diminué dans tous les secteurs au nord de Kelowna parce que les pertes fréquentes des récoltes et même des arbres fruitiers ont rendu cette industrie non rentable.

Dans cette étude, l'auteur établit une classification des sols quant à leur adaptation à la culture fruitière dans la vallée de l'Okanagan. La superficie des terrains propices à cette culture est relativement restreinte. Sur les 23,000 acres de terrain irrigué en vue de la culture des fruits de vergers, seulement 5,000 se prêtent à la production de toutes les variétés d'arbres fruitiers. Et la plus grande superficie sur laquelle se pratique cette dernière culture se trouve à l'extrémité sud du lac Okanagan où le sol est composé de terre franche limoneuse (Penticton). La région Summerland-Penticton-Naramata offre également les meilleures conditions climatiques pour la culture de tous les arbres fruitiers. Malheureusement, on établit souvent des vergers là où les conditions du sol et du climat sont défavorables.

Aujourd'hui, les fructiculteurs de la vallée de l'Okanagan doivent faire face à de nombreux problèmes économiques, tels que la cherté du terrain, l'augmentation des frais d'exploitation des vergers y compris l'irrigation, la grande distance des marchés à laquelle s'ajoute les frais croissants du transport et le coût élevé de la mise en marché des produits face à la baisse des prix.

On doit attribuer beaucoup de mérite à l'organisme central de vente, la *B. C. Tree Fruits*, pour les succès remportés par l'industrie fruitière de l'Okanagan. Cet organisme met tout en oeuvre pour maintenir les prix et assurer des revenus maximums aux fructiculteurs, que les récoltes soient mauvaises ou bonnes.

A l'avenir, si l'on prend soin d'établir les vergers aux endroits les plus propices et si l'on parvient à résoudre les problèmes d'ordre économique en cours, la vallée de l'Okanagan se maintiendra sans aucun doute au rang des principales régions fruitières du pays.

INTRODUCTION

The orchards of British Columbia provide a significant share of Canada's tree-fruit production. In recent years, British Columbia has contributed approximately one-fifth of the output of peaches and cherries, one-third of the pears, plums, prunes and apples, and virtually all the apricots.

This paper tells briefly why the orchard industry has grown or declined in different parts of the province. It continues with a more detailed discussion of the tree-fruit suitability of the climate and soils of the Okanagan Valley, the most important of the orchard areas.

HISTORY OF ORCHARDS IN BRITISH COLUMBIA

The first fruit trees in British Columbia were planted in the early 1840's around Hudson Bay Company forts at what are now Victoria, New Westminster, Hope and Yale. During the next few decades orchards were planted along the banks of the Upper Fraser as far north as Lillooet, the South Thompson as far east as Lake Shuswap, Okanagan Lake and its river system (including the tributary Similkameen), the Upper and Lower Arrow Lakes, Slocan Lake, the Columbia River south of Castlegar, the Kettle River from Rock Creek to Grand Forks, in the Creston area of the Kootenay River, and along the banks of the southern half of Kootenay Lake (MacPhee, 1958).

The present orchard-distribution map (Figure 1) shows that, of all the districts where fruit trees were planted, only the Okanagan has become a major orchard region, and that only in the southern part of the Okanagan Valley have soft fruits been planted extensively.

Vancouver Island and Lower Fraser Valley

Although the first orchards were planted in the southeast corner of Vancouver Island and in the Lower Fraser Valley, orcharding never became very important in these areas. Some horticulturists claim that there is a lack of winter chill and an insufficiency of summer heat and that the humid climate makes disease control more difficult than in the dry valleys of the interior. There is inadequate proof, however, that climatic factors retarded orchard development, several other factors seeming to have been much more important. In the first place, the Hudson's Bay Company did not encourage agricultural development since it was primarily interested in the fur trade. Because of early settlement, growers were faced with unsolved problems including those caused by unsalable varieties, poor quality, bad

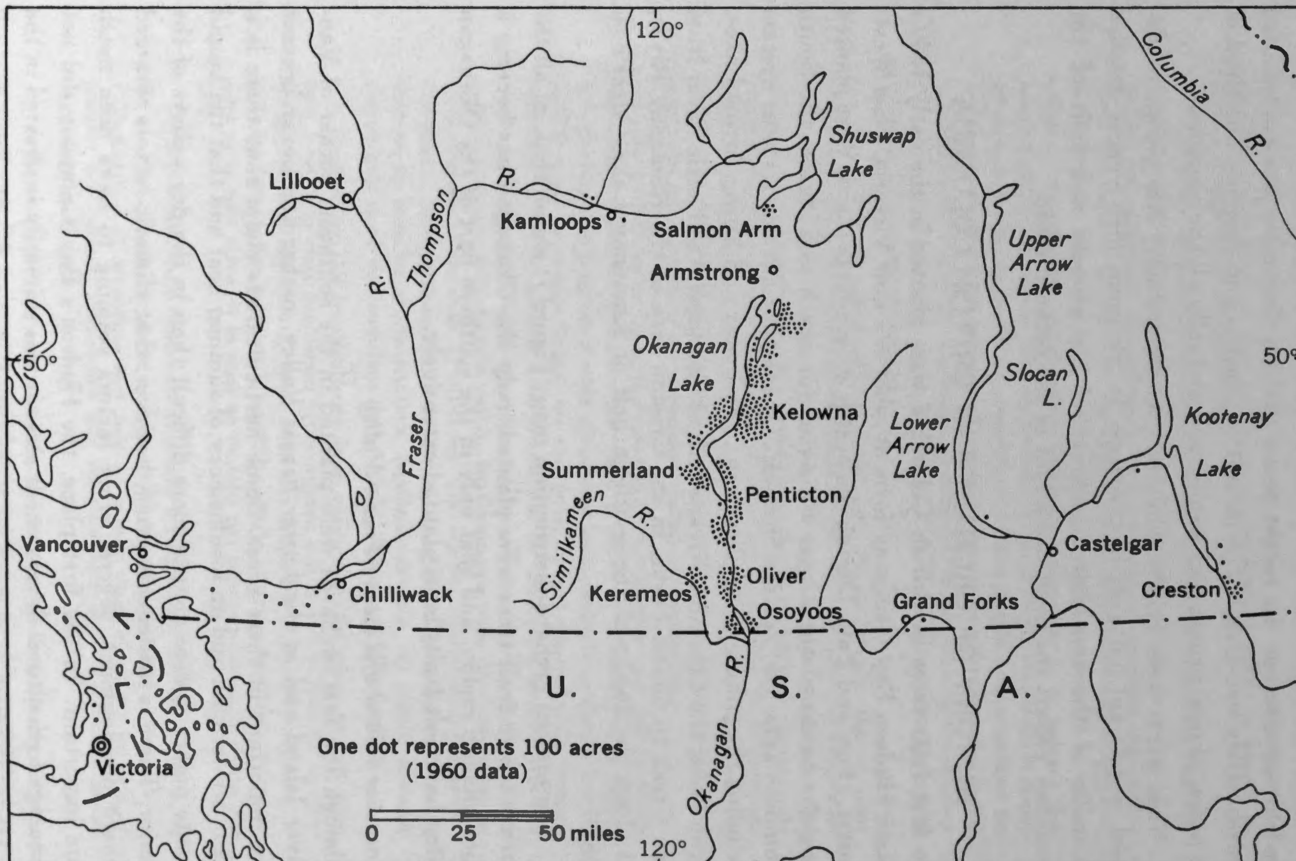

FIGURE 1. Distribution of orchards in British Columbia.

grading, inadequate packaging and disease. An unattractive and inferior product could not compete with the well-packed high-quality fruit imported from California, and consequently most of the fruit had to be sold at a price that made orcharding unprofitable. It is not surprising, therefore, that farmers turned to the cultivation of annual crops and dairying, which were apparently much less risky and more profitable.

By 1900 the Lower Fraser Valley had more commercial orchards than Vancouver Island. By about 1915, however, neither district was producing significant quantities of fruit. Today Vancouver Island production is negligible, and the Lower Fraser produces only a small volume of prunes, pears and summer apples for local markets. Whether the Lower Fraser could become a major orchard area is now an academic question since the area has been ruined for intensive fruit-growing by widespread low-density suburban development.

The regular orchard survey of British Columbia does not include the Vancouver Island and Lower Fraser areas because they are not organized under a central selling agency. For all areas other than Vancouver Island and the Lower Fraser, the numbers of trees shown in Table 1 indicate orchard trends between 1920 and 1960.

Upper Fraser-Thompson

In the Upper Fraser-Thompson area, orchard plantings increased slowly, until in 1950 there were approximately 72,000 trees. All the Upper Fraser-Thompson orchard districts, however, were hit hard by the severe 1949–50 freeze which killed more than 50 per cent of all fruit trees and resulted in a decrease of 53,000 trees in the 1950–60 decade.

Within the Upper Fraser-Thompson area only the Kamloops district has retained sizable acreages of producing orchards. For many years these orchards were supplied with irrigation water by private companies. Because the companies did not keep the irrigation system in good repair and failed to set up a renewal fund, the system had so deteriorated by the early 1940's that the water supply could not be guaranteed. In 1947 the B.C. Fruitlands Irrigation District was formed under the Provincial Water Act, and in 1959, with the assistance of both the provincial and the federal governments, given through the Prairie Farm Rehabilitation Act, it completely rebuilt the irrigation system. Since that time much of the irrigated land has been subdivided for houses, and it is expected that the 1960 orchard area of 309 acres will continue to decrease with the suburban expansion of Kamloops.

Table 1
Number of fruit trees, by major orchard areas, 1920–60

Major area	1920	1930	1940	1950	1955	1960
Upper Fraser-Thompson						
Apples	37,010	26,230	45,175	59,631	28,833	17,615
Soft fruits	715	510	2,049	12,271	3,550	1,642
Total	37,725	26,740	47,224	71,902	32,383	19,257
Salmon Arm-Armstrong						
Apples	88,673	128,390	77,553	86,443	47,425	23,977
Soft fruits	8,392	14,962	12,151	19,435	9,787	4,883
Total	97,065	143,352	89,704	105,878	57,212	28,860
Vernon						
Apples	257,359	171,435	172,245	186,680	156,146	131,737
Soft fruits	40,018	17,626	31,464	76,387	49,479	26,186
Total	297,377	189,061	203,709	263,067	205,625	157,923
Kelowna						
Apples	445,076	484,774	454,380	457,531	469,408	579,825
Soft fruits	68,910	66,313	143,857	334,847	388,424	357,880
Total	513,986	551,087	598,237	792,378	857,832	937,705
Summerland-Penticton						
Apples	238,289	241,827	227,837	186,386	194,034	208,195
Soft fruits	92,693	106,494	210,369	366,024	398,681	341,270
Total	330,982	348,321	438,206	552,410	592,715	549,465
Oliver-Osoyoos						
Apples	—	56,485	77,966	95,216	126,776	203,392
Soft fruits	—	46,181	112,542	281,181	277,460	267,044
Total	—	102,666	190,508	376,397	404,236	470,436
Keremeos-Cawston						
Apples	37,143	28,710	36,643	45,328	55,636	65,830
Soft fruits	6,471	6,077	14,726	62,052	95,867	87,245
Total	43,614	34,787	51,369	107,380	151,503	153,075
Creston						
Apples	98,101	91,468	78,524	86,975	70,712	49,825
Soft fruits	12,227	19,839	20,876	43,373	42,993	31,206
Total	110,328	111,307	99,400	130,348	113,705	81,031
Kootenay-Arrow Lakes						
Apples	281,014	172,457	57,876	29,611	7,360	3,488
Soft fruits	81,406	45,245	42,446	30,280	10,916	5,701
Total	362,420	217,702	100,322	59,891	18,276	9,189

Table 1

Number of fruit trees, by major orchard areas, 1920–60—Concluded

Major area	1920	1930	1940	1950	1955	1960
Grand Forks						
Apples	87,999	25,621	25,231	15,406	14,116	5,954
Soft fruits	19,145	2,966	7,144	2,851	3,492	964
Total	107,144	28,587	32,375	18,257	17,608	6,918
OKANAGAN TOTAL	1,283,024	1,369,274	1,571,733	2,197,510	2,269,123	2,297,464
GRAND TOTAL	1,900,641	1,753,610	1,851,054	2,477,908	2,451,095	2,413,859

NOTE: The major orchard areas in this table include certain districts as listed in the *Orchard Survey*, 1960, published by the B.C. Department of Agriculture. These districts, with their orchard acreage indicated by numbers in parentheses, are as follows:

Upper Fraser-Thompson: Lillooet (48a.); Kamloops (310a.).
Salmon Arm-Armstrong: Salmon Arm (598a.); Armstrong (28a.).
Vernon: B.X. (1,313a.); Vernon (398a.); Coldstream (959a.).
Kelowna: Oyama (1,220a.); Okanagan Centre and Winfield (2,131); Kelowna (7,889a.); Westbank (2,154a.); Peachland (630a.). In the 1920 survey, Oyama was included with the Vernon district.
Summerland-Penticton: Summerland (2,940a.); Naramata (968a.); Penticton (2,148a.); Penticton, West Bench (133a.); Kaleden (514a.); Okanagan Falls (361a.).
Oliver-Osoyoos: Oliver (3,590a.); Osoyoos (2,317a.).
Keremeos-Cawston: Keremeos (1,017a.); Cawston (1,109a.).
Creston: Creston-Erickson (1,132a.); Canyon-Lister (151a.); Alice Siding (177a.).
Kootenay-Arrow Lakes: Upper Arrow Lakes (20a.); Deer Park-Renata (100a.); West Kootenay (76a.).
Grand Forks: (134a.).

Grand Forks

Orcharding in the Kettle Valley around Grand Forks, Midway and Rock Creek (often called the Boundary district) began without irrigation. It was soon discovered that the annual precipitation of from 15 to 16 inches was insufficient for apple trees in production. In the early 1900's irrigation systems were established, and by 1920 the number of orchard trees had reached a peak of more than 107,000. The irrigation systems could not, however, provide an adequate supply of water for the mature orchards. A combination of lack of water, severe winter kill and spring frost damage to blossoms contributed to a rapid decline in tree numbers during the decade from 1920 to 1930.

Cultural factors hastened the decline. Many of the settlers were British Army personnel who were totally inexperienced in orchard management.

Also, there were a large number of Doukhobors, who organized fruit-growing on a communal basis. The death of Peter Verigin in 1924 brought about a breakdown of communal activity that destroyed the Doukhobors' ability to produce, process or market agricultural products on a large scale. Many orchards were abandoned, and by 1960 there were only 6,900 trees, mostly in the Grand Forks district. There are now no full-time orchardists in the entire Boundary district, and only around Grand Forks are any new orchards being planted.

Kootenay-Arrow Lakes

In the early 1900's orchards were also planted in various parts of the Kootenay-Arrow Lakes area: along the shores of Kootenay Lake and Upper and Lower Arrow Lakes, up the Slocan Valley and on the benches overlooking the Kootenay and Columbia Rivers. Fruit-growing in the various parts of this farflung region (except Creston, which is usually considered a separate orchard district) has a similar history. Orchard trees reached a peak of 362,400 in the early 1920's but by 1960 had declined to 9,200. The decline of orcharding has been attributed to injury caused by low winter and spring temperatures, poor horticultural practices, neglect of orchards occasioned by the departure of young farmers for employment in mining, lumbering or construction, and the 'little cherry' disease, which first appeared in the 1930's. This disease was a major factor in the downward trend of tree-fruit production because sweet cherries were the best source of income. Without cherries, the small orchard would not provide a living and was consequently abandoned.

Creston

Trends in fruit-growing in the Creston area have not followed the same pattern as in the Boundary and Kootenay-Arrow Lakes areas. Instead of declining rapidly after 1920, tree numbers remained around 100,000 until 1950, when the peak of 130,300 was reached. While orchards were on the decline in neighboring districts, production was thus maintained in the Creston area because: (1) frost damage was less severe; (2) the situation of the orchards in a more compact area made the obtaining of supplies and the shipping of fruit more efficient; (3) irrigation systems provided an adequate supply of water; (4) orchards were larger and fruit-growing tended to be a full-time job; and (5) apple scab and 'little cherry' were less serious.

Since 1950, however, orcharding in the Creston area has gradually declined, the decrease between 1950 and 1960 amounting to about 50,000 trees. For a number of consecutive years adverse weather conditions, such as winter and spring frost damage, hail and abnormally cool wet summers, resulted in poor sizing and color, as well as in an increase in apple scab. In recent years the 'little cherry' disease has been substantially reducing cherry production. The required tree replacement programs have not been carried out because financial returns have not kept pace with the growing cost of production and the rising cost of living. Orchards are consequently becoming overage, and their yields are decreasing. Under these circumstances fruit-growing has become only a part-time occupation for many orchardists, and they are quite willing to sell off part of their land. Some orchards have been divided into smaller holdings and sold as such to retired people, primarily from the Prairies, whereas others have been subdivided into building lots. Everything considered, it seems that the Creston area will continue to decline in importance as an orchard centre.

Okanagan

Although Okanagan Lake and its river system drain southward toward the Columbia River, the Okanagan Valley broadens toward its northern end and merges into the Shuswap Lake region, which is drained by the Thompson River. Here, for the sake of convenience, the term Okanagan Valley will refer to the entire valley from the United States boundary to Salmon Arm, on Lake Shuswap, and will include the tributary Similkameen Valley, which joins the Okanagan south of the forty-ninth parallel.

Today the Okanagan Valley is by far the most important orchard region of British Columbia (Figure 2), but this has not always been so. From the early 1840's to the turn of the century, the number of trees planted there was insignificant, and the census of 1901 showed the greater part of the province's orchard acreage to be in other areas. In the ensuing decade, however, one million apple trees were planted in the Okanagan Valley, and by 1911 it had become the leading orchard region. By 1925 the number of its apple trees had reached 1,147,500, a total not exceeded until 1960, when the record rose to 1,230,600. Although this increase is relatively small, today's apple production is two to three times what it was in 1925.

In the early 1900's, in addition, large soft-fruit plantings were also made in the Okanagan. They continued until in 1950 soft-fruit trees outnumbered apple trees, although by 1960 the latter had again nudged ahead.

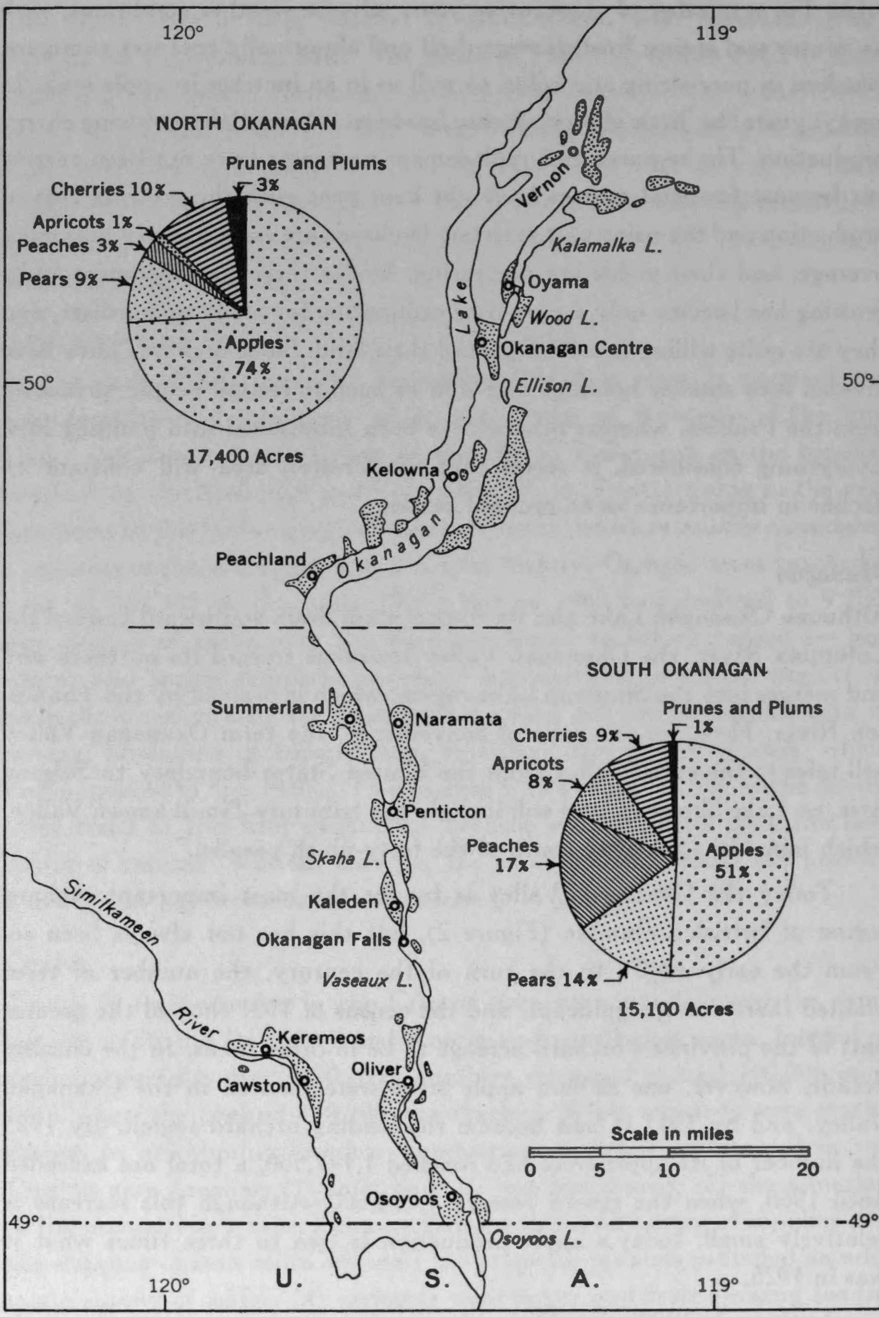

FIGURE 2. Orchard distribution in the Okanagan Valley. The shading represents intensive orchard areas. The acreage for North Okanagan includes 600 acres of orchard from the Salmon Arm district, not shown on the map.

Cherry trees showed a steady increase until 1960. The numbers of pear, peach and apricot trees rose steadily until 1955, when a small decline set in. Prune trees reached a peak in 1950 and then declined. After 1920, plum trees constantly declined and today are insignificant in the orchard economy.

Several explanations may be given for the early rapid growth of the Okanagan Valley's orchard industry and the prominence it has maintained while fruit-growing in other areas has been declining.

The promotion activities of land companies and individual speculators undoubtedly contributed to the rapid development of orcharding in the Okanagan in the early 1900's. Land valued at $1 an acre for cattle-grazing was sold for $1,000 an acre once irrigated and planted with orchards. Glowing accounts of this 'Garden of Eden' attracted settlers from other parts of Canada and from Europe. The establishment of large orchards on two famous ranches (the Guisachan, near Kelowna, and the Coldstream, near Vernon) by the Governor-General, Lord Aberdeen, did much for the prestige of the Okanagan as an orchard area.

A number of physical characteristics made the Okanagan attractive for orcharding. The natural steppe vegetation of most of the valley meant that land did not have to be cleared. The climate and soils gave early promise that not only apples but also soft fruits including peaches and apricots would thrive. Broad terraces at some height above the valley floor provided orchard sites with excellent air drainage. The very dry climate made disease easy to control and the large amount of summer sunshine and heat concentration helped to increase the size and heighten the color of the fruit. The presence of numerous creeks draining from the surrounding uplands made the irrigation problem easy to solve. A properly regulated water supply to orchards led to very high yields. The codling moth did not become a menace until about 1925, and 'little cherry' has not yet reached the Okanagan.

A large concentration of orchards led to the centralization of a group of highly competent agricultural experts both federal and provincial, who carried out research and experiments related to orchard growing and handling problems. This technological know-how, coupled with the fact that orcharding became almost the exclusive agricultural activity of much of the valley, led to improvement in horticultural practices, handling and packing methods, and selling organization. The establishment of a central selling agency has undoubtedly been the fruit-growing industry's chief safeguard against a serious decline in the face of the marketing problems of recent decades.

In building and maintaining the prominence of their orchard area, the growers of the Okanagan have had many difficulties to overcome. The economic problems of the valley are many: the high cost of land, the small uneconomic size of orchard units, the high cost of operation (including that of irrigation systems, which must be maintained and renewed), the unsuitability of the varieties of many early plantings, remoteness from large centres of population, the difficulties of maintaining overseas markets, United States competition and the constantly rising cost of transportation, machinery and marketing. In addition, there have been physical problems such as those caused by low-temperature injury, spring-frost damage and hail.

Since the 1949–50 freeze, orcharding north of Kelowna has been declining. From Kelowna south, however, fruit-growing has been intensifying, and from Summerland through to Osoyoos there has been an increase of emphasis on peaches and apricots (Figure 2).

The Okanagan at present accounts for more than 90 per cent of British Columbia's tree-fruit production. The following sections give a more detailed analysis of the physical suitability of the Okanagan for fruit-growing.

ORCHARD CLIMATE OF THE OKANAGAN VALLEY

A summary of climatic statistics for the Okanagan Valley is given in Table 2. The pertinency of some of these data and of other statistics to fruit-growing is now discussed in the text.

Sunshine and humidity

Fruit crops ripen and color properly only with long, warm, relatively dry sunny summers. The Okanagan Valley has an annual average of between 1,900 and 2,000 hours of sunshine, of which almost 90 per cent is received in the period from March to October. In summer, the average of bright sunshine is more than 300 hours a month, or about 65 per cent of the number of hours possible for the latitude; and in winter there is a large amount of cloud, which prevents loss of heat through radiation and so helps to moderate the temperature. The amount of sunshine in the Okanagan, although high, is not the highest in British Columbia. Kamloops and Victoria, for instance, have more than 2,000 hours.

Table 2

Selected climatic statistics for stations in the Okanagan Valley

Station	Elevation	Mean temperature			Absolute minimum temperature	Average frost-free days	Average hours of annual sunshine	Average annual precipitation
		Jan.	July	Ann.				
Salmon Arm	1,660′	23	68	46	−31	153	—	19.7″
Armstrong	1,200′	21	66	44	−44	114	—	16.8″
Vernon	1,383′	23	69	46	−31	152	1,899	15.5″
Okanagan Centre	1,140′	27	69	48	−22	184	—	13.4″
Kelowna	1,130′	26	67	47	−24	144	—	12.3″
Summerland	1,491′	25	70	48	−22	198	1,988	10.9″
Penticton	1,121′	27	68	48	−16	144	1,905	11.4″
Oliver	997′	25	72	49	−23	152	—	10.2″
Keremeos	1,165′	25	71	49	−22	184	—	9.8″

NOTE: Temperature and precipitation records from *Climate of British Columbia*, Department of Agriculture, Victoria, B.C., 1959. Frost-free records from A. J. Connor, *The Frost-Free Season in British Columbia*, Meteorological Division, Department of Transport, Toronto, 1949.

The warm sunny summers of the Okanagan are accompanied by low relative humidity. The average for the summer months ranges between 40 and 50 per cent. In daylight in the southern part of the valley it drops as low as 20 per cent. Such low relative humidity makes it easy to control apple scab, fungi, brown rot and other fruit diseases but provides conditions under which the codling moth and a number of other insects thrive.

Precipitation

Precipitation in the Okanagan ranges from an annual mean of 9.8 inches at Keremeos to 19.7 inches at Salmon Arm. The north receives more precipitation because of the closeness of the rainy west-facing slopes of the Monashee Mountains.

Irrigation is essential for tree crops in all of the Okanagan except Salmon Arm, although even there it greatly increases the yield. Providing orchards with irrigation water is a major cost item in orchard management. For most orchards the water charge falls between $10 and $20 an acre. In addition, the orchardist spends, on the average, between $50 and $60 an acre to cover the depreciation of his equipment and pay for labor to operate the irrigation system.

Most of the irrigation water is obtained from streams that originate in the upper levels of the surrounding mountains and plateaus. These higher elevations receive more precipitation than the valley floor, and much of this is stored in the form of snow until early in the summer.

The winter maximum of precipitation in the Okanagan results in a snow cover on the valley floor of from 30 to 50 inches a year. This snow cover insulates the roots of the trees from low temperatures.

Unfortunately for the cherry growers, there is a secondary peak of precipitation in late May or early June. In the southern part of the valley June rain is heavily concentrated in the middle of the month, just before cherry-picking time; and in some years it decimates the salable crop by splitting the skins of the cherries.

Because most of the summer rain is convectional, the incidence of hail is high. Hail damage usually occurs only in local areas. Some districts may have a number of years without hail damage, while others may suffer hail damage in consecutive years. The Penticton district, for instance, suffered severe hail damage in 1948, 1949, and 1950.

Temperature

Mean annual temperatures in the Okanagan Valley range from 44°F at Armstrong to 49°F at Oliver and Keremeos. January mean temperatures range from 21°F at Armstrong to 27°F at Penticton; July temperatures from 66°F at Armstrong to 72°F at Oliver. These averages indicate a generally hotter summer and milder winter in the southern part of the valley.

The frost-free periods range from 114 days at Armstrong to 198 days at Summerland. Table 2 shows that Penticton, which is south of Summerland and between two lakes, has a surprisingly low frost-free period of only 144 days. This is because the station is on flat low-lying land onto which drains the cold air from the terraces. Empirical evidence indicates that the Penticton terraces have as long a frost-free season as the terraces at Summerland. In places with an average frost-free season of less than 150 days, there is considerable risk of frost injury to blossoms in the spring or to mature fruit in the fall.

Absolute minimum temperatures, when extremely low, can wipe out entire orchards; they are therefore a good indication of orchard-climate suitability. Penticton has the highest absolute minimum (−16°F) while Armstrong has the lowest (−44°F). None of the areas of intensive orchard cultivation have an absolute minimum lower than −25°F.

Since 1900, fruit trees in the Okanagan have suffered serious low-temperature injury in seven winters: 1909–10; 1915–16; 1924–25; 1930–31; 1935–36; 1949–50; and 1955–56. This means that serious frost injury has occurred in about one out of every seven years. Because this kind of injury seems to be the greatest climatic liability in the valley, a detailed analysis of the frequency of critical minimum temperatures is given in the following section.

Critical temperatures

Despite the many complicating factors, it is possible to determine certain minimum critical temperatures for tree fruits. It is highly probable that temperatures between −10°F and −15°F will kill dormant peach and apricot blossoms and that temperatures between −15°F and −20°F will not only kill the dormant buds but also kill or seriously injure the peach and apricot trees themselves. Only the most vigorous of these trees will survive temperatures lower than −20°F. In Table 3 the critical temperatures of −12°F for dormant peach and apricot buds, and −20°F for dormant peach and apricot wood have been chosen to facilitate comparison with fruit-climate studies in Ontario (Mercier, 1955–56; Krueger, 1959).

In the very early or late winter, injury may also be caused by temperatures much higher than −12°F. On the basis of observations made over a period of years, the Winter Injury Committee of the Okanagan Agricultural

Table 3

Frequency of critical tree-fruit temperatures
Okanagan Valley, B.C.
(number of years in 30 with selected critical temperatures)

Station	−12°F or lower	−20°F or lower	15°F or lower in Oct.	10°F or lower in Nov.	10°F or lower in Mar.
Salmon Arm	13	8	1	8	16
Vernon	13	7	1	7	12
Kelowna	8	1	1	6	8
Summerland	3	1	1	6	7
Penticton	3	0	1	5	4
Oliver	11	3	1	5	5
Keremeos	7	1	1	9	5

NOTE: Raw data from *Monthly Record of Meteorological Observations in Canada*, Meteorological Branch, Dept. of Transport, Toronto. The first two columns are for 1927–56, the last three for 1930–59.

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Club has concluded that October temperatures of 15°F or lower and November and March temperatures of 10°F or lower are potentially damaging to all trees and particularly to peach and apricot.

At Salmon Arm and Vernon the danger of winter-frost damage to peaches and apricots is much greater than in the more southerly of the Okanagan districts (Table 3). It seems that the Penticton and Summerland districts have the most favorable peach and apricot climate and that the Keremeos district is second.

It is difficult to explain why Oliver has such a high frequency of −12°F and −20°F temperatures. A partial explanation may be that Oliver has no lake to moderate its climate and that the station itself is lower than the rest of the district and has poorer air drainage.

It is interesting to note that with respect to the frequency of temperatures of −12°F and −20°F, the records of Summerland and Penticton compare favorably with those of the Ontario peach districts. At both Vineland, in the Niagara Fruit Belt, and Leamington, in Essex County, the temperature dropped to −12°F only three times in 30 years, and in that period never reached a low of −20°F.

In October there is little risk of frost injury to trees anywhere in the Okanagan. The risk is greater in November and still greater in March. In the Salmon Arm district there is danger of March low-temperature injury every second year.

Tree and crop loss

Another way to compare climates of different districts is to analyze the actual damage caused by specific cold waves. The results of surveys made after the abnormally cold winter of 1949–50 are shown in Table 4.

Almost one-fifth of the fruit trees in the Okanagan were killed. The kill rate was lowest in the Summerland-Penticton area, around the southern end of Okanagan Lake, the only area where fewer than 10 per cent of the trees were lost. The tree losses in the Keremeos-Cawston area (28 per cent) and the Oliver-Osoyoos area (24 per cent) were unexpectedly high compared with those in the northern part of the Okanagan. This can be explained partially by the fact that the south is where the more tender fruits, such as peaches and apricots, are grown. South of Kelowna, most of the losses involved peach, apricot and cherry trees. In the Kelowna district and north of it, all stone-fruit trees and many apple trees were either killed or severely damaged.

Table 4

Tree kill and crop loss resulting from cold wave of 1949–50
Okanagan Valley, B.C.

District	Percentage of trees killed	Percentage reduction of 1950 crop from 1946–49 average		
		Peaches	Apricots	Cherries
Salmon Arm	31	100	100	98
Armstrong	37	—	100	100
Vernon	25	100	100	88
Oyama-Okanagan Centre	14	100	100	96
Kelowna	14	100	100	99
Westbank	15	100	100	100
Peachland	18	96	94	83
Summerland	9	89	99	57
Penticton	7	74	83	17
Naramata	7	75	88	33
Kaleden	12	84	98	25
Oliver-Osoyoos	28	92	75	27
Keremeos-Cawston	24	100	100	87
TOTAL OKANAGAN	19	87	88	59

NOTE: Tree-kill data from British Columbia's *Department of Agriculture Annual Report*, 1950. Crop-reduction data from E. M. King, *Winter Injury of Fruit Trees*, unpublished M.Sc. thesis, Department of Agriculture, University of British Columbia, 1954.

The crop losses following the winter of 1949–50 were very severe (Table 4). The peach and apricot crops were reduced respectively by 87 and 88 per cent. The cherry crop suffered a 59-per-cent reduction. Penticton had the best record for peaches (a 74-per-cent loss) and cherries (a 17-per-cent loss). Oliver-Osoyoos had the best record for apricots (a 75-per-cent loss).

In November 1955, an early-winter outburst of polar air plunged temperatures below 0°F and thus killed many of the young trees planted to replace the losses of 1950. The new losses, however, were generally much lower. The area around the southern end of Okanagan Lake again had the best record with a tree-kill rate of only 2.5 per cent. The Vernon district had the poorest record, suffering the loss of 11 per cent of its trees. In areas north of Vernon losses were relatively low because orchards had not been replanted after 1949–50 and the older trees remaining were hardy enough to withstand the later freeze.

The length of time that fruit trees remain in production is important to fruit growers. When a tree has to be replaced, not only is capital expended, but there is also a crop 'loss' until the young tree is in full production. This is most serious in the case of apples (except dwarfs) which take from 5 to 10 years to start bearing and do not reach peak production until the tree approaches 20 years of age.

The survival rates of orchard trees in the Okanagan are very low (Table 5). It is difficult to understand how an orchard operation can be profitable when more than half the trees must be replaced before they reach peak production. If 40 per cent is taken as the lowest survival rate at which orcharding is profitable, then no orchards, not even apple, should be planted north of Oyama. The districts around Summerland, Penticton and Naramata are the only ones with a survival rate of more than 40 per cent for all the crops listed.

Table 5

Percentage survival of trees for different fruit crops
Okanagan Valley, B.C.
(per cent)

District	Apricots (1945–55)	Peaches (1945–55)	Cherries (1935–55)	Pears (1935–55)	Apples (1935–55)
Salmon Arm	13	2	6	1	25
Armstrong	0	0	—	—	14
Vernon	11	7	16	20	32
Oyama	18	5	40	61	44
Okanagan Centre	43	40	34	57	46
Kelowna	36	16	35	50	47
Westbank	25	40	15	50	34
Peachland	33	35	27	33	50
Summerland	68	51	63	65	50
Naramata	57	44	50	56	50
Penticton	60	50	50	60	55
Kaleden	65	37	77	37	67
Oliver-Osoyoos	38	28	38	41	66
Keremeos	58	30	40	37	60

NOTE: Raw data from the British Columbia quinquennial publication *Orchard Survey* for 1935–55. The calculations were made for *The Report of the Royal Commission on the Tree-fruit Industry of British Columbia.*

For apricots and peaches, the statistics represent the percentage of the trees that existed in 1945 and were still alive in 1955. For cherries, pears and apples, because of the longer life span, the statistics represent the trees that survived for 20 years.

In analyzing Table 5, a number of complicating factors must be considered. Some districts may have had a greater proportion of old trees in the base year. In the northern areas the more hardy McIntosh is the predominant apple variety. In the south, apricots and peaches are usually planted on the best orchard sites, while pears are often planted in frost pockets and other areas unsuitable for other crops. This may explain why the survival rate for pears is lower from Kaleden south than it is in the Kelowna-to-Vernon area. Because of these and additional factors, small differences in survival rates should be ignored. Large differences are nevertheless highly significant.

Spring-frost damage to fruit blossoms is another major orchard hazard in the Okanagan. It is extremely difficult, however, to assess the past or potential spring-frost damage in different districts. A temperature of 26°F or lower will do grave damage to blossoms at all stages of development. The blossom date, however, varies so greatly that it is unrealistic to assume that damage will be incurred if there is a killing frost after the average-bloom date. The year in which there was a late frost may have had an abnormally cool spring which delayed subsequent blossoming. Then, too, each fruit crop blossoms at a different time, and at a different time in each district. Thus, to assess blossom damage from climatic statistics, it would be necessary to have a record of bloom dates for each crop in each district and then to go through the climatic records to see how often there was a killing frost during the bloom period for each crop in each district. Detailed records of bloom dates covering a long period for each district are not available.

An alternative method would be to estimate bloom time by using an accumulation of degree-days. This would require an analysis of the number of degree-days it takes for the blossoming of each kind of tree fruit in different districts over a period of years. The earlier the season, the higher the degree-day requirement because the days are shorter. The necessary degree-day statistics for the Okanagan Valley have not been worked out.

A third method of assessing spring-frost damage would be to go through records kept by district horticulturists for the major crop losses suffered each year owing to various climatic hazards. These records are summarized each year in British Columbia's *Department of Agriculture Annual Report.* Although this method does not give statistical evidence on the amount of crop loss, it does give the number of years in which spring-frost damage was severe.

In the decade from 1950 to 1960, according to the *Department of Agriculture Annual Report,* five spring frosts damaged blossoms of one or more fruit crops enough to reduce production considerably. In 1959, frost caught apricots and cherries in full bloom, peaches and prunes in the pink and apples in clusterbud, and all crops were 'cut substantially.' In 1954 spring frost cut the apricot, peach and cherry crops as much as 50 per cent. In 1952 spring frost damage was severe in the southern part of the valley. In 1951 extensive damage was caused by temperatures as low as 15°F from April 18 to 21. In all cases, most damage was incurred in areas remote from a body of water and in places with poor air drainage.

As already noted, the winter fruit-crop temperatures of the Summerland-Penticton area are comparable to those of the Niagara Fruit Belt. With respect to spring-frost damage to blossoms, however, the best districts of the Okanagan are inferior to the Niagara region, which has a record of 30 years' freedom from serious crop loss due to this cause.

ORCHARD SOILS OF THE OKANAGAN VALLEY

Soil origins

The topography and soils that affect fruit-growing in the Okanagan Valley are primarily a result of glacial, glacio-lacustrine and stream deposits (Kelley, 1949; Nasmith, 1962).

During the Pleistocene epoch, the Cordilleran ice sheet completely filled the Okanagan Valley and covered the whole of the surrounding plateau surface. The ice scoured out the previously existing depression, deepening and widening it, faceting spurs and leaving the typical U-shape of a glaciated valley. During this maximum stage of glaciation, till was deposited on the plateau surface as well as on the upper slopes of the valley.

When the glacier began to melt, ice disappeared from the surrounding plateau first, leaving a relatively stagnant tongue of ice in the Okanagan trench. At this stage, meltwater streams flowed along the edge of the ice and deposited sand and gravel, which formed the terraces along the valley walls. In some places the sandy and gravelly outwash material now forms smooth terrace surfaces. In others, the terraces have a hummocky shape resulting from the melting of blocks of ice buried by the outwash material. Orchards have been planted extensively on these terraces, which provide excellent air drainage except in the frost pockets resulting from depressions in the kettle topography.

As the valley glacier gradually retreated toward the north, large volumes of meltwater created lakes at the southern terminus of the tongue of ice; and sands, silts, and clays from meltwater streams were deposited on the lake bottoms.

One of these lakes extended from near Oliver to south of the forty-ninth parallel. After it was drained, its silt deposits were covered with sands and gravels washed down by streams, and the melting of blocks of ice buried by this outwash resulted in numerous kettles. The hummocky topography and sandy and gravelly soils of the Oliver-Osoyoos orchard district are the outcome of these processes.

Another lake took shape from Okanagan Falls to Shuswap Lake, covering ice that remained in the deepest part of the valley. Thus, silts were deposited over and around the ice. When the ice melted, the silt formation collapsed into the depression and some of its remnants now form cliffs along the edges of the southern part of the lake. On these distinctive white silt deposits have developed the excellent orchard soils of the Penticton district. Farther north, the lake deposits form clay soils in the Kelowna and Vernon districts.

After all the ice had disappeared from the valley, the lake gradually lowered until it reached the level of the present Okanagan Lake. Whenever it remained stationary for some time, the tributary streams formed deltas, remnants of which form terraces flanking the present creeks. These deltaic terraces are composed chiefly of gravels sorted from till, often with a thin capping of sandy or silty material. When Okanagan Lake reached its present level, the streams cut through the terraces and continued to build deltas into the lake. In some places, deltas on opposite sides of the valley continued to grow until they coalesced and extended from one side of the trench to the other. Those of Ellis, Penticton, and Shingle Creeks, for instance, have joined to form the flats on which Penticton is built. The deltaic deposits are composed of either gravel or stony outwash. In places where the water table is not too high, as on the Trout Creek delta, they are planted with orchards.

Soil classification

In the Okanagan Valley the silt loams are the best for all tree-fruit crops. The lighter-textured soils require that irrigation water be applied in greater quantities and more frequently, with the result that leaching is greater and more fertilizer is needed. Most of the clays are not well enough drained and so restrict root development too much for the growth of peaches or apricots and too much also, although to a lesser degree, for the growth of cherries.

Despite the preference for silt loams, fruit crops are grown on a wide variety of soil types. Peaches and apricots, closely followed by cherries, are the most demanding in soil requirements. Plums, prunes, and pears do well on a wide range of soils, and apples are grown commercially on soils on which none of the other fruit crops can be grown successfully.

The Reclamation Committee of the British Columbia Department of Agriculture has carried out studies of the orchard suitability of soils in the major orchard districts of the province (Reclamation Committee Briefs numbers 15–18, 24). The Committee's reports represent a pooling of the knowledge of a number of federal and provincial agricultural experts who have had long experience, conducted many experiments, made many observations and kept in close touch with orchardists. The Committee has assigned a percentage productivity rating to each fruit crop for each soil type in each district. A rating of 100 per cent is given to a soil with optimum potential for the production of a specific crop in the area under consideration. Lower ratings are given as percentages of optimum production. The Glenmore clay, for example, is rated at 90 per cent for pears, 80 per cent for apples, 60 per cent for plums and prunes, and 40 per cent for peaches and apricots.

With more than 30 soil types in the Okanagan Valley, many of them in small scattered patches, and with seven tree-fruit productivity ratings given for each type, it is extremely difficult to map these ratings so as to show a pattern of orchard-soil suitability. For a realistic soil classification that can be expressed cartographically, the soil types have been divided into six principal classes according to the number of different tree fruits for which they are suitable (Table 5). Class A includes the soils on which all tree crops are successfully grown; Class B all tree crops except apricots and peaches; and so on down to Class E, which is suitable only for apples, and Class F, which is not recommended for commercial orchards.

Each of the percentage ratings given in Table 6 is the average of the Reclamation Committee productivity ratings for all the fruit crops mentioned in a given class. In Class A, the percentages are averages of the ratings of all the fruit crops. In Class B they are averages of the ratings of all the fruit crops except apricots and peaches. On the basis of these summary ratings, the soil types within each class are divided into subcategories in

Table 6

Orchard soil classification
Okanagan Valley, B.C.

	Soil types	Rating[1]	Acreage[2] Irrigated	Acreage[2] Potentially irrigable
	CLASS A			
	Tree fruits grown successfully: All fruit crops—apples, pears, plums, prunes, cherries, peaches apricots.			
A–1	Similkameen silt loam	100%	369	0
	Penticton silt loam	96%	3,307	1,052
	Osoyoos sandy loam	83%	317	686
A–2	Similkameen gravelly sandy loam	75%	767	115
A–4	Skaha gravelly sandy loam	59%	698	159
	Osoyoos loamy sand	56%	31	461
	Total, Class A soil		5,489	2,473
	CLASS B			
	Tree fruits grown successfully: All except apricots and peaches.			
B–1	Glenmore clay loam	87%	1,771	1,514
B–2	Oyama sandy loam	79%	3,617	1,860
	Total, Class B soil		5,388	3,374
	CLASS C			
	Tree fruits grown successfully: All except apricots, peaches, cherries.			
C–2	Glenmore clay	73%	3,060	2,632
	CLASS D			
	Tree fruits grown successfully: Apples and cherries.			
D–3	Oyama loamy sand	65%	60	196
	Rutland gravelly sandy loam	65%	3,262	1,223
	Total, Class D soil		3,322	1,419
	CLASS E			
	Tree fruits grown successfully: Apples.			
E–3	Spallumcheen clay	65%	1,295	3,446
	Spallumcheen clay loam	60%	992	882
	Kelowna gravelly sandy loam	60%	381	290
	Kalamalka gravelly sandy loam	60%	135	380
	Kalamalka loam	60%	2,076	1,334
	Kalamalka clay loam	60%	334	66
	Grandview sandy loam	60%	318	1,941
	Armstrong gravelly sandy loam	60%	131	443
E–4	Nahun gravelly sandy loam	50%	573	176
	Grandview loamy sand	50%	0	0
	Total, Class E soil		6,235	8,958
	TOTAL OF CLASSES A TO E		23,494	18,856

Table 6 (continued)

Soil types		Rating[1]	Acreage[2]	
			Irrigated	Potentially irrigable
	CLASS F			
Not recommended for commercial orchards. (F–5 soils used for apples only, with very limited success.)				
F–5	Broadview clay loam	35%	0	602
	Broadview clay	35%	919	6,834
	Shuswap sandy loam	20%	4	67
	Glennemma gravelly sandy loam	20%	80	725
(F–6 soils rate 0% for all fruit crops.)				
F–6	Shuswap loamy sand	0%	0	17
	Sicamous gravelly sandy loam	0%	17	205
Total, Class F soil			1,020	8,450

[1]Based on the Reclamation Committee survey of productivity of soils. The ratings given represent percentages of optimum productivity.

[2]The acreages given here are for land well suited for irrigation for agricultural purposes. The potentially irrigable land includes areas that could be successfully irrigated if irrigation water were available.

order of suitability. These categories and the percentage ranges that determine them are as follows:

1. Excellent..........80–100%
2. Good.............70– 79%
3. Fair...............60– 69%
4. Marginal.........50– 59%
5. Submarginal......20– 49%
6. Non-usable........ 0– 19%

In summary, in this tree-fruit soil classification, the initial letter indicates *how many* kinds of fruit crops can be grown successfully, and the following number tells *how well* they can be grown. Thus, an A-1 soil can grow all the fruit crops with excellent results, while a B-1 soil cannot grow peaches or apricots successfully but can compete with an A-1 soil in growing the other fruit crops. An E-3 soil can grow only apples successfully, but cannot do so as well as the A, B, C or D soils that have a 1 or 2 rating.

It should be emphasized that the lead position of A does not necessarily indicate that an A soil is better for all orchard enterprises. For apple-growing only, a B-1 or C-2 would be superior to an A-3 or A-4 soil. Diversity of fruit crops, however, is recommended to Okanagan growers as a safeguard against specific crop loss.

In addition, Table 6 gives the acreages of the soil types that are well suited for irrigation. The term 'well-suited' includes any soil falling into the top three irrigation groups ranging from fair to good as designated by

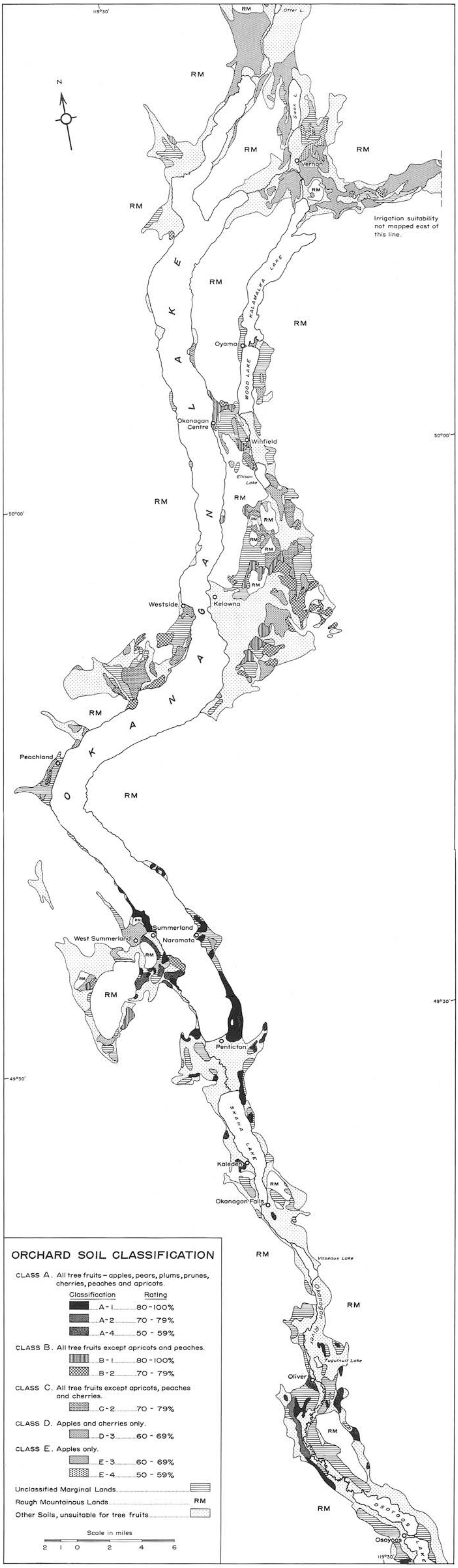

FIGURE 3. Orchard soil classification, Okanagan Valley, B.C.

Reclamation Committee Brief number 27. In ascertaining the 'potentially irrigable acreages' the Committee did not consider the availability of a water supply nor the economic feasibility of irrigating, but decided only whether or not the soil was physically well-suited for irrigation.

The orchard-soil classification presented in Table 6 has been mapped for the Okanagan Valley (excluding the Similkameen) from the forty-ninth parallel to a point north of Vernon (Figure 3). On the maps, only the parts of the soil areas well-suited for irrigation have been classified. The 'unclassified marginal' areas include all soil classes from A to E that are marginal from the viewpoint of suitability for irrigation. The unclassified marginal soils include heavy clays with alkali subsoil and with slow or impeded drainage, as well as thin, excessively drained, gravelly soils. A more detailed survey might show that some of these soils would be classified as suitable for orcharding while others would be classified as totally unsuitable. Successful orchards have been established, for instance, on Skaha gravelly sandy loam in places near Osoyoos where the solum is deeper and where the less desirable features of the soil type do not apply. These more favorable parts of the Skaha series would be classified as A-4. On the other hand, the less favorable parts of the same soil type require excessive irrigation, which promotes leaching, the breakdown of soil structure and seepage at lower elevations. The Class F soils are included with "other soils unsuitable for tree fruits."

Of the total of about 23,000 irrigated acres suitable for orcharding in the Okanagan, only some 5,000 acres are suitable for all tree crops. About two-thirds of this area is classified as A-1, which means that it is excellent for all crops. The largest continuous area of A-1 soil is provided by the Penticton silt loam on the east side of Okanagan Lake in the Penticton district. No Class A soils are found north of the Summerland district. The Kelowna district has large continuous areas of B, C and D soils. The Vernon district has primarily E soils.

More than 17,000 additional acres would be suitable for orcharding if water were available for irrigation. More than half of this soil is Class E, on which only apples can be grown. Only a little more than 2,000 acres of the Class A soil is potentially irrigable and still available for orchard-planting.

The orchard land of all classes, both irrigated and potentially irrigable, exceeds 40,000 acres.

The 1960 Okanagan orchard area was almost 33,000 acres, or about 10,000 acres more than the total of irrigated land suitable for orchards. This seems to indicate sizable plantings on marginal orchard land, much of which has been going out of production since 1950.

The tree-fruit classification presented in this paper should be considered provisional. Much of the soil-mapping on which the suitability maps are based was done as a detailed reconnaissance on a scale of 2 inches to the mile. The larger soil masses were accurately examined and mapped, but soil distinctions covering less than 5 acres were not shown.

Because of the limitations of this soil survey, individual plots may not represent the optimum slope and erosion conditions assumed in the rating; and because of the small scale, the maps cannot be used for guidance in the planting of an individual orchard unless the site is studied in detail.

OKANAGAN ORCHARD-DISTRICT ANALYSIS

Assuming the management factor to be constant, production records provide a good indication of the total physical suitability of districts for orchards. Table 6 presents per tree production records by district for the major fruit crops. The apple varieties shown are listed separately because the Delicious is one of the most tender and the McIntosh one of the most hardy. The two make up more than half the Okanagan apple output.

The period 1953–56 covered by Table 7 is highly significant because many of the trees that survived the freeze of 1949–50 were so damaged that production was greatly reduced. Since the odds of major winter injury to orchards in the Okanagan are about one year in seven, these production records give a better picture of the long-term potential of districts than would production records further removed from a freeze year. For example, the Kelowna peach output for 1943–46, which was 172 pounds per tree, would indicate that the district is excellent for peach-growing. The much lower production rate of 58 pounds per tree shown for 1953–56 gives a picture of the district's peach suitability that is much more in keeping with its climatic records and soil classification.

The Summerland-Penticton area, which includes Naramata and Kaleden, has the best production on record, rating first or second in all the fruit crops listed. Oliver-Osoyoos rates surprisingly well considering its climate and tree-survival statistics. It has the highest production record for peaches and Delicious apples, and equals Penticton in apricots. The districts from Vernon north rank ninth or lower in all fruit crops.

Table 7

Average annual production per bearing tree for different fruit crops
1953–56
Okanagan Valley, B.C.
(in pounds)

District	Apricots	Peaches	Cherries	Pears	Apples	
					Delicious	McIntosh
Salmon Arm	—	—	12	13	84	180
Armstrong	—	—	—	—	—	128
Vernon	6	—	12	34	168	280
Oyama-Okanagan Centre	16	44	28	71	168	524
Kelowna	22	58	34	126	340	580
Westbank	20	72	46	80	212	476
Peachland	40	106	68	130	312	432
Summerland	72	120	82	139	256	400
Penticton	100	124	96	172	360	700
Naramata	74	122	124	176	328	472
Kaleden	72	108	116	46	336	—
Oliver-Osoyoos	100	134	80	97	420	280
Keremeos-Cawston	46	42	22	88	328	444

NOTE: The number of trees is taken from the 1955 British Columbia *Orchard Survey*. The production data are from the British Columbia Department of Agriculture. The calculations were made for *The Report of the Royal Commission on the Tree-fruit Industry of British Columbia*. No calculations were made for districts with fewer than 500 trees.

On the basis of the orchard-climate analysis, soil classification and production records presented in this paper, it is possible to generalize about the orchard suitability of different districts. The generalizations apply to relatively broad areas, since within each district there are undoubtedly small areas with microclimate and soil combinations that are much better than those assessed here.

On almost all scores, the Summerland-Penticton area, including Naramata and Kaleden, has the best orchard-growing conditions in the Okanagan. It has the best climatic record and rates among the best in tree survival and production for all fruit crops. In addition to a favorable climate, the area has a large amount of the Class A-1 soils, which are excellent for all fruit crops.

Compared with the Summerland-Penticton area, the Oliver-Osoyoos area to the south has a much higher frequency of critical tree-fruit temperatures, had twice as high a tree-kill rate in 1950, and has a generally lower tree-survival rate. Despite this unfavorable record, Oliver-Osoyoos has the highest production rate per tree for peaches and Delicious and Winesap apples in the whole Okanagan, and equals Penticton in apricot production per tree. Primarily because of these high production rates, Oliver-Osoyoos is rated as the second-best orchard area.

Third place in orchard rating is shared by the Keremeos-Cawston area of the Similkameen Valley and the Kelowna area extending from Okanagan Centre to Peachland. Although the climatic statistics and tree-survival rates of these two areas are equal to or better than those of the Oliver-Osoyoos area, records indicate that they are unsuitable for the commercial production of peaches, apricots, or cherries. Both areas are well-adapted for the growing of plums, prunes, pears and apples. The per tree production records for apples compare favorably with those of other parts of the Okanagan. The district immediately around Kelowna, in fact, has the second-highest production rate for McIntosh apples. With 10,000 acres, the Kelowna area has almost half the Okanagan apple acreage.

The Vernon area is on the northern fringe of successful large-scale orchard operations, and its winters are too cold for any but the hardiest varieties of apples. The survival rate even of apple trees is only 35 per cent and the production rate per tree is only half that of Kelowna. The removal of more than 100,000 trees in the last decade is a good indication that growers now consider the Vernon area submarginal for orchards.

The Armstrong district, north of Vernon, at one time produced a considerable volume of apples, but severe winter injury and lack of irrigation water has decimated the orchards. With a tree-survival rate of only 14 per cent and a production rate of less than one-third of the average for the whole Okanagan, orchards proved to be an economic liability. In the Armstrong district apple production is now insignificant.

The Salmon Arm district, because of its proximity to Shuswap Lake, has slightly more moderate winters than Armstrong. Nevertheless, only the most hardy varieties of apple trees survive, and the production rates are very low. Orcharding around Salmon Arm is rapidly declining.

NEED FOR DETAILED SUITABILITY STUDIES

The Report of the Royal Commission on the Tree-fruit Industry of British Columbia (MacPhee, 1958) indicates that the orchard industry is not in the best of financial circumstances. The report says that on the average the tree-fruit growers have not been meeting living expenses from their

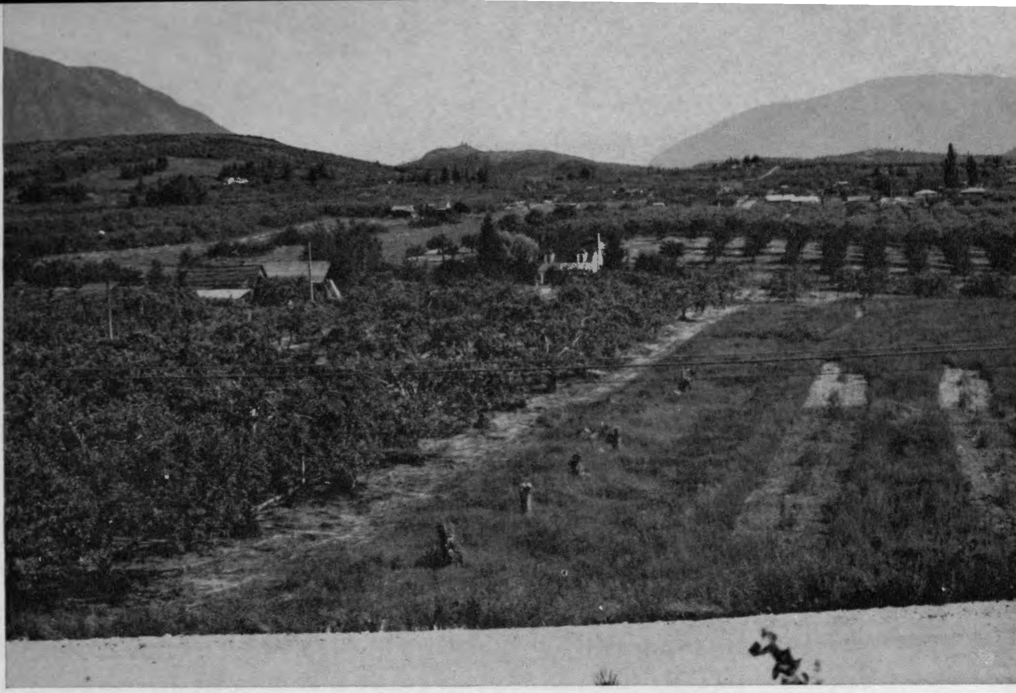

FIGURE 4. Orchards in the Creston district at the south end of Kootenay Lake. This is the only extensive orchard area outside the Okanagan Valley.

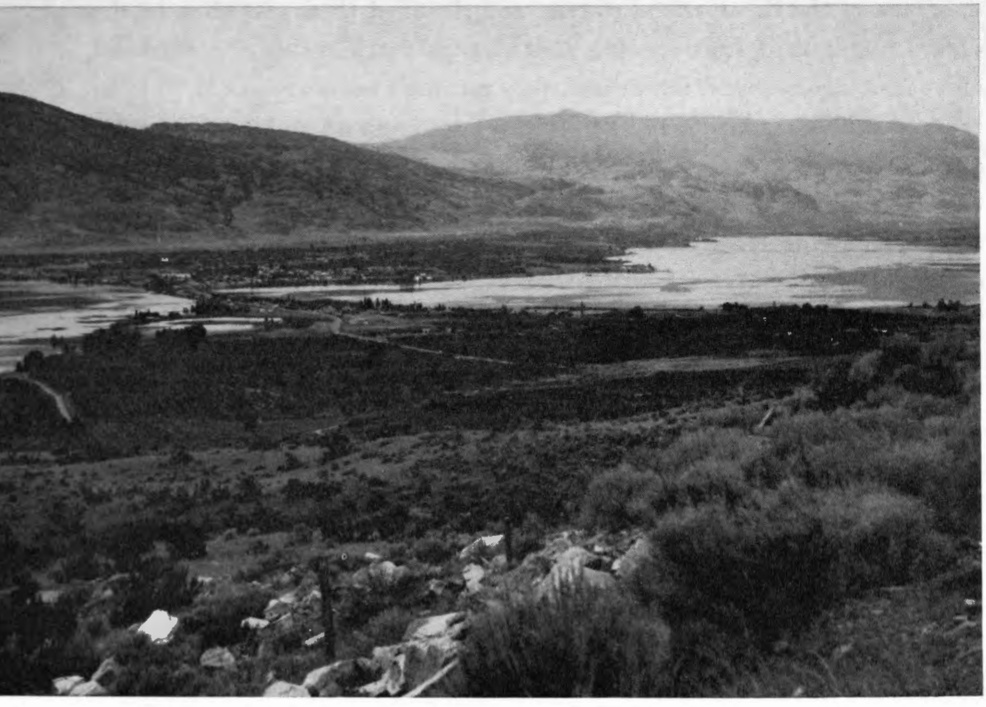

FIGURE 5. The Osoyoos district. In the foreground, the natural steppe vegetation; in the middleground, Osoyoos Lake with orchards on the near side, the town of Osoyoos on the far side; in the background, the Okanagan Valley slope.

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orchard operations. Although the reasons for these economic difficulties are many and complicated, they point to at least one means of improvement—the restriction of orchard-planting to the best soils and the best microclimatic conditions. One of the report's conclusions was, in fact, as follows: "Microclimates prevent a profitable industry being maintained in certain areas, regardless of capital, size, or effort; such land should be withdrawn from fruit growing and used for other agricultural purposes. There is need for an extensive, vigorous, and detailed district analysis by competent authorities to classify land in each district in terms of its suitability . . . Detailed investigations of climate . . . should be made, and should be correlated with soil conditions" (MacPhee, 1958).

The soil and climate analysis presented in this study are district in scope. Much more detailed microclimate-soil studies will undoubtedly be needed if the various tree crops are to be planted in the best places and sites unsuitable for orchards turned to other uses.

During the winter of 1957–58, a group of specialists in different aspects of horticulture made a highly detailed study of the soils within a 28-square-mile area of the Summerland district and classified them according to the differences in their fruit-growing suitability (Anstey, 1959). By means of an automobile-mounted thermistor, they recorded temperatures at 98 locations on calm clear nights and adjusted the reading's up or down in accordance with the fluctuation of temperature at the base station. They studied the conditions of soil and temperature on given sites and then correlated them with the degree of success of specific orchards on the same sites. They considered the opinions of experienced growers within the different zones when deciding where the various kinds of fruit could be cultivated satisfactorily. The main factors they considered were winter injury to trees, crop losses due to winter temperatures and spring frosts, the reduction of marketable yield due to late fruit maturity, and the general vigor of the trees.

The study revealed that temperature differences resulting from differences in elevation, slope and distance from the lake were more significant in the determination of fruit-growing suitability than were differences in soils. It was discovered that 29 per cent of the apricots, 17 per cent of the cherries and 9 per cent of the peaches were planted in unsuitable locations.

Such a study, if extended over the whole Okanagan Valley, would greatly assist growers in choosing the best places for planting orchards.

FIGURE 6. Peach orchards in the Similkameen Valley south of Cawston. Note how the prevailing downvalley winds have bent the trees in one direction.

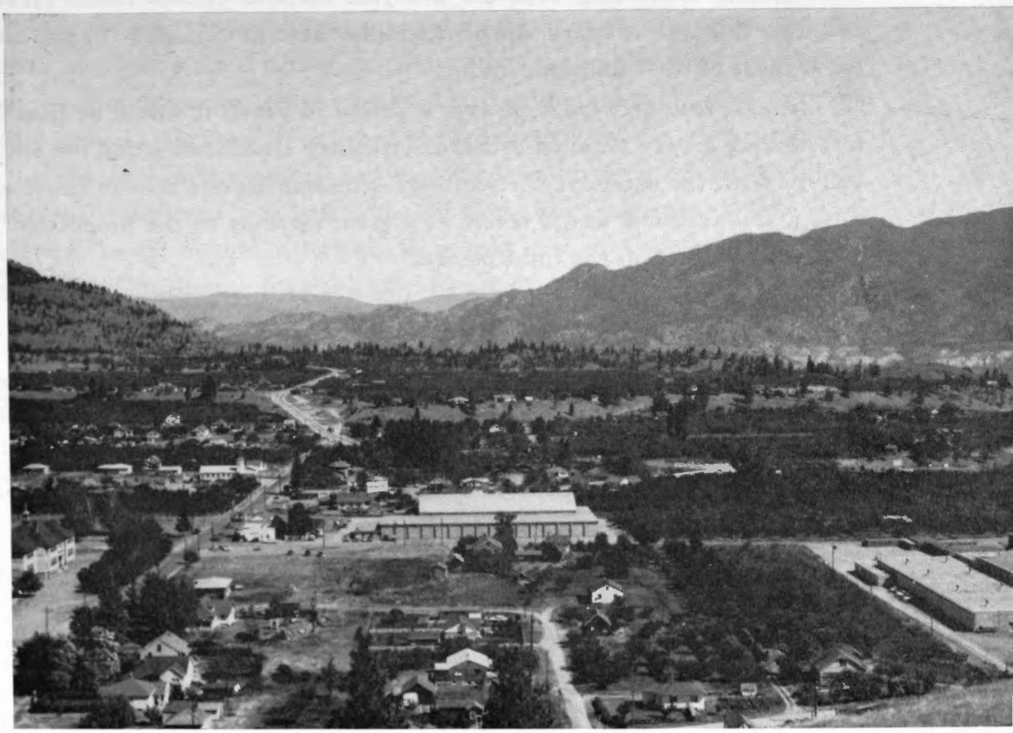

FIGURE 7. The town of West Summerland with surrounding orchards.

Because of the unpredictability of microclimates, however, such an experiment would need to extend over a number of years. To do a long-term survey of the whole Okanagan would take many years of intensive painstaking work.

As an alternative method, the writer proposes that the horticultural experts and growers who have had long experience in the valley pool and record their knowledge on air photographs. Accumulated experience, interviews, and field observations would make possible a considerably detailed delimitation of the following: (1) areas where the various fruit crops and varieties suffered most damage in 1949–50 and 1955; (2) areas that have frequently suffered spring-frost damage; (3) areas that have not produced well or that have a low tree-survival rate because of other factors (e.g. poor soil conditions); and (4) areas with the best tree-survival and production records.

For future correction and refinement, district horticulturists, by means of air photographs, could keep detailed records showing when, how much and where the various types of crop loss and tree damage occurred. Air photography coinciding with the five-year orchard census would greatly facilitate this type of study. Air photographs taken in 1955 and 1959 already cover most of the Okanagan Valley.

If such records were kept over a period of years, it would be possible to establish a very detailed orchard-suitability classification for the entire valley. With the excellent horticultural extension service now in existence, such a classification would result in a great increase in the proportion of fruit trees planted in the right places.

CONCLUSION

The Okanagan Valley has an orchard climate superior to that of most other valleys in southern British Columbia. It has milder winters than the other interior valleys and warmer summers than Vancouver Island or the Lower Fraser Valley. To become a major orchard region, the Okanagan has nevertheless had to overcome several physical limitations.

The low winter and spring temperatures seem to make the valley marginal for the most tender of the soft fruits. The growers, however, have shown great resilience after orchard and crop losses and a great deal of initiative in adopting new varieties and improving cultural practices to help prevent future losses. Because of the high concentration of heat and the control of moisture in the orchards, the yield is much higher than in eastern Canada and thus helps in part to offset the periodic crop losses. The efficient selling agency, B.C. Tree Fruits, has assisted immeasurably in stabilizing fruit prices and obtaining the maximum returns for growers in both poor and bumper-crop years.

The acreage of good orchard soils is relatively small. On the whole, orcharding has been intensifying in the districts where the tree-fruit climates and soils are best and declining in those where they are poorer. Within districts, on the other hand, fruit trees are still being planted on sites unsuited to their specific needs, but more detailed orchard-suitability studies supplemented by a first-rate extension service should eventually end this practice.

High land prices, which do not seem to reflect orchard returns to the grower, have been a major economic problem in the Okanagan. Running as high as $2,500 an acre, they add to the cost of production and have made it difficult for growers to enlarge their orchard holdings to more economic size.

As in most other spheres of agriculture, production costs have been increasing more rapidly than produce prices. A major item in the Okanagan Valley is the cost of providing the irrigation water needed to counteract the aridity of the climate. Further, no district has been able to set up renewal reserves proportionate to the rise in construction costs. Present reserves would provide less than 10 per cent of the urgently needed replacements.

If the economic problems can be solved, and if orchards in the future are planted only on the best orchard land, the Okanagan Valley from Kelowna south, should nevertheless remain one of Canada's important orchard regions despite imposing physical limitations.

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AGRICULTURAL LAND USE IN THE FORT VERMILION-LA CRÊTE AREA OF ALBERTA

J. H. Lovering

ABSTRACT: The Fort Vermilion-La Crête area, north of the 58th parallel, is part of the northernmost extension of the agricultural fringe of the Canadian Prairies. This paper describes the area's land use and discusses its relationship to relevant physical, economic and ethnic factors that have combined to produce a cash-crop and livestock economy. Problems and trends are compared with those of the Whitemouth Valley, Manitoba, another part of the fringe area. The comparison indicates that accurate generalizations about agriculture in the fringe area, as a whole, are not possible and that the two areas are tending toward agricultural specialization.

RÉSUMÉ: La région de Fort Vermilion-La Crête, située au nord du 58ᵉ parallèle, fait partie du prolongement le plus septentrional des terres arables marginales des Prairies canadiennes. Le bulletin décrit l'utilisation des terres dans la région à l'étude et traite de ses rapports avec les facteurs physiques, économiques et ethniques qui ont concouru à édifier une économie fondée sur une récolte marchande et sur le bétail. L'auteur compare les problèmes et les tendances à ceux de la vallée Whitemouth, au Manitoba, qui fait également partie des terres marginales. La comparaison indique qu'il est impossible d'en arriver à des généralisations précises au sujet de l'agriculture dans l'ensemble de la zone marginale et que les deux régions comparées tendent vers une spécialisation de l'exploitation agricole.

INTRODUCTION

The 60,000 acres of cultivated land in the Fort Vermilion area of northwestern Alberta form the largest commercial farming district in Canada north of the 58th parallel.

It is the purpose of this paper to analyze land utilization in the Fort Vermilion-La Crête area, which lies on the south and east sides of the big bend in the Peace River and comprises about half of the cultivated area (Figure 1). The area of study has a cash-crop (oilseeds and wheat) and livestock economy in which Mennonites are the predominant group. Owing to the area's physical, economic and ethnic homogeneity, major differences in the land-use pattern are limited to only two localities.

The other part of the general farming area, which extends westward for 50 miles along the road connecting High Level and Fort Vermilion, is one of oilseed emphasis and is settled predominantly by people of Ukrainian origin.

MS submitted March 1963.

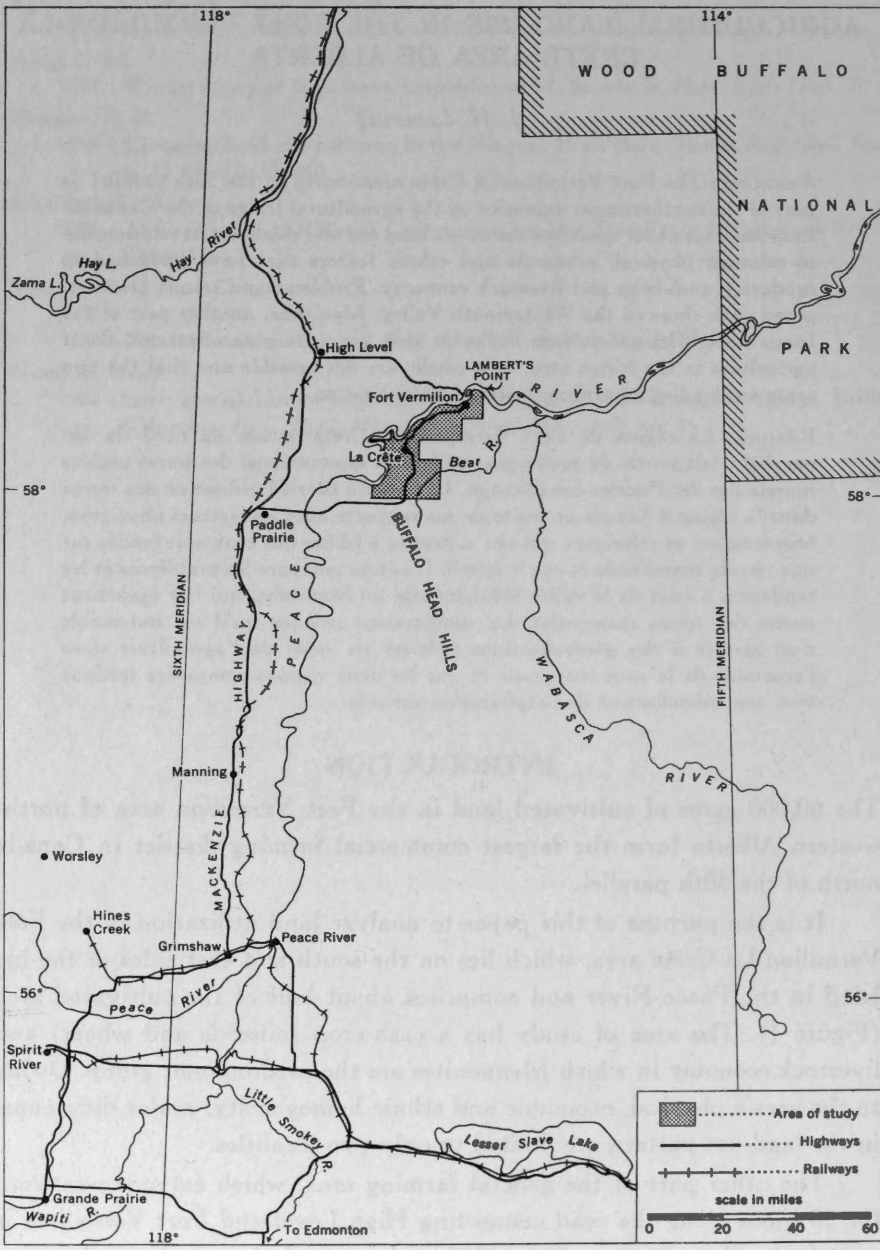

FIGURE 1. Location map, Fort Vermilion-La Crête area.

PHYSICAL GEOGRAPHY

Physiography

During the latter stages of the Pleistocene, lacustrine silts and clays were deposited on the bottom of a post-glacial lake that covered the area. Along the Peace River, however, between Lambert's Point and the Buffalo Head Hills, there is a strip of sandy and silt loam, which supports most of the agriculture of the area.

The Peace River lies from 100 to 200 feet below the adjacent farmlands. Only in a few places near Fort Vermilion are the river terraces cultivated. Although the river was the major determining factor in the early fur trade and modern agriculture, it now has no significant role in the regional economy.

The land surface of the area is level to depressional, broken only by a few gently undulating sections. The most prominent feature is a gently rolling aeolian sand deposit in Townships 105–107, Ranges 15 and 16 W. 5M.

Climate

The climate of the area is transitional between the subarctic and the humid continental, short-summer categories of the Köppen classification. Figure 2 shows the temperature and precipitation at Fort Vermilion and Buffalo Head Prairie.

The coincidence of the period of maximum precipitation with that of maximum temperature and greatest length of day is very important to agriculture, because it makes the annual precipitation, although low, quite efficient in terms of crop production. Early growth depends on the adequacy of June rains, but August rains delay plant maturity and thus increase the danger of autumn frost damage (Can. Dept. Agr., 1958).

Table 1 shows the marginal nature of the area as regards crop production. The difference between the frost-free period and the period free from killing frosts (temperature above 28°F) is critical even for the crops that mature earliest, such as barley.

Frost-free periods at Buffalo Head Prairie are normally shorter than at Fort Vermilion owing to the greater altitude (150 feet above Fort Vermilion) and the cold-air drainage from the nearby Buffalo Head Hills. These hills, which rise 1,500 feet above the surrounding plain, invariably have lower temperatures and higher precipitation than the adjacent area.

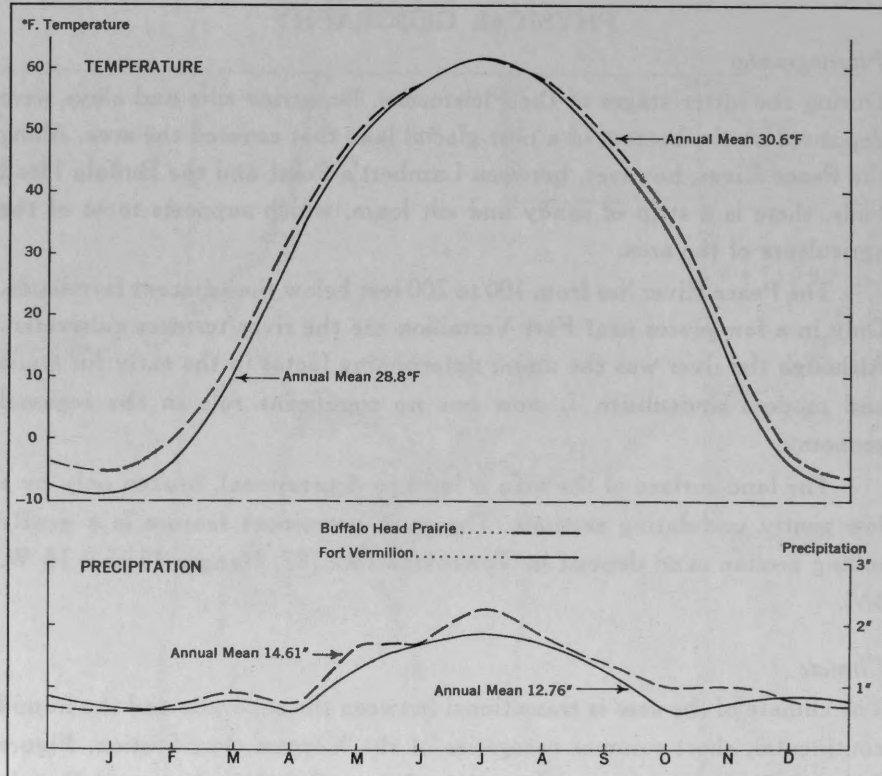

FIGURE 2. Precipitation and temperature, Fort Vermilion and Buffalo Head Prairie, 1921-50.

Soils

At present, the extent of alienated land virtually coincides with that of the Dark Grey* soils developed in the strip of sandy and silt loams along the river (Figures 3 and 4).

Most of the cultivated soils of the district appear to be moderately well to imperfectly drained. Despite the relatively high permeability of the loams, standing water may cause some difficulty in the spring and in wet years. These soils frequently have a finer-textured layer that ranges from clay loam to clay and lies about 20 inches below the surface. This layer may contribute significantly to their productivity by keeping the ground-water table high in the sola (Can. Dept. Agr., 1948). It also keeps the coarser loams from being too droughty under adverse conditions.

*The color terminology that appears with initial capitals on this and following pages is that used in the Report of the Meeting of the National Soil Survey Committee of Canada, held at the Ontario Agricultural College, Guelph, Ont., in 1960.

Table 1

*Averages of frost-free periods and annual temperatures, by 10-year periods, at Fort Vermilion, 1909–58**

Period	Number of days free from killing frosts	Number of days free from frost	Mean annual temperature, °F
1909–18	81	47	26.1
1919–28	101	76	27.5
1929–38	108	78	28.2
1939–48	122	79	30.2
1949–58	109	79	28.8

*Can. Dept. Agr., 1958.

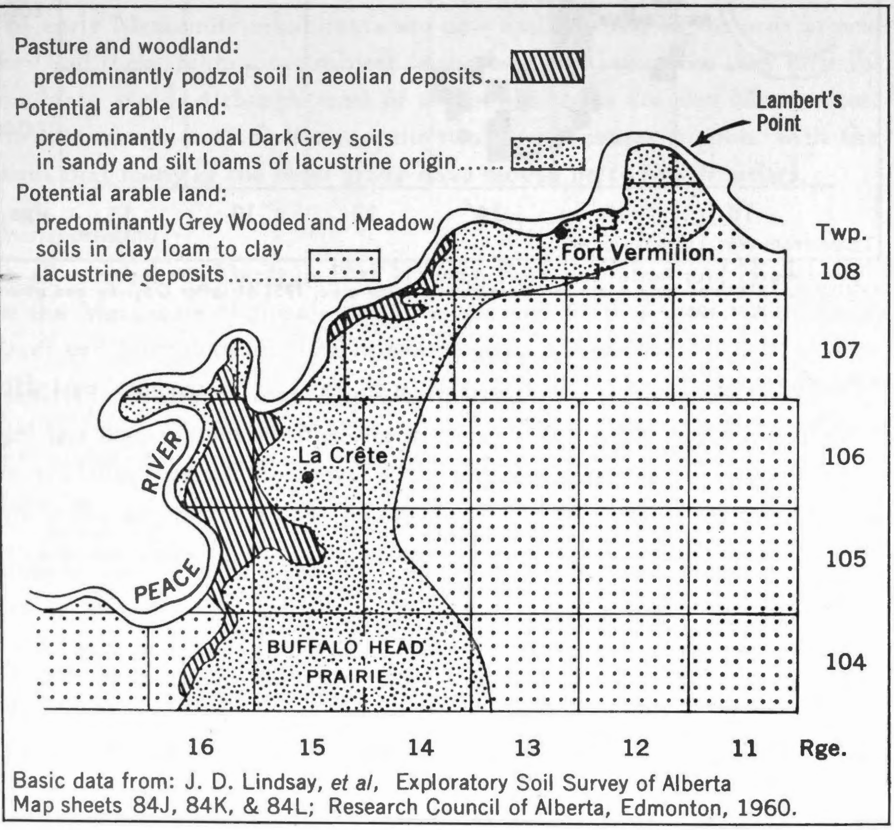

FIGURE 3. Generalized soil-survey and rating map, Fort Vermilion-La Crête area (after Lindsay, 1960).

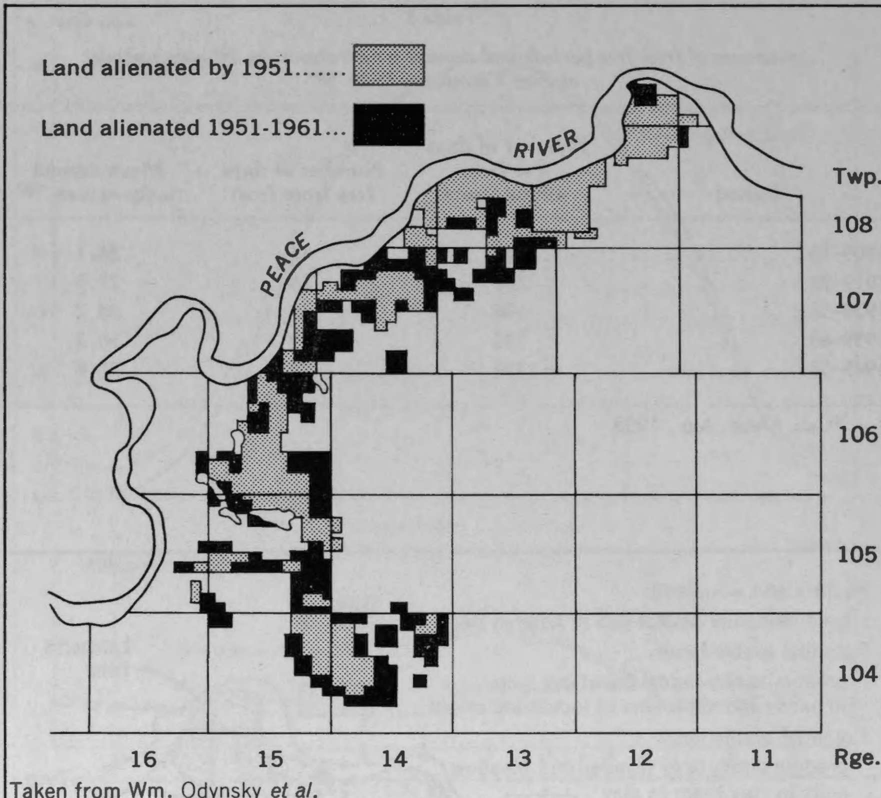

FIGURE 4. Alienated land in the Fort Vermilion-La Crête area, 1951-61 (after Odynsky and others, 1951, 1961).

The Dark Grey soils are of relatively high natural fertility. Fertilizer trials (Can. Dept. Agr., 1958) nevertheless indicate that grasses and legumes respond to nitrogen and that flax, oats and barley mature more quickly and are yielded in greater quantities when treated with phosphorous fertilizers. With a short growing season, the need for early maturity is obvious.

LAND UTILIZATION

Most farms in the area have been occupied for less than 15 years and are characterized by the smallness of their cultivated acreages and the great extent of their forest or wasteland. Farm programs usually combine cash crops with feed grain and livestock. Table 2 indicates the relative importance of various crops, on both an areal and a per farm basis.

Table 2

Total and per farm crop acreages in the Fort Vermilion-La Crête area

	Total farm area	Forest or waste-land	Newly broken	Total area culti-vated	Wheat	Oats	Barley	Flax	Rape-seed	Seeded grass	Seeded pas-ture	Sum-mer fallow
All farms	72,470	39,114	1,439	31,917	4,494	10,098	3,120	3,376	2,746	1,777	1,632	4,674
Average	320.7	173.1	6.4	141.2	19.9	44.7	13.8	14.9	12.2	7.9	7.2	20.6

Farm fields and buildings are generally in poor condition. Log buildings with earthern roofs that support a coarse rank growth of weeds and grasses are common.

This is an expanding area in terms of cultivation, population, road network and services, but the influx of settlers has brought social problems. The early Mennonite inhabitants are now finding that, as the area grows, they and their children are subject to the 'worldly' influences they initially sought to avoid. Although most of the new arrivals are also Mennonites, the difference in outlook between the two groups causes friction, with the result that many of the older group have moved on to new frontiers.

Transportation

An all-weather road built in 1952 between Fort Vermilion and High Level, on the Mackenzie Highway, gave the area its first easy access to Peace River and Grimshaw. In 1961 a second road joined Buffalo Head Prairie with the Mackenzie Highway at a point about 5 miles north of Paddle Prairie. Since the ferries cannot operate during the freeze-up and break-up of the Peace River, these road links are severed for a month each spring and fall.

Before 1952, most agricultural produce was shipped upstream to Peace River by boat. Although not so fast or convenient as present road transport, this means was cheaper. It was discontinued, however, when highway transport began to compete.

In the early 1950's, about 25,000 pounds of dressed beef and pork, 2,000 pounds of dressed poultry and 5,000 dozen eggs a year (Gilchrist, 1954) were transported by air to Yellowknife. Since then a road has been built to connect that town with the Mackenzie Highway, and air shipments from Fort Vermilion have ceased. Yellowknife is now supplied largely by more southerly centres such as Edmonton and Peace River.

An all-weather road built between Fort Vermilion and Buffalo Head Prairie in the period 1957–59, replaced an earlier trail that was almost impassable to tractors in wet weather.

Before the completion of the all-weather roads to the Mackenzie Highway, commercial agriculture in the area was at a tremendous disadvantage. Even now the great distance from the railroad at Grimshaw imposes the severe handicap of high transportation costs.

Because of these difficulties farmers have given priority to such high-unit-price produce as livestock, oilseeds, legume and grass seeds and, to a lesser extent, wheat. The growing of oats or barley as a cash crop is largely precluded by the 57 cents per 100 pounds it costs for trucking to Grimshaw, 230 miles to the south. The Great Slave Lake Railway, due for completion in 1965, will greatly alleviate the grain-shipping problem, its shipping charges being substantially less.

Distribution of cultivated land

The distribution of the Dark Grey soils and their proximity to the Peace River (the only means of shipment for produce before 1952) are the main reasons for the distribution of cultivated land.

A comparison of Figures 4 and 5* indicates that while alienated land coincides with the belt of Dark Grey soils between Lambert's Point and the Buffalo Head Hills, the distribution of cultivated land is discontinuous, especially in township series 108. The 'details' of this distribution in the Mennonite area south of these townships are due to local drainage and forest cover.

In township series 108, however, only a small part of the land is under cultivation because most of the landowners, who are of English and French origin, derive their income from non-agricultural sources. The Mennonites, who in normal circumstances might be expected to buy this land, refrain from doing so because it lies in the Fort Vermilion school area. They prefer, instead, to send their children to the schools in the area to the south, where many of the teachers are themselves Mennonite and where the influence of Fort Vermilion is less pronounced. Some of the cultivated land in township series 108, however, is rented by Mennonites living farther south.

In the future the pattern of cultivated land in the area will probably become more regular as many of the younger farms are exploited in greater measure and as improved drainage makes cultivation possible where it is

*Farmsteads outside the cultivated area are those of 'squatters' in the Fort Vermilion locality and of very recent homesteaders in the Mennonite area.

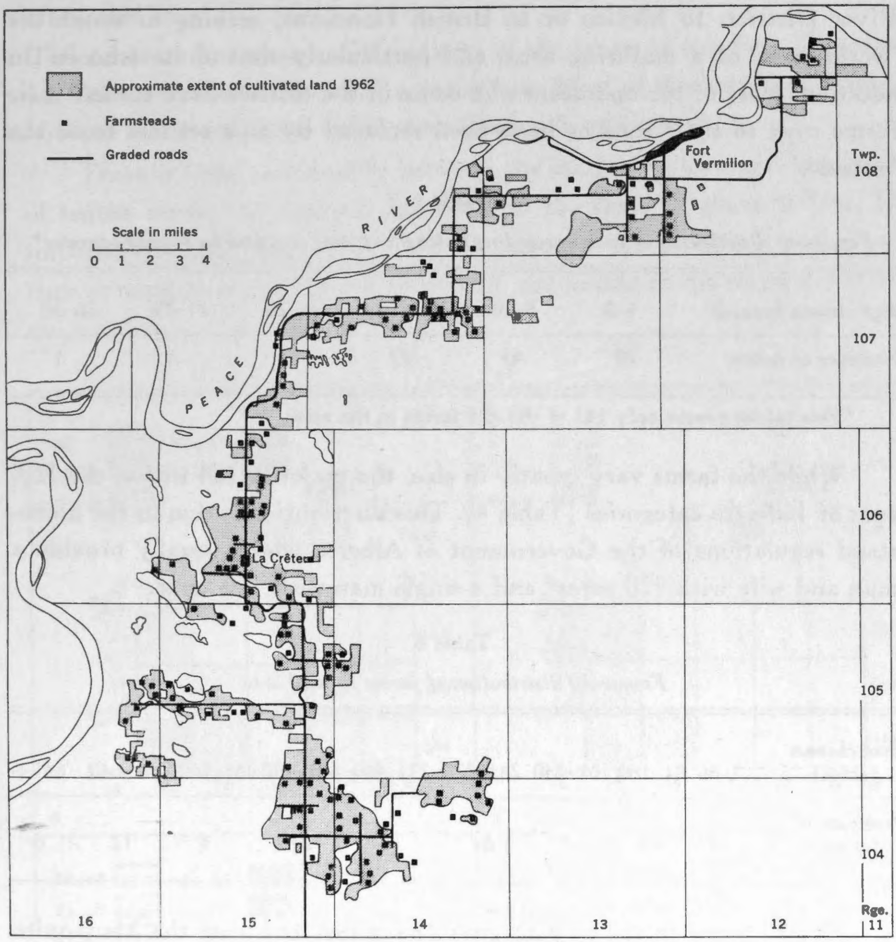

FIGURE 5. Agricultural settlement, Fort Vermilion-La Crête area.

not now feasible. As most of the better soils have now been brought under cultivation, the expansion of cultivated acreage in the Fort Vermilion-La Crête area will, of necessity, occur on the more poorly drained clay and clay-loam soils to the east of the present agricultural area.

Length of tenure and farm size

It is striking how short a time the operators in the Fort Vermilion-La Crête area have been on the farms they occupy (Table 3). Much of the occupied land has been homesteaded only within the last decade (Figure 4). At the same time many of the highly mobile Mennonite settlers who took up land before 1951 have moved to the Worsley section of the Peace

River District, to Mexico or to British Honduras, seeking to avoid the 'worldliness' of a maturing area, and particularly that of its schools. In addition, most of the operators who came in the thirties have turned their farms over to their sons or have been replaced by new settlers from the 'outside.'

Table 3

*Frequency distribution of farms according to length of time occupied by present operator**

Age classes (years)	1–5	6–10	11–15	16–20	21–25	26–30
Number of farms	70	43	23	3	3	1

*This tables covers only 143 of the 226 farms in the area.

While the farms vary greatly in size, the majority fall within the 320-acre or 160-acre categories (Table 4). This distribution is due to the homestead regulations of the Government of Alberta which usually provide a man and wife with 320 acres* and a single man with 160 acres.

Table 4

Frequency distribution of farms by total area

Size classes (acres)	1–80	81–160	161–240	241–320	321–400	401–480	481–560	561–640	641+
Number of farms	15	48	18	84	14	24	3	12	8

The 15 farms in the 80-acre group have resulted from the Mennonite practice of dividing a parent's land among his children. The parents usually continue to live on a portion of the original farm while the children increase their holdings by homesteading an additional 160 or 320 acres. So long as land is available for homesteads, it is unlikely that there will be any difficulty due to the formation of these units of 80 acres or less. In south-central Manitoba, however, in the Mennonite area south of Winkler, many of the farm units resulting from similar practices have proven uneconomic and have given rise to the social problems attendant upon their being so. Even if capital for the outright purchase of land is available, the reincorporation of such small farms is very difficult because, once formed, they tend to be a continuing source of problems.

*In a homestead sale, a man and his wife may have an extra 160 acres for a total of 480 if the arable area with the first 320 acres is less than 240 acres.

Cultivated area

The cultivated acreage cn 70 per cent of the farms in the Fort Vermilion-La Crête area amounts to 160 acres or less. Most of the rest have between 161 and 400 acres under cultivation (Figure 6, section A).

There is little relationship between the cultivated area and the length of tenure where the operator has been on the farm 15 years or less. The important determining factors are the amount of cultivated land at the time of occupancy, the supply of capital, the nature of the forest cover and the weather.

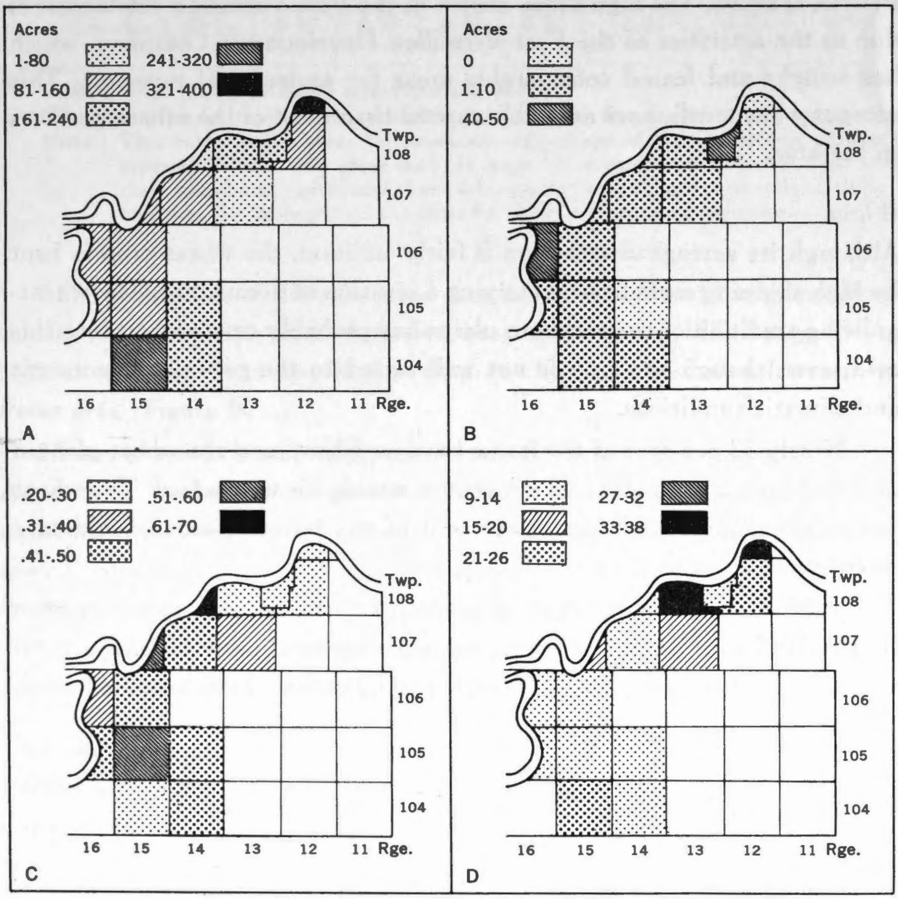

FIGURE 6.

A. Average cultivated area per farm.

B. Average area of new buildings per farm.

C. Ratio of oats and barley acreage to total cultivated acreage.

D. Number of cultivated acres per head of cattle.

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B. above: for buildings *read* breakings

According to a farm business study made in 1952–53 (Gilchrist, 1954) of the entire Fort Vermilion area, operators earned an average of only $639 in excess of all living and operating costs. Since the cost of clearing and breaking runs between $20 and $30 an acre (Can. Dept. Agr., 1959), depending on tree cover, it follows that bringing land under cultivation is a slow process even when all available capital is used for this purpose.

Figure 6B, which shows the per-farm acreage of new breaking, indicates the rate of progress for 1961, an exceptionally favorable year because of drought. As might be expected, the acreage of new breaking in the older settled areas, Lambert's Point and the southern part of the Buffalo Head Prairie, is small. The high value shown in the Fort Vermilion Settlement is due to the activities of the Fort Vermilion Development Company, which has bought and leased considerable areas for agricultural purposes. This company has much more available capital than most of the other operators in the area.

Wheat

Although its acreage distribution is fairly uniform, the wheat crop is kept by high shipping costs from occupying a position of dominance. The wheat-growing tradition of the southern plains has probably carried over into this area, even though the crop is not well suited to the prevailing economic and climatic conditions.

Nearly 33 per cent of the farms have no wheat, and the wheat planted on 1 to 10 acres of another 13 per cent is mainly for use as feed. The wheat produced on the remaining 54 per cent of the farms is usually sold as a cash crop.

Table 5 shows approximate gross crop returns per acre based on price for the 1962 crop year, and yields indicated by farm interviews. For comparative purposes the costs of transport to Grimshaw have been deducted.

Oats and barley

Because of the distance to market, both oats and barley are grown solely for local livestock feed. Only barley of malting quality has a high enough unit price to warrant shipment to Grimshaw. Here, as elsewhere on the northern fringes of the Prairies, barley acreage is only about one-third that of oats, despite the fact that it matures quickly, has a high nutrient value and can be useful in weed control. The farmers interviewed indicated, however, that it does not produce well in this area.

Table 5

Approximate gross returns per acre for various crops in the Fort Vermilion-La Crête area, 1962

	Wheat	Oats	Barley	Flax	Rapeseed	Alfalfa seed	Brome-grass seed
Gross returns $/acre..........	37.50	19.80	21.00	36.96	45.50	60.00	45.00
Gross returns delivered at Grimshaw $/acre.........	29.00	11.60	12.80	33.15	34.45	58.30	42.45
Assumed mean yields/acre....	25 bu.	45 bu.	30 bu.	12 bu.	1,300 lbs.	200 lbs.	300 lbs.
Unit price $[1]................	1.50	0.44	0.70	3.08	0.035[2]	0.30	0.15
Cost of shipment Fort Vermilion to Grimshaw $/100 lbs..	0.57	0.57	0.57	0.57	0.85	0.85	0.85

[1]Averages for the Peace River crop-reporting district.

[2]The 1962 price for rapeseed is below that paid over the five preceding years.

NOTE: This table makes clear the economic advantage of the production of flax, rapeseed, alfalfa and grass seed. It must be remembered, however, that all these prices and yields, and thus cash returns per acre, are extremely variable and that the table should therefore be taken merely as an indicator.

The proportion of the cultivated area used for oats and barley production in the Mennonite area south and west of Township 107, Range 13W. 5M., is uniform. It is also higher than in the Fort Vermilion-Lambert's Point area (Figure 6C).

Some of the oats and barley grown is sold to local livestock producers. As in other areas, many operators do not raise livestock in appreciable numbers, preferring to derive their income from grain and oilseed production. Feed grains grown on these cash-crop farms must of necessity be sold locally.

Interviews with operators indicate that the average yields for oats and barley are respectively about 45 and 30 bushels an acre.

Flax and rapeseed

Forty-two per cent of the farms in the Fort Vermilion-La Crête area produce oilseeds (flax or rapeseed), the acreage of which exceeds 10 acres on 40 per cent of these farms.

Owing to their high unit price, these crops are well suited to the area. Considerable difficulty, however, has been caused by severe rusting of flax, particularly in fields where it is continually produced (Can. Dept. Agr., 1958).

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The greatest concentrations of oilseed crops are in the western part of the Buffalo Head Prairie and in the neighborhood of Fort Vermilion, where the non-Mennonite groups have broken away from the traditional production of wheat, oats, barley and livestock.

Seeded grass and pasture

Only 20 per cent of the farms in the Fort Vermilion-La Crête area produce grass or legumes for hay, or seed. The average per farm area within this group is 39 acres. Grass crops are not of major importance except in the seed-producing Fort Vermilion-Lambert's Point area.

The Fort Vermilion Experimental Farm recommends grass seed or legume seed as a cash crop. Not only has the seed a high unit price, but the rest of the plant is available as green manure. These forage crops also help to maintain soil fertility and tilth by adding organic matter. Alfalfa, with its deep root system, is especially useful in providing nitrogen and improving subsurface drainage.

The seed set on alfalfa crops is extremely variable, depending on such factors as the wild-bee population and the date of pollination. Operators have found that brush piles left in the fields after clearing promote an increase in the number of wild bees by providing nesting places in the rotting wood.

Twenty-eight per cent of the area's farms use legumes or seeded grass as pasture. These seeded areas average 26 acres. Another 58 per cent of the farms graze cattle solely on natural pasture that usually consists of wooded areas or open, poorly drained meadows. Natural pasture, however, is not conducive to efficient cattle production since it is often of poor quality and is usually heavily infested with insect pests, such as mosquitoes and black flies.

Farm interviews indicate that 1 acre of seeded pasture will support one animal more efficiently than 5 acres of natural pasture. These values, of course, vary widely from one pasture to another.

Summer fallow

With the exception of a slight concentration in the eastern part of Buffalo Head Prairie, the acreage of summer fallow is small and evenly distributed.

Of the area's 226 farms, 29 per cent have neither seeded grass (for all purposes) nor summer fallow, 24 per cent have both, and 47 per cent have one or the other but not both. These statistics suggest that the 29 per cent use no rotation scheme and that the remaining 71 per cent rotate between a cash crop and fallow or between a cash crop and seeded grass. Interviews with operators indicated an almost even division in the use of the two rotations.

Fifty per cent of the area farms have no summer fallow, and its acreage on the remaining farms is low, being only 15 per cent of the land cultivated. In 1961 summer fallow comprised about 20 per cent of the cultivated acreage of the whole Peace River District (Dominion Bureau of Statistics, 1962). Summer fallow is proportionately low probably because of the inherent fertility of newly broken land, the reluctance to summer fallow on farms with a small cultivated acreage, and poor soil-management practices.

Care needs to be taken when land in the area is left as summer fallow because the sandy loams are susceptible to wind erosion. Thus, in the original land-clearing, strips of bush should remain as shelter belts.

Cattle

Most of the area supports one head of cattle per 7 to 12 cultivated acres (Figure 6D); thus the land is not used intensively for livestock production. The Fort Vermilion-Lambert's Point district has relatively few cattle, its emphasis being on the production of oilseed and grass seed.

Sixty-three per cent of the area's operators own 10 head or fewer. Only 14 per cent of the farms support no cattle. Many of the smaller herds consist of two or three animals that provide milk for the operator. These and larger herds, up to about 15 head, often consist of dual-purpose animals of doubtful ancestry, which frequently serve neither purpose well. Most operators with this type of herd ship cream to Grimshaw. The animals themselves are usually marketed in Edmonton.

The larger herds appear to be of a better-quality beef type and are usually provided with reasonable amounts of seeded pasture. The Fort Vermilion Experimental Farm makes breeding stock available for herd improvement.

Hogs

The areal distribution of hogs is uniform except in the Fort Vermilion-Lambert's Point section, where the concentration is low. This distribution is much more uniform than that for cattle and shows a stronger correlation with the distribution of oats and barley.

The farm business study (Gilchrist, 1954) mentioned earlier indicates that for 30 farmers interviewed the average gross returns per head of cattle and per hog respectively were $31 and $50. On this basis, the fact that there are 5,780 hogs and 2,269 head of cattle in the area shows that hogs are by far the most important source of livestock income.

Farm practices

The crop rotations outlined under summer fallow make it clear that there is need for an improvement in soil management. Twenty-nine per cent of the farms have neither seeded grass nor summer fallow, and many of the remaining 71 per cent have only small acreages of seeded grass or summer fallow. For a balanced farm enterprise that includes livestock, the following basic rotation is recommended: fallow, coarse grains or oilseeds, hay (brome grass and alfalfa), hay, hay, and break, coarse grains or oilseeds (Can. Dept. Agr., 1958).

Very few of the operators now use commercial fertilizers, but several, especially on the older and larger farms, said they intended to use it in the near future. With the recommended rotation, however, the need for commercial fertilizers would probably be greatly limited.

Of the 32 operators interviewed, 13 had combines, 5 had threshing machines, and 14 had neither. Many of the operators in the area have their crops custom-harvested. It is also a common practice for two operators, especially for father and son, to share their machinery. Lack of available capital is doubtless the reason for the apparently low level of mechanization. High labor costs inhibit the use of threshing machines, although much can be said in favor of operating them where weather conditions may frequently be marginal.

Farm income

Twenty-one of the 32 operators interviewed derived their main income from livestock; the remaining 11 reported that cash crops, mainly grains and oilseeds, provided their greatest income.

Of the $639 earned in 1952–53 in excess of all farm and living expenditures, $300 came from family allowances and $153 from casual work (Gilchrist, 1954). The low living standards of the area indicate that cash returns from the farms are still very small. This is understandable in a newly settled area, where capital resources are limited, operating and land-clearing costs are high and the cultivated acreage is small.

Economic returns from the holdings will probably be limited by present farm size since many larger farms on the southern plains, although well favored economically and physically, are not economic units.

Six of the 32 operators interviewed spent an average of two months in non-farm work during the winter of 1961–62. They were nearly all new settlers trying to augment their incomes. Many more operators would certainly work off their farms if employment in the area were available.

Problems and trends

The cost of transportation is the main problem facing the Fort Vermilion-La Crête operators. The present rates from Fort Vermilion to the railway at Grimshaw are about $10 for a head of cattle, $4 for a hog and 57 cents for 100 pounds of most crops.

Operators interviewed predict that the production of grain, and particularly of wheat, will increase sharply when the Great Slave Lake Railway comes into operation. The distance to steel will be reduced to about 50 miles, the result for most crops being a reduction in trucking costs to about 15 cents for 100 pounds.

The proximity of the railway will undoubtedly make this area more attractive to settlers. Even now, land is being taken up as quickly as it is 'opened to homestead.' Most of the land in the two townships 'opened' in 1961 was taken by the sons of operators already living in the area. Several recent settlers, however, have come from southern Saskatchewan and Manitoba, where land is not readily obtainable. These recent arrivals seem considerably more 'progressive' than the early settlers.

Table 6 shows population trends over a five-year period extending from 1956 to 1961. Despite decreases in the two non-Mennonite townships (Townships 108, Ranges 13 and 14W. 5M.) adjacent to Fort Vermilion, the entire area had an increase of 30 per cent over this period.

The population growth is being matched by the increase in services and transportation facilities.

Table 6

Population, by township, in the Fort Vermilion-La Crête Area, 1956–61 (D.B.S., 1962)

Year	Township													Total change
	108–14	108–13	108–12	107–14	107–13	107–12	106–16	106–15	105–16	105–15	105–14	104–15	104–14	
1956	144	219	650	172	0	0	9	249	18	305	16	53	170	
1961	95	148	759	284	22	5	12	472	51	428	47	63	212	
Change	–49	–71	109	112	22	5	3	223	33	123	31	10	42	593

This study of the Fort Vermilion-La Crête area provides one small example of settlement in the 'pioneer fringe' of the Canadian Prairies, but its land-use pattern cannot be regarded as typical. Whereas the Fort Vermilion-La Crête area is expanding, other parts of the fringe are contracting, remaining static, or changing their agricultural emphasis.

The Whitemouth Valley, in Manitoba (Lovering, 1963), for example, has had population decreases over the past 20 years through farm consolidation and land abandonment in some sections of poorly and imperfectly drained coarse-textured soils. To escape the high cost of land in their original settlement, centred on Steinbach, southeast of Winnipeg, Mennonites have established large poultry farms in other parts of the area. This group, however, cannot be described as 'pioneer' in the usual sense, for they have arrived with the capital, knowledge and skill required for these highly specialized commercial enterprises. Dairy farms have also prospered in the northern part of the area, which lies within the Winnipeg and Kenora, Ontario, milksheds. Here as elsewhere, this type of farming has provided relatively high and stable incomes.

Although the author has studied only two small parts of the pioneer fringe in detail, it seems clear that generalizations are not possible for the fringe as a whole. Whereas the Whitemouth Valley has developed poultry and dairy specialties, the new expanding areas of the northern Alberta fringe show strong indications of specialization in grass and oilseed production.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to C. Graham Anderson of the Prairie Farm Assistance Act office in Edmonton for cultivated acreage data, to C. H. Anderson of the Fort Vermilion Experimental Farm, who provided much information about the area of study, and to the 32 farm operators interviewed in 1962 during the course of the field work.

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SNOWCREEP STUDIES, MOUNT SEYMOUR, B.C.: PRELIMINARY FIELD INVESTIGATIONS

W. H. Mathews and J. R. Mackay

ABSTRACT: Snowcreep is a slow, continuous, glacier-like downhill movement of the snowpack which takes place under shear stress sufficient to produce permanent deformation but too small to produce shear failure as in snowslides and avalanches.

The main contribution of this paper is the discussion of instrumentation developed for the measurement of snowcreep on Mount Seymour, B.C. during the period 1958–62. Methods are described, and preliminary results show that displacements of from 2 to 3.5 feet do occur in a single winter within the bottom 3 to 6 inches of the snowpack on steeper slopes. It is postulated that pressure of the downslope component of load is enough to push loose stones down inclines, and presumably for this reason the bedrock slopes at the Mount Seymour test site are free of soil and boulders. The loads and amount of movement are also considered adequate to account for the deformation of trees on the nearby timbered slope.

RÉSUMÉ: Le creep nival est le mouvement lent et continu d'un banc de neige dans le sens de la pente. Le phénomène se produit lorsque les forces de cisaillement provoquent des déformations permanentes de la masse de neige sans atteindre le degré de rupture qui caractérise les avalanches.

Cet article décrit les méthodes de travail et les instruments mis au point pour mesurer le creep nival sur le mont Seymour de 1958 à 1962. Les résultats préliminaires montrent que dans les 3 à 6 pouces de la zone basale des déplacements de 2 à 3.5 pieds ont lieu au cours d'un seul hiver.

On suppose que la composante tangentielle de la pression de la masse de neige est suffisamment grande pour entraîner les blocs sur les pentes. On peut ainsi expliquer l'absence de sol et même de débris de roche à l'endroit étudié. La charge et le creep nival expliquent également les déformations de certains arbres sur les pentes boisées des environs.

Snowcreep is a slow, continuous, glacier-like downhill movement of the snowpack (U. S. Dept. Agr., Forest Serv., *Avalanche Handbook*, 1953, p. 145). The quasi-viscous movement takes place under shear stress sufficient to produce permanent deformation but too small to produce shear failure as in snowslides and avalanches (see definition by Stokes and Varnes, 1955, repeated in A.G.I. Glossary, 1957, p. 67).

The movement of the snowpack can be considered as having three components: (1) a vertical settling or compression of the layers under the direct influence of gravity; (2) a shearing within the snowpack usually parallel to the ground surface, higher layers gradually riding downslope over

MS received January 1963.

lower ones; and (3) at least locally, a sliding of the snowpack as a whole over the ground beneath. The resulting movement of any point within the pack depends on the magnitudes of all three components, the slope of the ground surface and the distance of the point above the ground.

The settling or compression of the snow layers and the shearing movement within the snowpack have been investigated by a number of research workers (Kojima, 1960; Martinelli, 1960). By means of markers set in the snow it has been demonstrated that the rate of downslope movement diminishes with depth and that in many cases the creep velocity at the base of the snowpack is too small to record. It is possible, however, to demonstrate that an appreciable slip may occur along the interface between the snowpack and the ground beneath, although few experiments have been undertaken to establish the basal rate of movement.

The creep of the snow may have an appreciable effect in moving subjacent loose rocks and soil, injuring vegetation and disturbing man-made structures in its path. This study was prompted, in fact, by observations in the alplands north of Garibaldi Lake, B.C., which suggested that basal snowcreep was an important agent in the downslope migration of soil and the formation of sorted soil stripes (Washburn, 1956). Movements at higher levels within the snowpack are also of interest since these can affect the growth and shape of shrubs and trees (Shidei, 1954; Kataoka and Sato, 1959) and exert pressures against poles, avalanche fences and buildings (Furukawa, 1956; Haefeli, 1953; Bucher, 1948).

The present study has been concentrated on the movement of the lowest snowpack layers that might shift stones and soil and that increases the displacement of higher layers of snow. This is the component least investigated to date and, indeed, the one that Bucher (1948), in his valuable theoretical study of pressures exerted against avalanche defences, intentionally ignored so as to make the mathematical derivations manageable.

The site for the investigations was selected at Mount Seymour, B.C., which, unlike neighboring Garibaldi Lake, is reasonably accessible during winter and has adequate snowfall and where snowcreep is amply evidenced by the bent trunks and branches of shrubs and even of large trees. The experiments were made at the crest and on the upper slope of a rocky knoll, at an altitude of 3,600 feet, a half mile northwest of the terminus of the Mount Seymour Park road, and 10 miles northeast of Vancouver (Figure 1).

Factors that might affect the rate of the basal snowcreep studied at this site have included snow depth, density, grain size, the liquid-water content of the snow, and temperature. The possibility of adhesion to the ground and the influence of obstacles upslope have also been considered. Field studies were started on Mount Seymour in the fall of 1958 and have been continued each winter since then. Visits have been made to the site about once a week during the period of snow cover, usually from December to April. Much more limited observations of snowcreep have also been made at Garibaldi Lake and, in 1961–62, at Ottawa, Ont.

INSTRUMENTATION AND METHODS

Design of simple, inexpensive and reliable apparatus to record the behavior of the basal layers of the snowpack has so far been the main task. From this has come experience in problems and their solutions that may be the most valuable result of the work. Methods have now been established to measure with reasonable success and accuracy the following items: (1) the direction of movement; (2) the rate of movement of the lowermost layer of the snowpack; (3) the total movement of the basal layer during a single winter; and (4) the pressure exerted by the creeping snow against a stationary object at any level.

Direction of movement

An obvious way to establish the direction of movement of the snowpack is to place a loose identifiable object (e.g., a stone with distinctive lithology or a colored marble) on a fixed point on the ground surface and to locate it when the snow disappears the following spring. A paint spot or chiselled mark can serve as a reference point on a rock surface; a buried ceramic magnet can be used beneath loose soil. Precautions must be taken to ensure that the movable objects are not dislodged by passing animals, are not deflected by irregularities on the surface or do not roll on steep slopes. Replicate tests are desirable to check against such accidents.

Metal ribbons capable of being bent downslope by the winter's movement of the snowpack may also be inserted in the ground or in cracks in bedrock. Such ribbons should be sufficiently strong to escape flexure by wind or freshly falling snow but flexible enough to bend in the creeping snow. They should be sufficiently broad to avoid cutting the moving snowpack but narrow enough to exert no influence on the direction of bending. For the type of snow occurring at Mount Seymour, 2.5-mm-wide metal ribbons that become permanently flexed with a bending moment

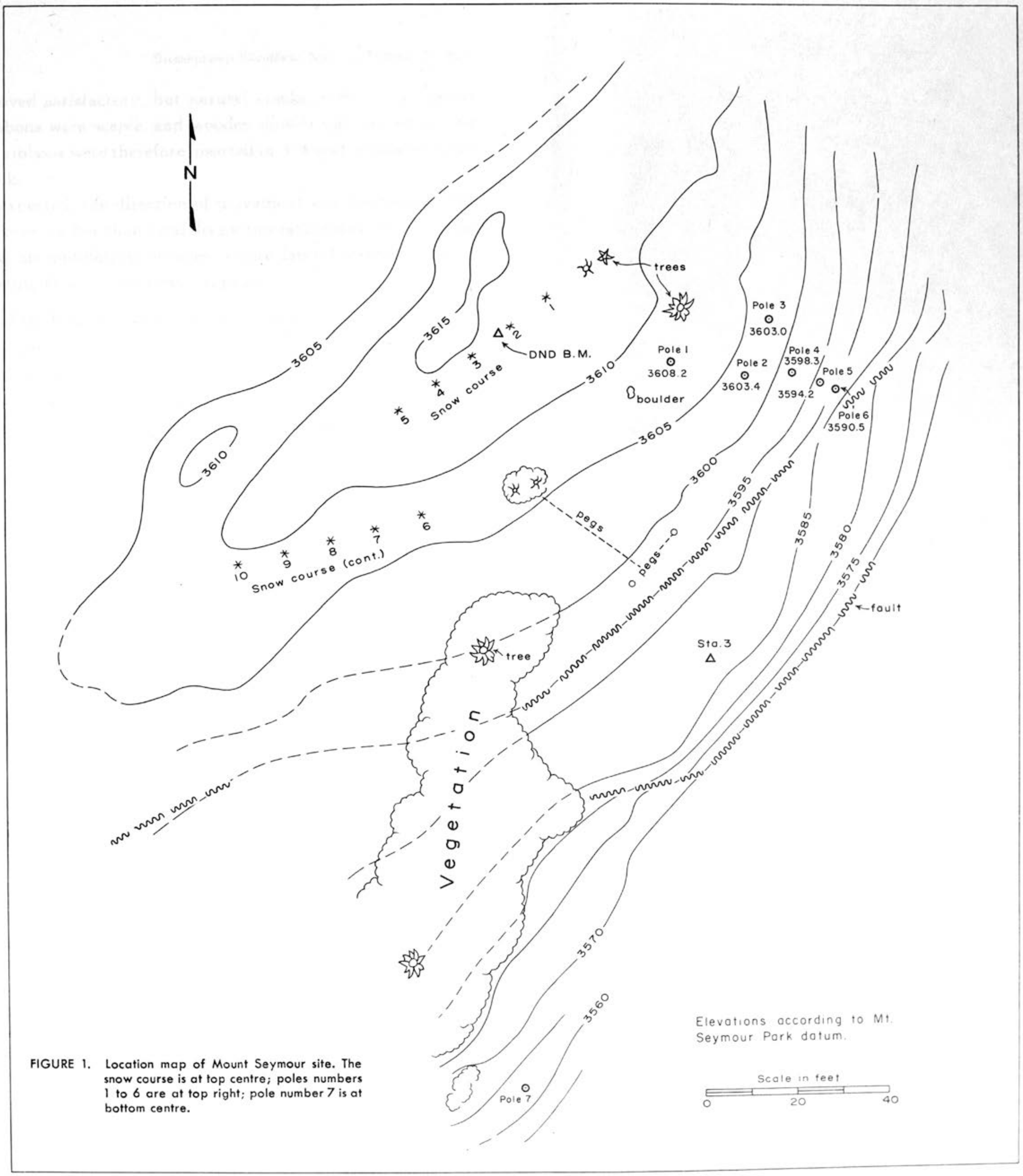

FIGURE 1. Location map of Mount Seymour site. The snow course is at top centre; poles numbers 1 to 6 are at top right; pole number 7 is at bottom centre.

of 75 gm/cm proved satisfactory, but natural cracks in the rock capable of holding the ribbons were scarce, and wooden dowels split to receive the lower ends of the ribbons were therefore inserted in 3/4-inch-diameter holes drilled into bedrock.

As might be expected, the direction of movement was downslope. The general slope, however, rather than local declivities establishes the direction of movement, and on undulating surfaces, where lateral stresses may be significant, interesting flow patterns may appear.

Rate of movement of the lowermost layers of the snowpack

The most satisfactory technique tried to date for measuring the rate of movement of the lowermost layers of the snowpack consists in the use of 3- and 6-inch-diameter wooden spheres tethered loosely by means of single-strand Monel wire a few feet downslope from slender steel posts mounted vertically in holes drilled into bedrock. Although the balls are coated with white or aluminum paint to minimize the melting of adjacent snow, a rind of frozen snow found around some of them when they are dug out in the spring suggests that disturbance of the thermal condition of the adjacent snow has not yet been eliminated. As the posts are only an inch in diameter and are at least several feet upslope from the balls, they are believed to be too small to exert any significant influence on the basal snowcreep at the site of the balls. As creep proceeds, the movement of a ball causes the withdrawal of a graduated tape that is mounted at the top of the pole and so is visible above the snowpack (Figure 2). Displacements of the balls can thus be observed from a distance at convenient time intervals.

A similar technique was adopted by in der Gand (1957) at Davos, Switzerland. The wire, however, was attached upslope to a continuous recorder capable of monitoring displacement as small as 0.5 mm within a 15-minute interval. One such unit has been installed at Mount Seymour for the winter of 1962–63.

Instead of wooden balls, spherical plastic fish-net floats and ellipsoidal wooden net floats were also tried. The plastic net floats were found to be subject to serious denting and crushing against the ground. Ellipsoidal floats proved unsuitable because, when they rotated about the vertical axis during creep, they presented cross sections of varying sizes and shapes to the moving snow, and their downslope rotation during movement was no longer free.

Radioactive rock specimens were also placed over a sheet of photographic paper protected from light and water by black paper and pliofilm

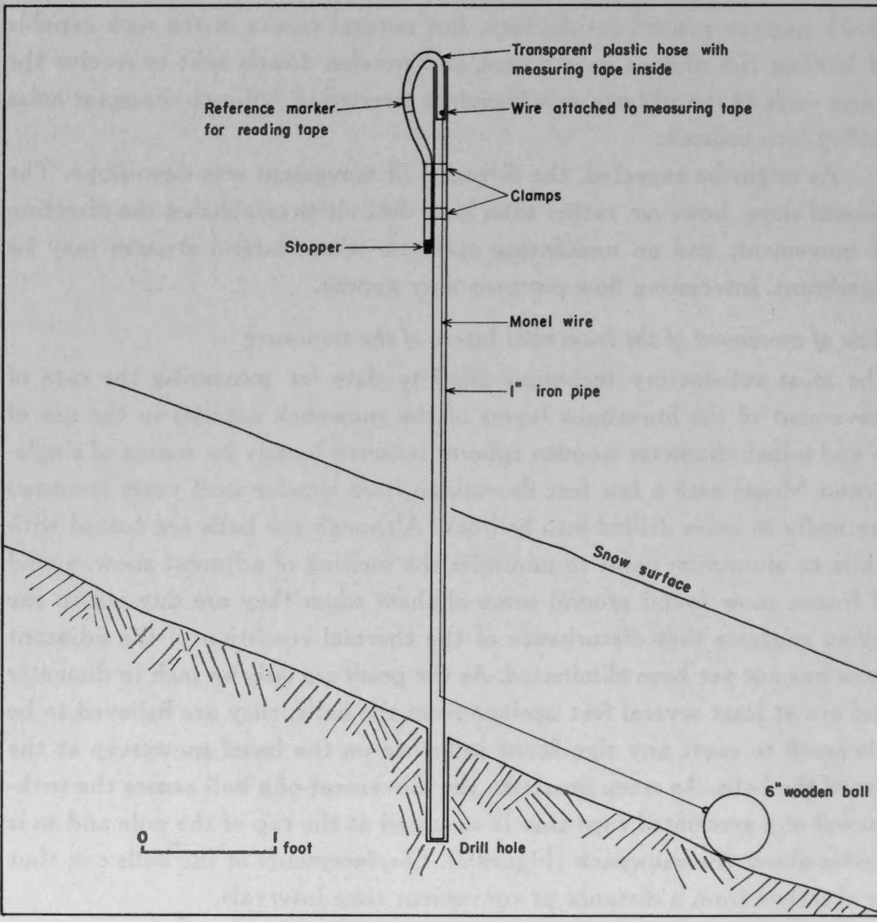

FIGURE 2. Arrangement of a snow pole with an attached 6-inch wooden ball for recording movement near the ground. The pole, marked at 6-inch intervals with colcred tape, serves also to measure snow depths.

and from the scoring action of the rocks by a sheet of thin masonite. The separation of the radioactive specimens from the photographic paper was so great, however, that the only result was a diffuse fog.

Another method required the vertical insertion of polyethylene tubing in the snowpack with the object of measuring deformation by means of an electronic strain-gauge probe (Williams, 1957, 1962), but the tubing proved to be too flexible to resist the stress of the wind against the protruding tube. Moreover, the tube curved and stiffened at freezing temperature.

Total movement of the same basal layer of snowpack during a single winter

Some of the methods previously discussed for measuring the rate and direction of movement can be applied to this problem. For the most consistent observations, the writers are using 6-inch and 3-inch-diameter fir balls placed on the ground and tethered loosely with Monel wire to slender stakes inserted upslope. The stakes consist of wooden dowelling 1 1/8 inches in diameter drilled horizontally through with 1/4-inch-diameter holes plugged on the upslope sides with small corks. A slit in the cork holds the wire, and tension can be adjusted by easing the cork into or out of its seat. The distance from stake to ball, not less than 2 feet, is measured at the beginning of the winter season and again on exposure in the spring to determine aggregate movement. Some of the stakes are long enough to measure snow depth.

The methods requiring the use of movable objects (e.g., stones) placed on the ground and metal ribbons have proven less satisfactory. The use of movable objects calls for precautions against movement prior to snow burial; and metal ribbons are not free to move at the ground surface.

Pressure exerted by the creeping snow against stationary objects

This is being measured hydraulically (Figure 3) by means of transducers consisting of a square plate mounted at the upslope end of a piston, which, in turn, bears against a flexible brass bellows. The bellows, a length of 1/4-inch O.D. copper tubing and a Bourdon gauge form a continuous closed system, which is first evacuated of air and then filled with liquid. Initial experience with 6 feet of tubing between transducer and gauge indicated some temperature sensitivity, which became accentuated as the length of the tubing was increased. A 60:40 water-glycerine mixture, which remains unfrozen down to about +4°F and has a relatively small thermal coefficient of volume expansion, has been selected as the most suitable fluid for the system. Moreover, as the transducer, tubing and gauge are mounted near the ground surface, all parts of the system can be maintained during the winter at or very close to 32°F at the Mount Seymour site. The instruments have been calibrated at this temperature, and the calibration permits conversion of Bourdon-gauge readings to loading on the plates and pistons. Transducers have been mounted to record the component of load applied parallel to the ground surface on plates 3 and 5 inches square. Other-size plates can be installed as required providing, however, that the load totals do not exceed the limits of either the bellows or the Bourdon gauges.

It is recognized that scaling of loads from single or clustered plates to large structures is not possible with the data on hand, but information is being sought on the snow conditions contributing to maximum loading at any one site on a given size of plate.

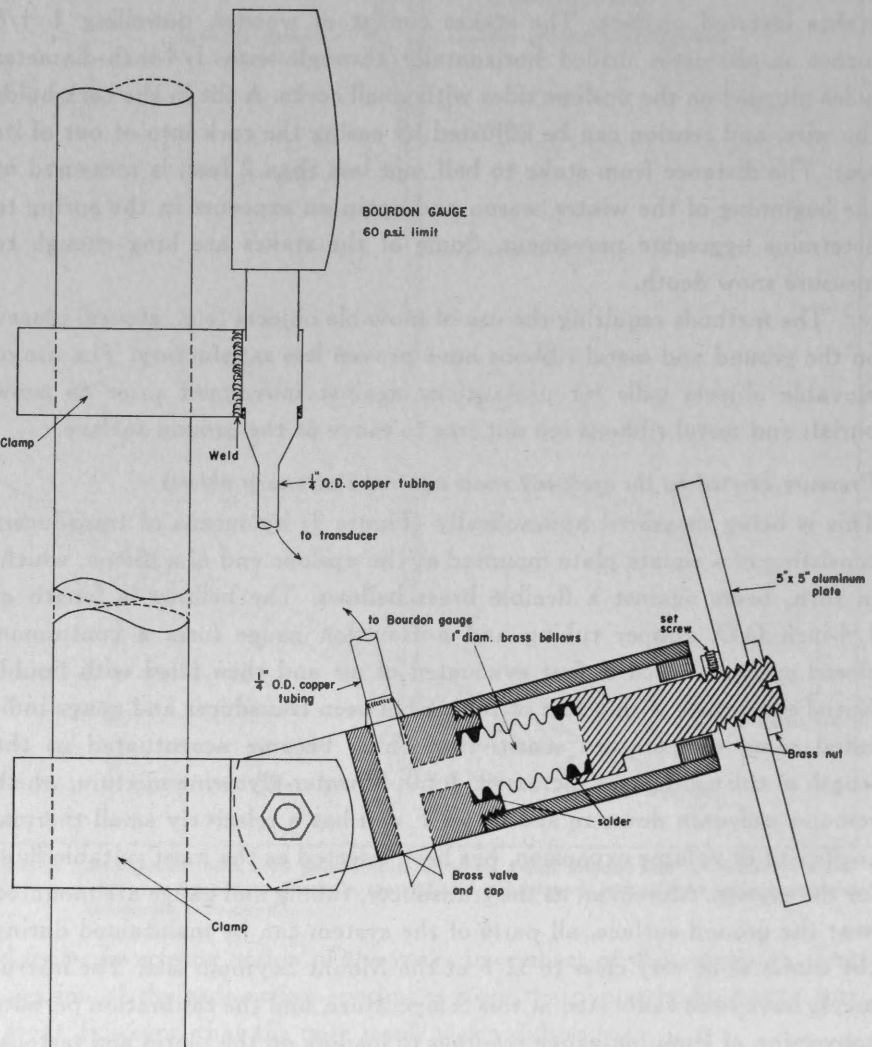

FIGURE 3. Transducer and Bourdon-gauge assembly for recording the component of load applied parallel to the ground surface. The size and shape of the aluminum plate can be varied. The Bourdon gauge is usually mounted on a separate pole in a position where it will be covered with snow and yet where excavation of the snow for reading purposes does not disturb the snowpack at the transducer. Thus the temperatures of both transducer and Bourdon gauge are nearly identical and constant, which at the Mount Seymour site means a temperature close to 32°F for most of the winter.

Miscellaneous snow properties

Mean snow depth and density at the Mount Seymour site have been determined by standard methods of snow-surveying with a Mount Rose sampler. Because of marked drifting of snow and variations in depth, however, seven snow poles were set up on the slope where the creep studies were undertaken. These poles have served also for tethering the wooden balls and for mounting pressure transducers. Snow depths were recorded weekly. From time to time a pit was dug several feet away from the poles and densities at various depths were determined by using a sampling tube of known internal volume and a spring scale.

Temperatures for the winters of 1960–62 were measured at depths of 20.75 and 39.25 inches (0.5 and 1.0 meters) below ground surface in a hole drilled into bedrock and later filled with zonolite. A telethermometer that could be read to 0.1°C and thermistor probes were used for ground temperatures. The thermistors were calibrated on the site by using snow-fresh water mixtures. Snow temperatures were also obtained in pits at various depths below the snow surface.

A few attempts have been made to determine the free-water content of the snow by means of simple calorimetric methods (see Yosida, 1959) requiring the use of thermos flasks.

Ramm penetrometer tests were made on a few occasions.

DISCUSSION

Observational data obtained by consistent methods are available for the most part for only one or two winter seasons. As snow conditions vary from year to year and from place to place as well as from month to month, it would be premature to draw firm conclusions. Some consistent results have nevertheless been obtained, and they show that displacements of 2 to 3.5 feet do occur in a single winter within the bottom 3 to 6 inches of the snowpack on the steeper slopes. Movement persists throughout much of the season and reaches a maximum rate of 5 inches a week, especially on the steeper slopes, beneath deep snow that is being subjected to rapid recrystallization during thawing periods. Pressure-plate observations indicate that downslope components of load on 25 square inches (roughly comparable to the cross-sectional area of the 6-inch balls) can reach 25 pounds, which is enough to push loose stones down inclines. Presumably for this reason the bedrock slopes at the Mount Seymour test site are free of soil and boulders. The loads and amount of movement are also adequate to account for the deformation of trees on the nearby timbered slope.

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Individual studies are detailed year by year and discussed in what follows.

Winter, 1958–59

On November 29, 1958, five round plastic fish floats, each 6 inches in diameter and weighing 310 grams, were placed on bare rock surfaces of varying slopes. A Monel wire, attached to a ring in each ball, led upslope through a lower and an upper pulley fixed firmly to a tree, and had a counterweight suspended from its free end. The downslope movement of the ball beneath the snowpack was then read by observing the displacement of the counterweight against a scale. As there was a snow cover of 1 to 2 feet when the equipment was installed, trenches were dug to bare rock so that each plastic ball and wire leading from the ball to the tree rested on the ground. After installation, the trenches were filled with snow. Thus the initial movement of the counterweight resulted from the taking up of slack in the wire. The counterweights, which weighed less than 100 grams, were too light to exert any uphill pull on the balls, especially since the connecting wires were bent around two pulleys and were covered by snow for at least 15 feet. The displacement of the counterweights might therefore equal, but could not exceed, the basal movement of the snowpack. Ball number 1 was on a 19-degree slope; number 2 was mounted below number 1 on a 35-degree slope; number 3 was on a 13-degree slope; number 4 on a 35-degree slope; and number 5 below number 4 on a 50-degree slope. As the balls had to move downslope slightly to take up slack in the wires, the readings during December were considered unreliable and the movements shown in Figure 4, section a, are therefore calculated from the beginning of January. On February 28, it was found that a vandal had severed the wires connecting ball numbers 1, 2 and 3 to the trees. On March 7, the wire from ball number 2, was repaired, but those from numbers 1 and 3 could not be reattached.

Ball number 5 was exposed by April 25; numbers 2 and 3 were bare by May 10, but both were found partially crushed by snow pressure, and the added friction may have restricted movement; number 5, also bare on May 10, was not crushed. Movement of the balls was obviously fastest on the steepest slopes. The ball on the 50-degree slope moved nearly half an inch a day in early March.

To determine the relative movement within the snowpack, vertical holes made with a snow-sampling tube were filled with sawdust, and numbered ping-pong balls were inserted at measured intervals. The filled holes were later excavated, and the movement was determined. Hole (a), made

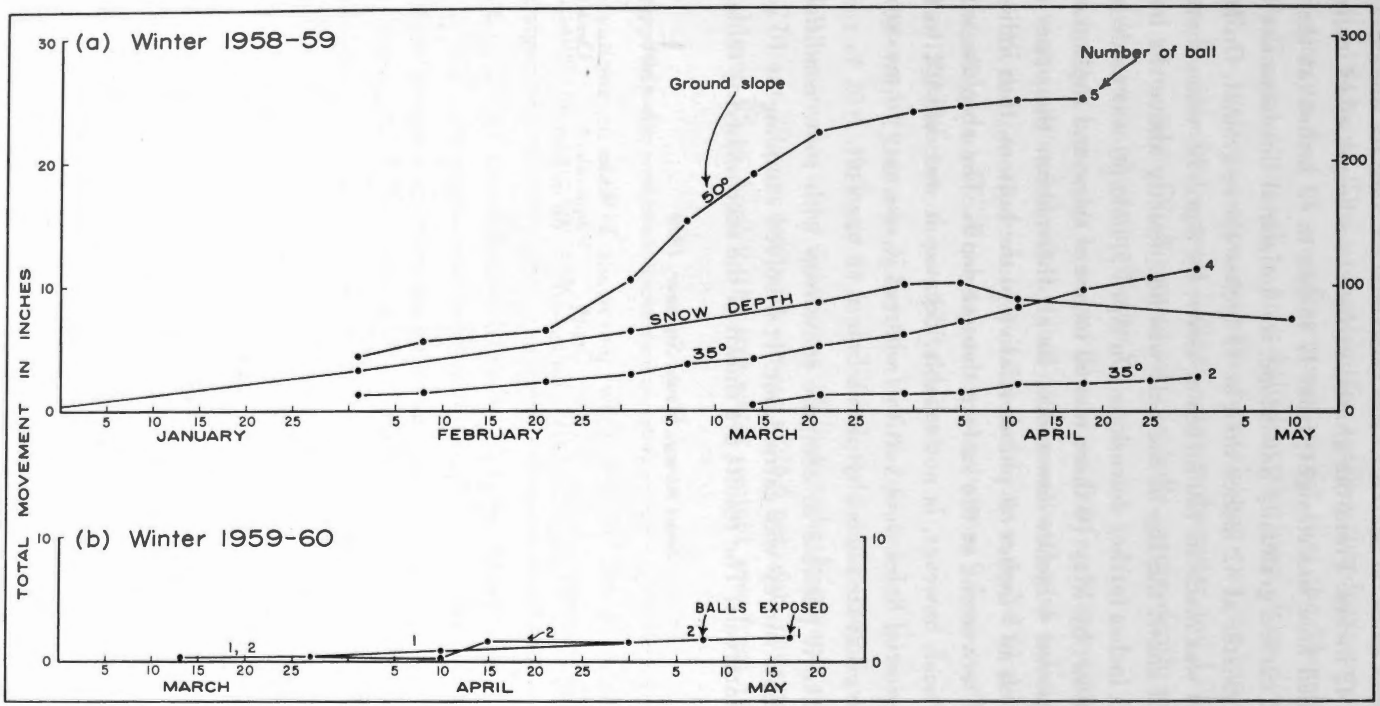

FIGURE 4. The top graph (section a) shows the total winter movement of balls placed on varying slopes for the winter 1958-59. The snow depth (scale in inches on the right) is for the snow course shown on Figure 1 (see table page 72). The bottom graph (Figure 4b) shows the total movement for the winter 1959-60.

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in 92 inches of snow on March 15 was excavated on May 18, when the snow depth was 42 inches. From the ground surface to a height of 17 inches the sawdust-filled hole was straight; from 17 inches to 42 inches (at the snow surface), it curved gradually downslope, its horizontal displacement being 1.5 inches greater at 42 inches than at 17 inches above ground. On March 30, hole (b) was made in 120 inches of snow; by April 30, when there was 53 inches of snow, the top of the hole was not directly above the bottom but was 5.5 inches farther downslope. On April 5, hole (c) was made in 103 inches of snow; by May 10 there was 60 inches of snow and the top of the hole had moved 4 inches downslope. In all there holes, the upper parts were as much as 5 inches off plumb relative to the bottom, thus indicating more rapid movement at the surface than at depth. The absolute amount off the vertical, however, is not reliable, because it was difficult to make certain the initial holes were vertical, whereas it was easy to measure the slope of the excavated holes by plumb bob in an open pit.

To make it possible to compare snowcreep with snow conditions, a standard snow survey was carried out. It involved sampling at 10 points at 10-foot intervals. The results are shown in the accompanying table.

Snow survey, Mount Seymour, 1959

Date	Day (from Dec. 31)	Depth (in inches)	Water equivalent (in inches)	Density
Jan. 1	1	6	—	—
" 31	31	35	—	—
Feb. 28	59	68	27.4	.41
Mar. 21	80	89	32.9	.37
" 30	89	101	38.3	.38
Apr. 5	95	101	—	—
" 11	101	89	40.5	.46
" 30	120	75	36.5	.46

Winter, 1959–60

On December 13, 1959, three balls were installed in a manner similar to that of the previous winter (Figure 4, section b). Ball number 1 was of plastic (as used the year before), whereas numbers 2 and 3 were wooden ovoids 6 inches long, 3.5 inches in diameter and 255 grams in weight. As the movement of number 3 was exactly the same as that of number 2, only the movements of 1 and 2 are shown in Figure 4, section b.

Winter, 1960–61

In the winter of 1960–61, six steel poles were inserted upright in holes drilled in bedrock. The mechanism for reading the displacement of balls was similar to that of preceding years, except that the Monel wire from each ball passed through a hole drilled at the base of its pole, then up through the pole to a tape readable above the snow at the top of the pole (Figure 2). Spherical wooden balls 6 inches in diameter and 1,080 grams in weight were used. Displacement of the balls, snow depth and ground temperatures are shown in Figure 5.

Attempts were also made to determine the free-water content of the snow near pole number 2, by using thermos bottles as calorimeters. On March 25, the free-water content of 2 feet of snow, sampled from the bottom, middle and upper part of the snow core was: bottom 9.5 per cent free water; middle, 12.0 per cent; upper, 12.0 per cent.

On April 2, snow sampled for the full 2-foot depth gave a free-water content of 20.8, 19.8 and 21.5 per cent with a mean of 20.7 per cent. On April 9, when the snow depth was 18 inches the free-water content was 27.1, 27.1 and 25.7 per cent with a mean of 26.6 per cent. Thus in the period from March 25 to April 9, the free-water content rose from 11 to 27 per cent.

Winter, 1961–62

Observations on rate of snowcreep were repeated at the same site with essentially the same equipment as in the previous winter (Figure 6). The most significant changes were the substitution of one 3-inch wooden ball for a 6-inch ball, the addition of two 3-inch balls operating in tandem with 6-inch balls previously installed and the design and installation of four hydraulic gauges for measuring pressure exerted by creeping snow against stationary surfaces. Records of snow depths, temperatures, displacements of the 3-inch and 6-inch balls, and snow pressures were made about once a week and were compared with weather and snow conditions.

The rates of snowcreep in 1961–62 corresponded with remarkable closeness to those of 1960–61 at the same sites; but, during two cold periods, in mid-January and late in February, when the snowpack froze to the underlying rock, snowcreep slackened noticeably (Figure 6).

The increase in the rate of movement upward through the snowpack is clearly indicated. Thus the 3-inch ball at pole number 2 moved only 56 per cent of the distance that the 6-inch ball moved at the same site; at

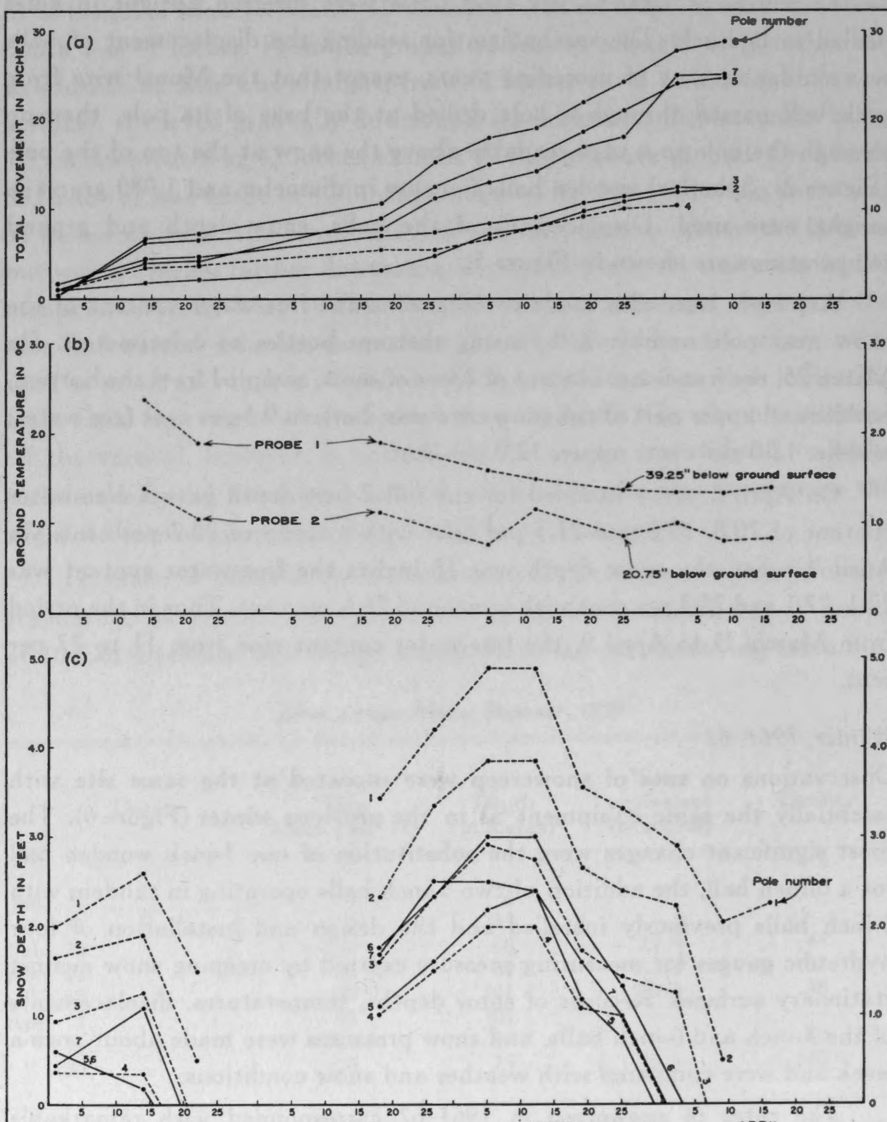

FIGURE 5. Data for the winter 1960-61. Section a shows displacements of the balls attached to the numbered snow poles. Section b shows ground temperature measured at the site of pole number 1. Temperatures were based on thermistor readings. When the stability of the thermistors was checked in late 1962, some drift was observed; so the readings may be slightly inaccurate. Snow depths are shown in section c. The gap at the end of January and in early February is due to melting of the early January snow cover and exposure of the slope.

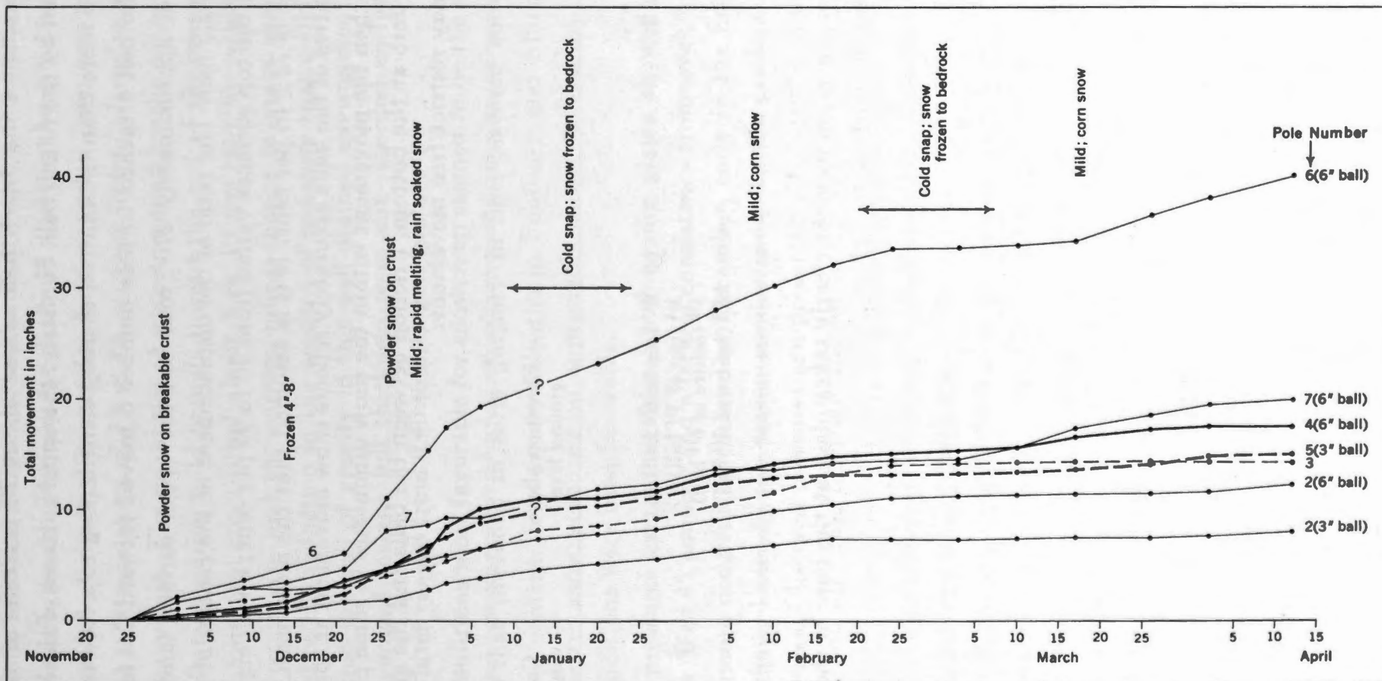

FIGURE 6. Winter conditions of 1961-62 are shown. The pole numbers correspond to those of Figure 5.

pole number 4 the 3-inch ball moved about 70 per cent of the distance travelled by the 6-inch ball. Similarly, the upper surfaces of the balls moved forward more than the centres, thereby contributing to a forward rotation; thus the ball attached to pole number 6 moved forward 2.0 feet but, because of approximately 270° rotation, the upper surface (and the tape) moved 3.5 feet. The ratio of the displacement of the centres of the balls to that of the top surfaces varied from 50 to 95 per cent; for all eight balls the average is 72 ± 18 per cent. If it is assumed that the movement of the tops and centres of the balls accurately reflects snow movement at corresponding levels, then the movement within the snow diminishes in some places virtually to zero at the bottom. Friction between the balls and the ground however, may restrict free movement.

	Elevation above ground level	Cumulative displacement
		(feet)
Pole No. 2	6" (top of 6" ball)	1.15
	3" (top of 3" ball)	0.65
	3" (centre of 6" ball)	0.58
	1½" (centre of 3" ball)	0.32

At other places, movement clearly takes place at the base of the snowpack or within the bottom 1½ inches.

	Elevation above ground level	Cumulative displacement
		(feet)
Pole No. 4	6" (top of 6" ball)	1.47
	3" (top of 3" ball)	1.08
	3" (centre of 6" ball)	1.38
	1½" (centre of 3" ball)	0.92

Downslope increase both in rates and in total movement (most notably within 3 inches of the ground surface) without any very marked increase in slope were observed both in 1960–61 and 1961–62.

The snow varied from the fresh powdered kind found early in the season to fine, damp snow and frozen snow; with the alternation of cold and mild moist weather, frozen and wet snow alternated, becoming coarser as the season progressed. The content of liquid water in the snow, as determined by crude calorimetry in thermos bottles, varied from zero in cold, frozen snow to a maximum of 15 to 20 per cent in fine, damp snow subjected to heavy rain. The quantities of water retained by the coarse 'corn' snow that formed during mild periods toward the end of the season were roughly uniform and constituted about 5 to 10 per cent by weight. The increase in grain size and the corresponding change in grain shape presumably led to the reduction in the amount of moisture that could be retained against the pull of gravity in this well-drained environment. Snow densities averaged for the full thickness were not recorded early in the season but later ranged from 0.40 to 0.45 gms/cm^3.

The conditions most favorable for snowcreep seemed to be the state of mild thaw that prevailed in early January in finer-textured snow with higher water content. Similar snow depths in February and March with wet but coarser snow produced an appreciably slower movement. Below-freezing conditions were least favorable.

Snow pressures exerted against 5-inch-square plates showed a very great range (0 to 45 pounds) and a lack of consistency from week to week. Their maximum occurred at the end of December, early in the first main period of thaw. Later in the season similar snow depths produced much lower pressures. Observed pressures can presumably be correlated not only with depth but with rate of creep; and on two occasions pressures on the higher plate on pole number 4 matched or exceeded the lower plate, then buried under four times the depth of snow. The results, however, are too erratic to prove any firm relationship.

Instrumental problems in measuring the rate of creep were minor. Of greatest concern was the coating of hard frozen snow found around three of the balls still buried when the installation was dismantled. This coating, if it persists through the season and adheres to the rocky substratus, could all result in marked discrepancy between the movement of the balls and the movement of the surrounding snow. The cause of this coating is not at all clear.

Instrumental problems in measuring snow pressures include the disturbing effect of variable air temperature on exposed parts of the tubing and on the Bourdon gauge, and the melting of snow in front of the plates because of the conduction of heat down poles and tubes. All parts of the equipment should remain buried beneath the snow, the gauges being enclosed in a box to permit reading.

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A PRELIMINARY MAP OF CONTINENTALITY FOR CANADA

D. K. MacKay and Frank A. Cook

ABSTRACT: Formulae for the computation of continentality indices are discussed, and the formula k = 1.6A/sin ϕ–14 (Johansson, 1931) is chosen as the basis for an index of continentality for Canada. A map has been constructed to show the areal variation of this phenomenon and to indicate the influence of various factors on it. One of the most important climatic factors affecting continentality is the westerly circulatory system. The values for stations on Canada's west coast, for example, are considerably lower than those for stations on Canada's east coast, and the east and west coasts of inland waterbodies show similar characteristics.

RÉSUMÉ: Dans leur étude, les auteurs nous présentent certaines formules qui peuvent servir au calcul de l'indice de continentalité climatique. Ils ont choisi la formule k = 1.6A/sin ϕ14 (Johansson, 1931) pour établir un indice de continentalité pour tout le pays et dresser une carte qui montre les variations d'étendue de ce phénomène ainsi que l'influence des divers facteurs climatiques sur l'indice. L'un des facteurs les plus importants est sans doute le système circulatoire en direction ouest. Ainsi, les indices calculés pour les stations météorologiques de la côte Ouest du pays sont de loin inférieurs aux indices obtenus des stations de la côte Est. On a relevé un phénomène analogue sur les rives Est et Ouest de grandes étendues d'eau réparties à travers le pays.

INTRODUCTION

Continentality is a climatic parameter on which little research has been done in Canada, although it is often discussed topically by geographers and others. A continental climate may be defined as one in which the summer is hot, the winter is cold, and both the diurnal and the annual ranges of temperature are great, as in the interior of a continent. It is thus obvious that temperature is a prime criterion of the degree of continentality, and that a significant measure of continentality is the mean annual temperature range. As the amplitude of the annual solar-radiation heat-supply curve is affected by the geographic latitude, so, in consequence, is the amplitude of the annual air-temperature curve. One method of partially eliminating the effect of latitudinal differences is to divide the annual air-temperature range for a specific site by the sine of its latitude. This method is applicable to mid- and high-latitude stations but does not give realistic results in low latitudes.

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This paper discusses some of the formulae used for computing continentality. Data from 205 stations with a wide geographical distribution are analyzed, and a map of the relative continentality of Canada based on these data is presented.

CONTINENTALITY

Usual formulae

A number of formulae have been advanced, giving indices of continentality in percent. Most approaches have involved the use of a formula of the general form (Zenker as quoted in Conrad, 1946)

$$k = mA/\sin \phi + n \quad (1)$$

where k = the continentality coefficient in per cent, A = the mean annual range of temperature, ϕ = the geographical latitude, and m and n are constants.

Formulae of the Zenker type seem to provide a satisfactory index in mid-latitudes, although they become meaningless as the sine of the latitude approaches zero in low latitudes and reaches it at the equator. One suggestion for overcoming this problem was advanced by Conrad (1946), who suggested the formula

$$k = mA/\sin (\phi + \phi_0) + n \quad (2)$$

The additional angle ϕ_0 (10°) eliminates the absurd values obtained for the continentality coefficient, k, in the inner tropic belt. One disadvantage, however, is that the formula loses its validity where latitudes exceed 80 degrees.

Other approaches to indices of continentality have been made by Spitaler (as quoted in Brunt, 1924) and Dinies (1932). Brunt maintains that Spitaler's index depends on the percentage of land area within one-degree latitudinal zones and on the difference between the mean radiational intensities of each zone's latitudinal boundaries. Dinies (1932) used the quotient of all continental air masses as contrasted with those maritime in character (C/M) to derive an index.

Landsberg (1958) indicates that the formula best adapted for determining an index of continentality based on the annual amplitude of temperature is the one devised by Johansson (1931). This formula

$$k = 1.6A/\sin \phi - 14 \quad (3)$$

is essentially Zenker's with constants derived from empirical limits based on Torshavn, The Faeroes (62° 02' N, 6° 47' W) as the maritime extreme and Verkhoyansk, East Siberia (67° 35' N, 133° 25' E), as the continental extreme. The index based on these limits provides an approximate range of from 0 to 100 per cent in mid and high latitudes.

As indicated in the introduction, the annual range is but one aspect of temperature that is influenced by continentality. Others, for example are the diurnal range and the relative symmetry of the annual temperature curve. In addition, meteorological elements such as vapor pressure, cloud cover, precipitation, wind speed, etc. show the effects of varying land/ water ratios over a given area. Thus it appears that a number of approaches to the problem of continentality are possible and that a number of formulae can provide adequate descriptions of the regional differences in continentality. In this preliminary investigation, Johansson's formula, which is based on the mean annual temperature range, is used to calculate an index of continentality for Canada, as it is probably the most satisfactory between latitudes 42 and 83 degrees.

Data

Isopleths are indicated by a broken line because there are inequalities in data coverage. On the Arctic Islands, specific index values are recorded as there is an insufficient number for isopleth interpretation. The 15-per-cent and 25-per-cent isopleths of continentality are omitted on the west coast because of the steep index gradient. The 45-per-cent and 55-per-cent isopleths are omitted in western Canada to avoid cluttering the map with information that adds little to its value.

Mean monthly temperatures based on observations made during the period 1921 to 1950 (Canada, Department of Transport, Meteorological Branch, 1959), are used to derive the mean annual ranges for the stations selected. The records for a number of these stations do not cover the full 30-year period. Many have been adjusted (i.e. by the Meteorological Branch) by comparison with those of other stations, and a few, particularly in the Arctic regions, are based on short periods of record.

DISCUSSION

Canada is greatly influenced by continentality as would be expected because of its extensive land mass and its location on the globe. The third largest country in the world, stretching through nearly 90 degrees of longitude, it extends from within a few hundred miles of the North Pole to latitude 42 degrees north. Situated in the northern half of the hemisphere, Canada lies in the latitudinal zone dominated by the prevailing westerlies, and

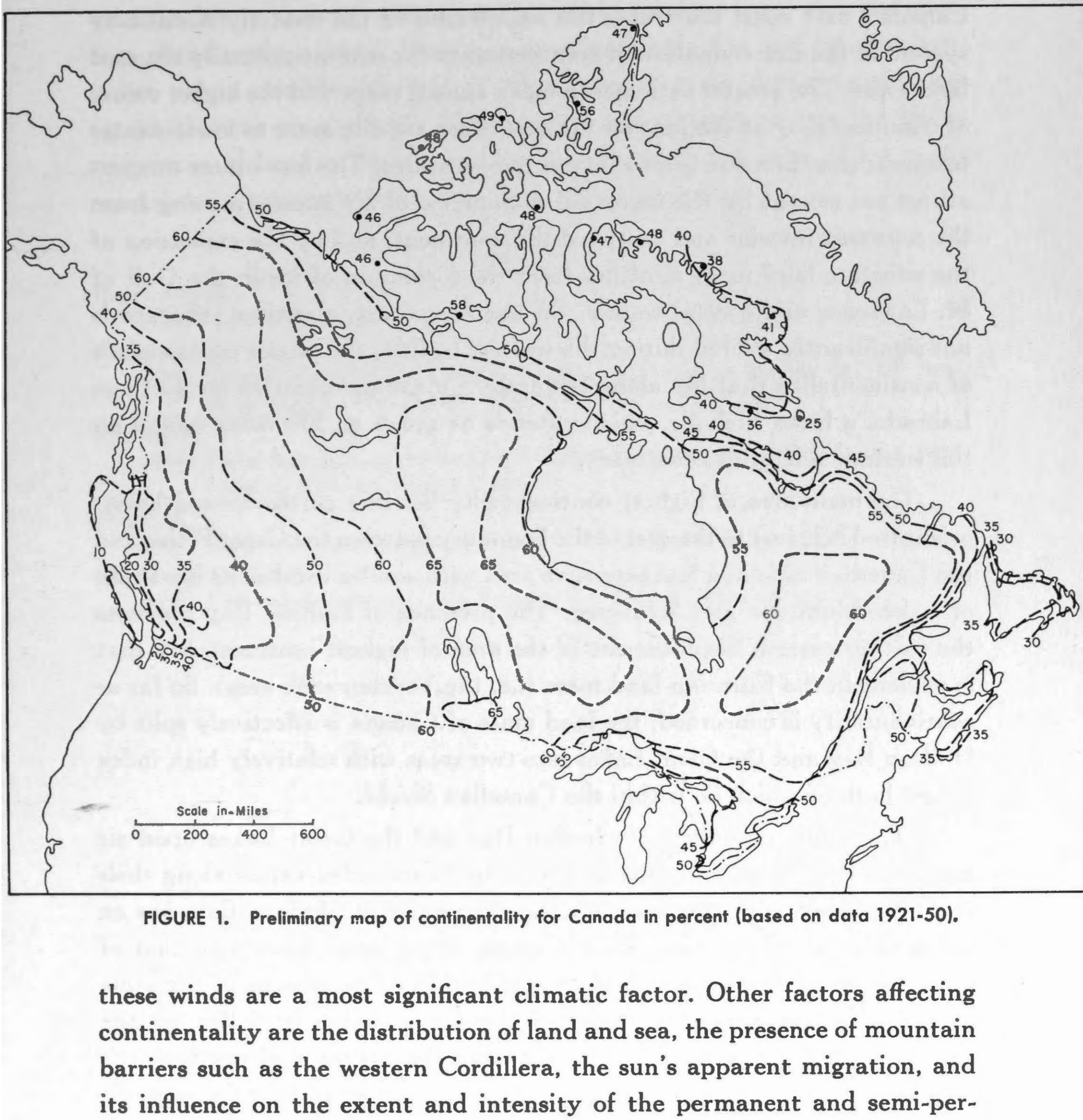

FIGURE 1. Preliminary map of continentality for Canada in percent (based on data 1921-50).

these winds are a most significant climatic factor. Other factors affecting continentality are the distribution of land and sea, the presence of mountain barriers such as the western Cordillera, the sun's apparent migration, and its influence on the extent and intensity of the permanent and semi-permanent high- and low-pressure areas. Thus the map of continentality displays the integrated effects of many physical factors operating on the land mass.

The lowest values of continentality are found along the western periphery of Vancouver Island and the Queen Charlotte Islands, and on the mainland coast in the vicinity of Prince Rupert. On the leeward side of these islands and on the mainland coastal section sheltered by them, the values increase to about 20 per cent. Their comparison with those of

Canada's east coast illustrates the importance of the westerly circulatory system in the determination of continentality for mid-latitudinally situated land areas. The greater extremes in mean annual range and the higher values of continentality at stations on the east coast are due more to lower winter temperatures than to higher summer temperatures. The low winter temperatures are caused by the increased dominance of air masses moving from the northern interior and centre of the continent, and by the expansion of the effective land mass resulting from the formation of ice in the Gulf of St. Lawrence and coastal waters. On the west coast, maritime influence is not significantly altered during the winter. In fact, the 40 per cent isopleth of continentality that lies along the eastern mainland coast as far north as Labrador's Lake Melville region extends as much as 500 miles inland on the western side of the continent.

The main area of highest continentality lies in a northwest-southeast-orientated belt just to the east of the boundary between the Great Plains and the Canadian Shield; a less extensive area with similar conditions lies south of Lakes Manitoba and Winnipeg. The presence of Hudson Bay prevents the further eastern displacement of the area of highest continentality that is evident in the Eurasian land mass (i.e. the Verkhoyansk area). So far as continentality is concerned, the land mass of Canada is effectively split by Hudson Bay and the Great Lakes into two areas with relatively high index values both of which lie within the Canadian Shield.

The modifying effects of Hudson Bay and the Great Lakes upon air masses that pass over them is indicated by lower index values along their eastern shores. Port Harrison, on the east shore of Hudson Bay, has an index value of 51 per cent. This is about 10 per cent lower than that of Churchill which is on the west shore and within a few minutes of the same latitude. The modifying influence of the Great Lakes is shown by the increase in index values with distance from the eastern and northeastern shoreline. These facts, like others already presented, show how the westerly circulation affects continentality.

On the northern mainland west of Hudson Bay and on the Arctic Islands, the values of continentality are relatively high. The gradient north of Fort Norman and Baker Lake appears fairly shallow, the index values being about 50 per cent at coastal stations. In this area, however, data are very scarce. Along the western periphery of the Arctic Islands, the values are similar. On the east coast of Baffin Island, continentality drops to 40 per cent; in Hudson Strait to 30 per cent or less. These differences may be attributable to variations in the extent of the local ice cover and the duration of the ice-free season. Two stations, Cambridge Bay and Eureka, have index values considerably higher than those of other Arctic Island sites for which data are available. These values are probably due to the higher proportion of land in the surrounding areas and the presence of ice in the constricted water areas for most, if not all, of the year.

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THE CROSS-VALLEY MORAINES OF NORTH-CENTRAL BAFFIN ISLAND: A QUANTITATIVE ANALYSIS

J. T. Andrews

ABSTRACT: Statistical evaluation of data collected during 1961 allows five working hypotheses on the genesis of the cross-valley moraines to be re-examined. The paper presents three complementary studies on the following: (1) the sediments of cross-valley moraines and central kames; (2) the orientation and dip of included particles within the cross-valley moraines; and (3) the spacing of the moraines in relation to distance from the Isortoq watershed and to the effective stress operating at the base of the glacier when the moraines were being formed. For each section the sampling methods and statistical treatments are outlined. In the first section this involves conversion of grain sizes in millimetres to a logarithmetic unit, phi, which enables the phi mean, standard deviation and skewness to be determined by graphical procedures. The t test enables comparisons to be made on tills from different sections of the moraines. The till-fabric diagrams are subject to the Chi-square and t tests to determine the degree of isotropicity of both orientation and dip of the 'a' axes and to evaluate the relation between the mean fabric orientation and the ice movement, the dip of the fabric and the slope angle. Finally, the spacing of the moraines is analyzed by regression analysis, and correlation coefficients for the number of moraines per unit distance to other factors are calculated.

The cross-valley moraines are formed of a coarse, unsorted, sandy till. The change that certain parameters, notably skewness of grain size frequency distribution, roundness and sphericity show with elevation probably reflects the pre-last glacial distribution of river gravels and weathered materials. Two sections in which sand and gravel are separated by till deposits indicate at least a major fluctuation of the ice cap. The central kames are formed of bedded and sorted sand and gravel and in one locality overlie till of a cross-valley moraine and are thus younger.

Till fabrics were taken from proximal, distal and lateral slopes. Fabrics from proximal slopes show strong orientation at right angles to ridge crests and a predominant upglacier dip component. Distal fabrics, on the contrary, have no preferred dip direction, but the mean orientation is still at right angles to the crest. The fabrics from lateral ridges, on the other hand, have a mean orientation that is also at right angles to the crest and therefore bears no relation to the direction of ice movement.

An analysis of the spacing of the cross-valley moraines indicates strong positive correlations between distance from the watershed and effective stress at the base of a glacier ending in a glacial lake; correlation coefficients are as high as $r = 0.90$.

On the basis of these results the various possible origins of the cross-valley moraines are examined. A basic permise for each thesis is the association of former glacial-lake basins with the cross-valley moraines. It is concluded that three of the five hypotheses are not applicable, whereas the fourth, that they are formed by shear moraines in a shallow-water locality, cannot apply to the Rimrock and Isortoq valleys, where proglacial lakes attained depths of 400 to 700 feet. It is further concluded that the moraines are formed by the flow of saturated till into a system of basal crevasses when

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a critical hydraulic condition is reached. This conclusion is supported by the till fabrics, the relation of the effective stress at the glacier base to the spacing of the moraines and the location and structure of the central kames. The similarity between the De Geer moraines, certain washboard moraines and the cross-valley moraines is pointed out.

RÉSUMÉ: Afin de déterminer la genèse des moraines transversales de vallée, on a examiné à nouveau cinq hypothèses au moyen de l'étude statistique des données recueillies au cours de l'été de 1961. Trois éléments offrent une étude complémentaire. Ce sont: 1) la nature des sédiments des crêtes morainiques et des kames du centre des vallées; 2) l'orientation et l'inclinaison des cailloux à l'intérieur des moraines; 3) le rapport entre l'espacement de ces formes suivant la distance à partir du bassin hydrographique de la rivière Isortoq et la force de contrainte active à la base du glacier lors de la formation des moraines.

On souligne dans le cas de chaque élément les méthodes d'échantillonnage et les opérations statistiques utilisées. L'analyse statistique permet de comparer la granulométrie des différentes moraines; l'orientation des particules par rapport à la direction d'écoulement du glacier et, enfin, l'inclinaison des cailloux et des pentes. La répartition des moraines par rapport à d'autres éléments morphologiques fait aussi l'objet d'une étude statistique.

Les moraines sont formées d'un till sableux et grossier non remanié. Cependant, la nature du matériel ainsi que la morphoscopie des grains varient suivant l'élévation. On en attribue la cause à la distribution des alluvions et des produits d'altération antérieurs à la dernière glaciation. La présence de till entre les couches de sables et de graviers témoigne de fluctuations importantes du glacier. Quant aux kames, ils sont formés de sables et de graviers interstratifiés et reposent en un endroit sur les moraines transversales de vallée.

On a procédé, ensuite, à l'étude de l'orientation des cailloux en amont, en aval et sur les côtés des crêtes morainiques. En amont, l'orientation dominante est perpendiculaire à la crête et l'inclinaison est vers l'amont. Sur la pente en aval, l'orientation est la même et on note aucune inclinaison dominante. Les cailloux des crêtes latérales sont également perpendiculaires à la ligne de crête et leur grand axe n'est pas parallèle à la direction du mouvement glaciaire.

On a déterminé dans le cas du troisième élément un coefficient de corrélation de l'ordre de $r = 0.90$. Il existe donc une très forte relation entre la distance qui sépare les crêtes de la ligne de partage et la force de contrainte active à la base d'un glacier qui se jette dans un lac glaciaire.

En se fondant sur ces résultats, l'auteur a étudié les différentes origines proposées jusqu'ici et a réussi à confirmer l'association génétique des crêtes morainiques aux lacs pro-glaciaires, notion commune à tous les auteurs. Cependant, trois des cinq hypothèses classiques ne peuvent s'appliquer. Dans le cas des vallées Rimrock et Isortoq, par exemple, la quatrième hypothèse ne peut être soutenue puisque les lacs pro-glaciaires qui s'y trouvent atteignent des profondeurs de 400 à 700 pieds. De telles conditions ne sauraient être propices à la formation des moraines de cisaillement en eau peu profonde. Aussi nous croyons que ces crêtes morainiques se sont formées dans un réseau de crevasses basales par l'écoulement d'un till saturé d'eau lors de conditions hydrauliques extrêmes. Les trois éléments étudiés viennent appuyer cette conclusion. Enfin, l'auteur souligne la similarité qui existe entre les moraines de «De Greer», les moraines de récession et les moraines transversales.

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INTRODUCTION

In an earlier paper (Andrews, 1963), the cross-valley moraines of north-central Baffin Island were described in detail; air-photograph interpretation was used to extend the observations of the ground survey, and it was found that the cross-valley moraines occupy large areas, though nearly all are restricted to valley positions. In every instance, moreover, they were located in valleys that during deglacierization had contained proglacial lakes similar to those about the present Barnes Ice Cap.

After the description of these glacial forms, a series of five working hypotheses of origin was advanced. It was proposed that the cross-valley moraines could have been formed by one or a combination of these processes. The five hypotheses provided for genesis of the moraines as subglacially engorged eskers, frontal deep-water deposits, shear moraines deposited in shallow water, push moraines produced underwater, or features formed by the squeezing of till into a basal crevasse system behind a calving ice front.

It is the purpose of this paper to present and review the quantitative data collected during 1961 and to re-examine the five hypotheses. The observations and conclusions reached here are applicable mainly to the Rimrock Valley and a small sector of the Isortoq Valley; further study should show to what extent till characteristics and fabric patterns are uniform throughout the entire range of the Baffin Island cross-valley moraines. The studies of these moraines, which are continuing, were part of the 1962 field survey made immediately northwest of the Barnes Ice Cap.

LOCATION OF THE FIELD AREAS

In the 1961 field season, glacial forms in the Rimrock and middle Isortoq valleys were examined in detail. These areas lie about 25 miles north of the present margin of the Barnes Ice Cap (Figure 1). The detailed maps of the areas in the previous paper (Andrews, 1963) should be consulted.

SAMPLING AND STATISTICAL MEASURES FOR SEDIMENTS

Samples were collected during the field season and transported to the laboratory in Ottawa. Sedimental-unit sampling (Steinmetz, 1962) was employed on all stratified deposits; tills were sampled by the channel technique. In this way the deposits were examined in a manner consistent with

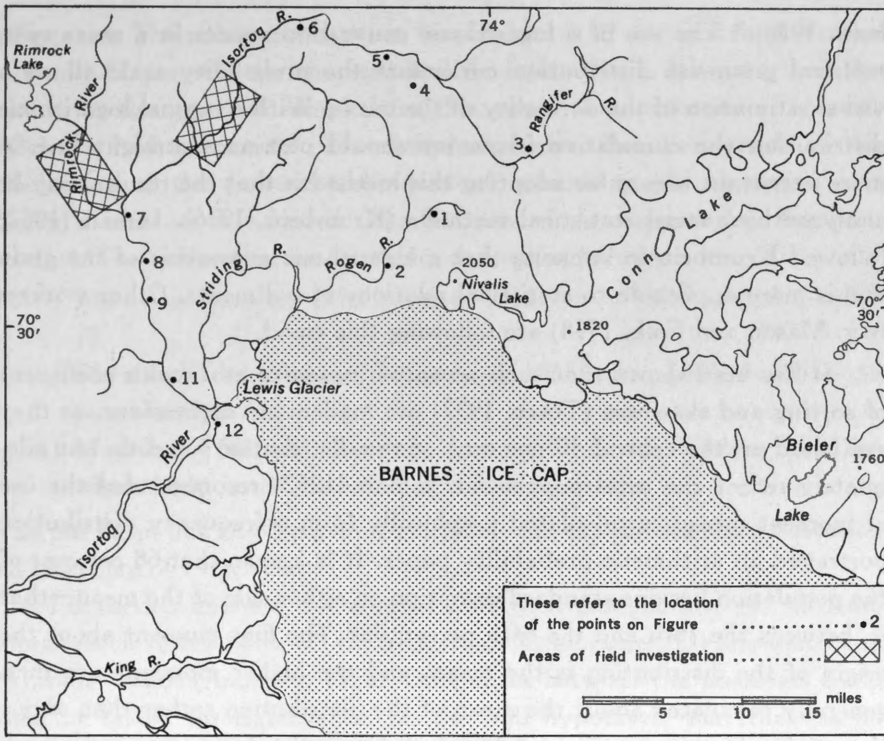

FIGURE 1. Location map showing field areas relative to the Barnes Ice Cap and the location of areas where the relationship of former lake depth and number of moraines has been calculated (Figure 14).

the variation within the exposure. As all samples were composites of four smaller units, the possible sampling error was reduced by one half* (Krumbein and Pettijohn, 1938). The samples were subjected to the standard sieve analysis on a series of seven sieves, Tyler numbers 4, 8, 16, 30, 120, 230 and pan. Because of the small residual fraction in the pan (3 to 8 per cent silt and clay), hygrometer analysis was not undertaken. Some samples would have benefited from the use of coarser sieves, and the grain size curves would then have been more amenable to statistical treatment.

The resulting frequency distributions were plotted on arithmetic-probability paper (Codex 3127). The dependent variable is frequency (f(x)) expressed as a cumulative percent finer by weight, while the independent variable is grain size with diameters expressed in phi (ϕ) units (Krum-

$$^{*}\sigma \, n = \frac{\sigma}{\sqrt{n}}$$

bein, 1936).* The use of a logarithmic conversion results in a more symmetrical grain-size distribution curve and the probability scale allows a visual estimation of the normality of the curve. With a normal logarithmic distribution the cumulative frequency should plot as a straight line. A more important reason for adopting this method is that the results may be analyzed by normal statistical methods (Krumbein, 1936). Inman (1952) followed Krumbein in stressing that a logarithmic expression of the grain size is more applicable to statistical relations of sediments. Other workers (e.g. Mason and Folk, 1958) are following this trend.

It has been shown that such accepted measures as Trask's coefficient of sorting and skewness (Trask, 1932) are inadequate expressions, as they are based on the central 50 per cent of the distribution† and do not adequately reflect the total population. Inman (1952) recommended the use of moment measures calculated graphically from a frequency distribution portrayed on arithmetic-probability paper. It is known that 68 per cent of the population lies one standard deviation on either side of the mean—that is, between the 16th and the 84th percentiles. The first moment about the origin of the distribution is the mean, and the higher moments are then generally calculated about the mean of the distribution rather than about the origin. These measures are based on the entire frequency curve and, since grain-size distributions are generally open, practical limitations are thus imposed on their use. Inman proposed a series of graphical procedures to calculate the first four moments. These moments are: the phi mean diameter, a measure of central tendency; the phi standard deviation, a measure of dispersion or sorting about the mean; the phi skewness, a measure of the symmetry of the distribution; and phi kurtosis, a measure of the peakness. It is worth noting that if the phi mean is converted to millimetres, it becomes the geometric mean of the non-logarithmic distribution.

The actual efficiency of percentile measures is currently being discussed. McCammon (1962) points out that a percentile measure is a random variable and that percentile measures of the mean and standard deviation are estimates of the population mean and standard deviation. McCammon examined the efficiency‡ of the published methods of deriving the mean and standard deviation from percentile measures and computed the various

*The diameter in millimetres is converted to phi units by: $\phi = -\log \epsilon_2$ where ϵ is the diameter in mm.

†So = $\sqrt{Q75/Q25}$ where Q refers to the relevant percentile.

‡McCammon defines the efficiency of an unbiased estimate as the ratio of the minimum possible variance to the variance of the estimate.

efficiencies. The maximum that can be obtained is 97 per cent for the mean size and 87 per cent for the standard deviation. Such, however, was the nature of the material sampled for this paper that measures of a lower efficiency had to be used. No similar evaluation has been made of the efficiencies of the present techniques of computing phi skewness, and Inman's measure is adopted. The kurtosis of the samples has not been studied. The three other moments are defined as follows:

(i) Phi mean diameter (McCammon, 1962) $\bar{x}\phi = (\phi20 + \phi50 + \phi80)/3$

(ii) Phi standard deviation (McCammon, 1962) $s\phi = (\phi85 + \phi95 - \phi5 - \phi15)/5.4$

(iii) Measure of first phi skewness (Inman, 1952) $\alpha\phi = \bar{x}\phi - Md\phi/s\phi$ where $Md\phi$ is the median at the 50th percentile.

The phi mean has an 88-per-cent efficiency and the phi standard deviation an efficiency of 79 per cent.

For further analysis the samples were then grouped into (1) till from moraines on valley sides, (2) till from river-cut moraines, (3) fine sands and (4) coarse sands (Andrews, 1963). Differences between the materials could then be tested for significance, on the null hypothesis that there is no difference between the population means from which the samples were drawn. The mean of the phi mean diameters, the phi standard deviation, etc., were calculated in the normal manner, as were the standard deviations. The 'student's' t test was employed to test for significant differences between the main groupings.

'Law of crushing' paper, described by Elson (1961), has been used to examine the tills of north-central Baffin Island. On this paper the frequency distribution of crushed rock plots as a straight line. Breaks appear in the graph if the material is heterogeneous. The bedrock in the Rimrock and Isortoq valleys has not been closely examined, but it is typical of the Archean basement, being composed mainly of gneisses and granite gneisses. Till samples from the field have been plotted against the distribution of crushed gneiss.

EXPOSURES IN THE CROSS-VALLEY MORAINES FROM THE VALLEY SIDES

Natural exposures in the cross-valley moraines were numerous but were limited to the valley bottoms, where the moraines had been eroded by the rivers. At higher elevations digging was necessary, but it required much labor, and permafrost limited its depth. The maximum depth of the active layer below the crest of a moraine was 5 feet. The average depth attained was 3 to 4 feet.

In the upper and middle sections of the moraines the same sequence was always observed. The 2 to 3 inches immediately beneath the surface, which had a covering of unstable and angular boulders, consisted of a lag gravel heavily impregnated with silt. The silt is further evidence that the moraines were once covered by a lake or lakes of glacial origin and it was seen everywhere except in the higher parts of the moraine system. There the boulder cover was such that fine material, if there was any, was invisible. Below the silt was an obdurate sandy till, about 95 per cent sand and gravel and 5 per cent silt and clay (less than 0.05 mm), of a type that is common over areas of gneissic bedrock. Figure 2 compares the various units sampled during 1961.

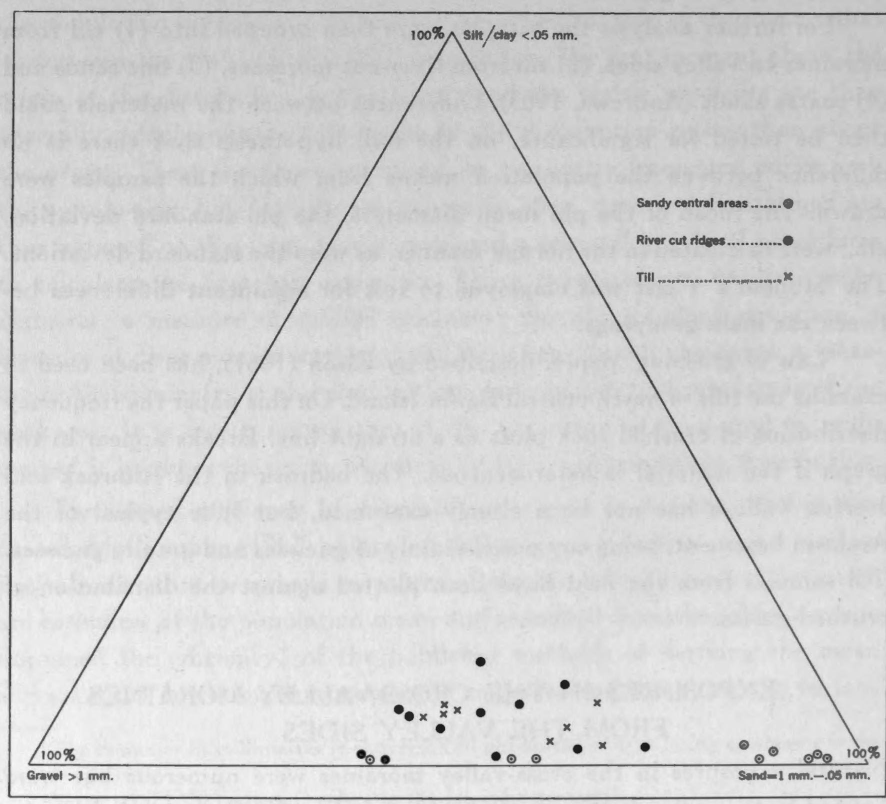

FIGURE 2. Triangular diagram showing the percentage of gravel, sand, and silt and clay for the stratified central kames, and tills from river exposures and higher elevations.

Numerous large boulders were embedded in the till. Silt and clay were commonly concentrated in small pellets within the normally sandy till and formed a thin coating on pebbles and cobbles. Toward the base of the exposures the amount of silt and clay increased and the till appeared more plastic. Further evaluation was impossible owing to the permafrost.

Eight till samples analyzed showed but slight differences. Visually and in texture they were remarkably uniform. The phi means ($\bar{x}\phi$) ranged from -0.70 to 0.92, with an over-all mean ($\bar{X}_t$) of -0.15 and a standard deviation (S_t) of 0.53. The tills were poorly sorted, with a mean phi standard deviation of 2.9 (Figure 3). The grain-size distribution curves were slightly skewed toward the larger particles. If a curve is symmetrical, the measure of first phi skewness should equal 0, with extreme values of 1.0 to -1.0. The mean skewness of the tills sampled is -0.097, and its standard deviation is 0.011 (Table 1).

Table 1

Analysis of till samples

Sample number	1	2	3	4	5	6	7	8	$\bar{X}_t$	S_t
$\bar{x}\phi$	0.40	−0.40	−0.33	−0.40	0.15	0.92	−0.70	−0.45	−0.15	0.53
$s\phi$	2.5	3.5	3.3	3.3	3.5	1.9	3.9	2.4	2.9	0.65
First skewness measure	0.017	−0.130	−0.090	−0.150	−0.020	0.017	−0.280	−0.140	−0.097	0.011
Per cent silt/clay	5.0	7.0	7.0	8.0	3.0	2.5	7.0	1.1	5.1	—

In the eight exposures that were minutely examined, no bedding or stratification was observed, but there were ill-defined 'bands' where the silt and clay content was above average. The increase, however, amounted only to 5 to 7 per cent of the total. No fissures or hollows were noted in the lee of included boulders.

If the frequency-distribution curves of the samples are plotted on the 'law of crushing' paper (Figure 4), they resemble the curve for crushed gneiss. Tests, however, showed a significant difference between the till curves and those for crushed gneiss, although the local bedrock is variable. A composite till curve from New Hampshire (Goldthwaite, 1948, in Elson, 1961) plotted on the 'law of crushing' paper emphasizes even more strongly the general similarity between the Rimrock and middle Isortoq tills and the crushed bedrock. The similarity suggests that the till is mainly local and is derived principally from gneisses and granites, though there is

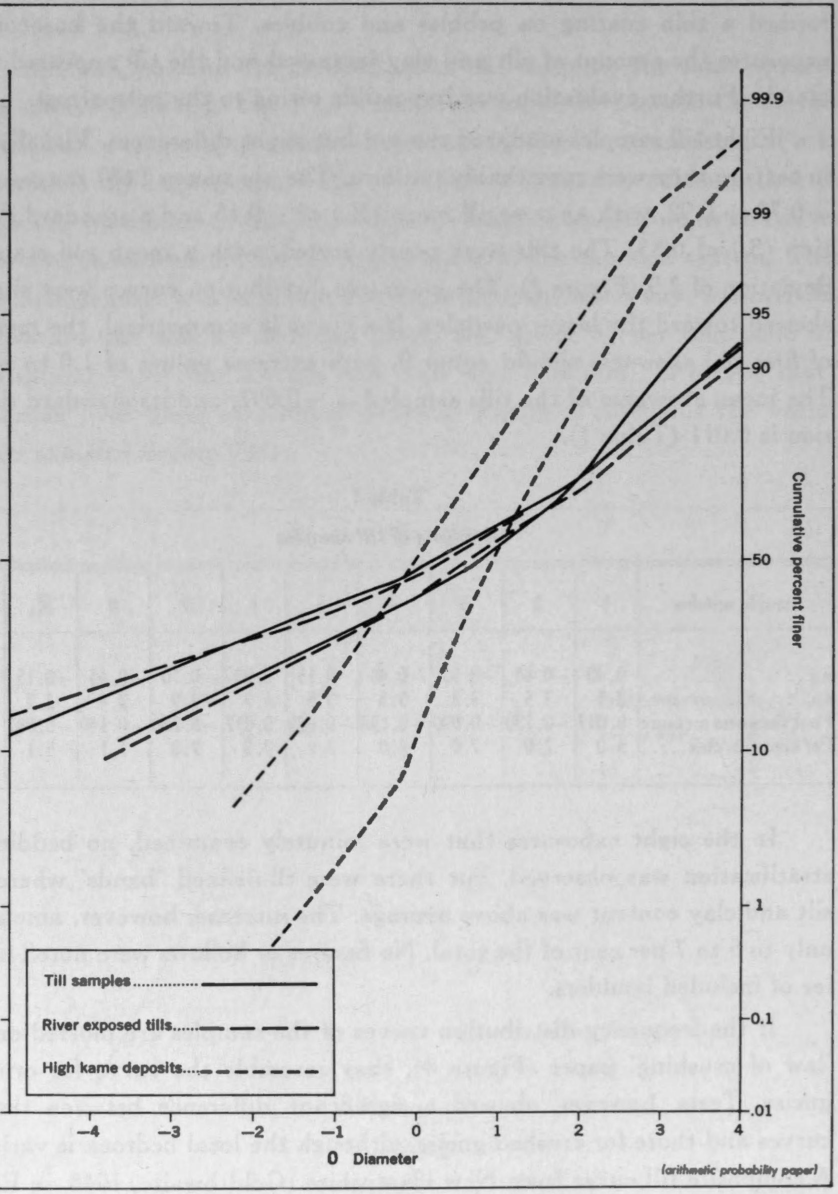

FIGURE 3. Grain-size curves of till and sand from the central kames plotted on arithmetic-probability paper. Note the zig-zag nature of most of the curves and the displacement away from lognormality. The samples noted as 'till samples' are from cross-valley moraines away from the river at higher elevations.

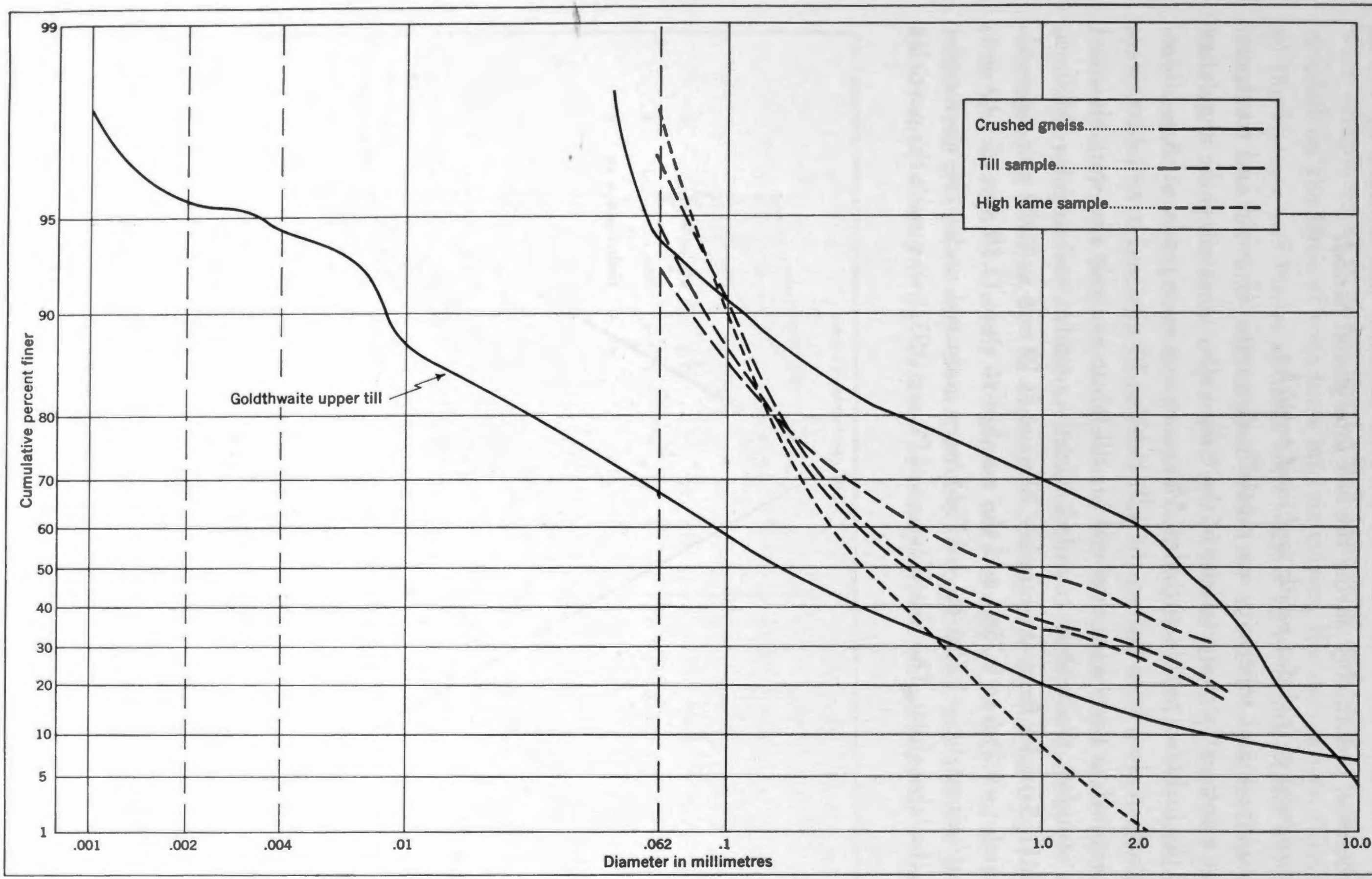

FIGURE 4. 'Law of crushing' paper with an example of the plotting of crushed gneiss to indicate the similarity between this gneiss and the tills from the cross-valley moraines. Note the disparity between the gneiss, a composite till from New Hampshire and a water-sorted kame deposit.

evidence that some of the incorporated material was affected by fluvial processes, presumably during the last interglacial period.

Roundness of included pebble and sand particles

Roundness and sphericity are partially diagnostic of origin and transport, but a noticeable characteristic of the cross-valley moraines is the angularity of the included pebble particles. Measurements were made on three different grain sizes from within the till. Pebbles 10 mm and over (-3ϕ) were examined as they were removed for till-fabric analysis and were classified as rounded, moderately rounded, slightly rounded and angular (Holmes, 1941). Samples from the number 30 sieve (1.19 mm to 0.590 mm, approximately -0.25ϕ to 0.75ϕ) and the number 16 sieve (2.38 mm to 1.19 mm, approximately -1.75ϕ to -0.75ϕ) were examined under the microscope in the laboratory. The classification of Power (1953) was used: the particles

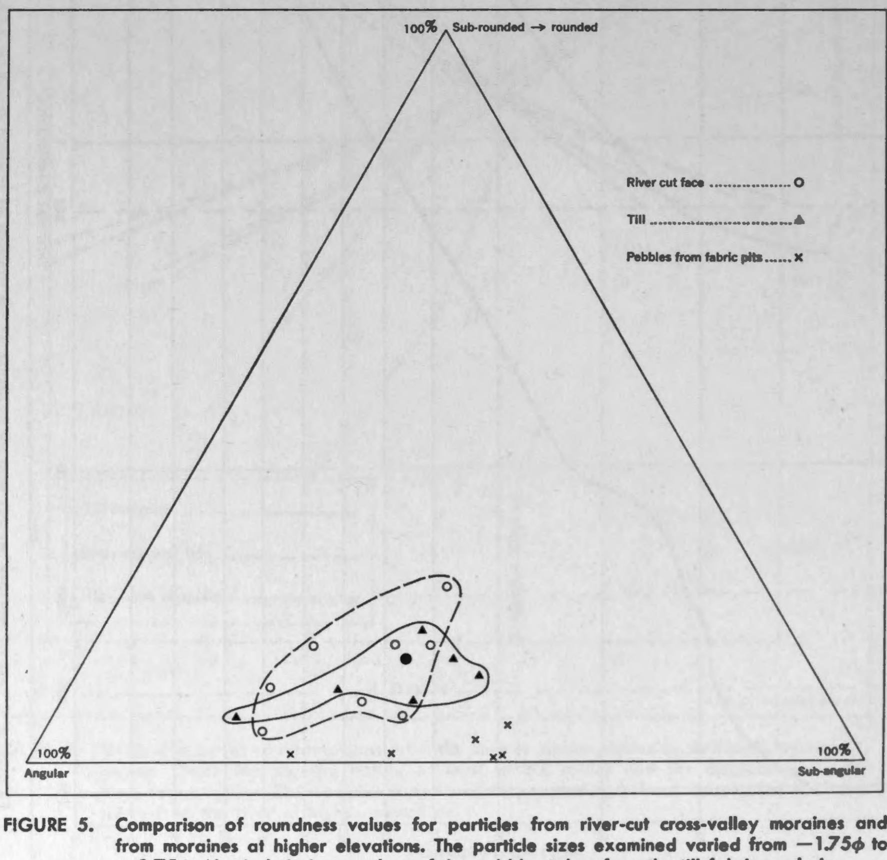

FIGURE 5. Comparison of roundness values for particles from river-cut cross-valley moraines and from moraines at higher elevations. The particle sizes examined varied from -1.75ϕ to -0.75ϕ. Also included are values of the pebbles taken from the till-fabric analysis.

were designated as of either low or high sphericity and were further subdivided on the basis of roundness into six classes. For comparison (Figure 6) the Holmes and Power systems were unified by equating Power's well-rounded, rounded and subrounded with the rounded classification of Holmes. Subangular was judged similar to Holmes' slightly rounded, and very angular and angular were grouped with angular. As the two systems are not wholly reconcilable, this procedure is justified only if treated with reservation. In the four exposures where the larger particles were noted, 0 to 5 per cent were classified as rounded, and 45 to 50 per cent as either subangular or angular. In the highest pit, 68 per cent of the particles were classified as angular. In all, 400 stones were closely examined and about 1,500 were given a cursory glance, but not a single stone was striated and 95 per cent showed little evidence of transport, except perhaps in a very

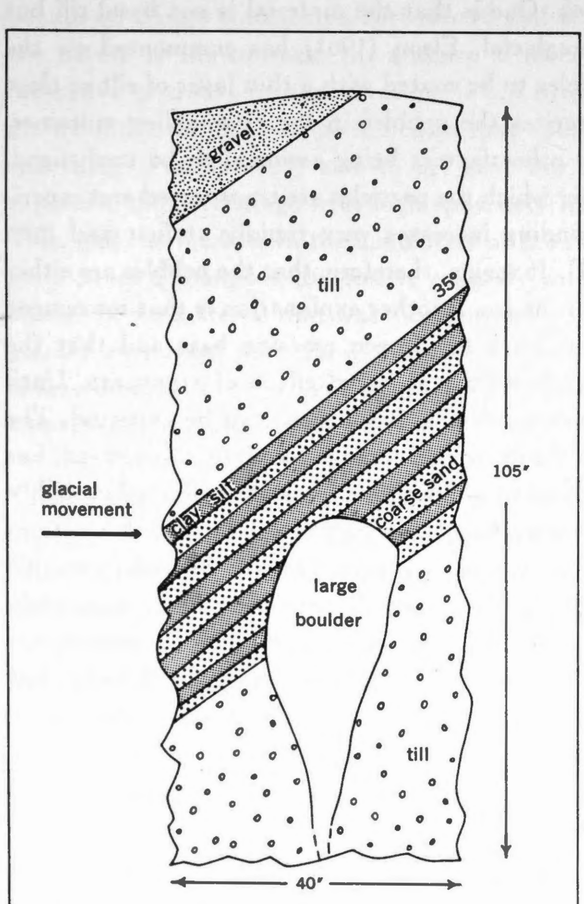

FIGURE 6
Sketch made from field notes and photographs of an exposure in the river-cut face of MRI. The exposure revealed a coarse sandy till overlying banded clays, which dipped steeply upglacier.

slight rounding of edges. This is common in areas of granitoid rock. As yet there are few data for a comparison of arctic and temperate glacier deposits, but a comparison of tills from areas of similar lithologies would be of great value in determining differences between glacier types, in basal movement and erosive power.

The lack of striation and the marked angularity of the particles are not wholly compatible with other lines of evidence. The till should show signs of the basal movement that caused the *roches moutonnées* and striations found within the Rimrock and middle Isortoq valleys. On the other hand, the composition of the boulder fields has apparently been determined by the underlying bedrock. This suggests that the very coarse element in the till is mainly local and that the basal motion is consequently small. Several explanations are possible for the lack of striation on the stones, including the lithology of the bedrock. One is that the material is not basal till but is either englacial or supraglacial. Elson (1961) has commented on the tendency of englacial particles to be coated with a thin layer of silt or clay, and this tendency characterizes the pebbles in the cross-valley moraines. The rounding of particles, other factors being assumed to be unchanged, varies with the distance over which the particles are transported and experiments show that such rounding increases very rapidly at first and then levels off (Krumbein, 1941). It seems, therefore, that the pebbles are either local or were carried within the ice. Another explanation is that movement in an arctic glacier occurs above the frozen moraine base and that the material is thus protected from the abrasive effect of transport. Until further studies are undertaken, no positive answer can be expected. The local nature of the boulder fields, which denotes restricted movement, has to be balanced against the finding of limestone fragments, derived probably from Foxe Basin. To determine the percentage of calcite and dolomite in the fine fraction of the tills, samples were analyzed by the Chittick apparatus (Dreimanis, 1962). The fines in the 230-mesh sieve were found to contain about 2 per cent calcite and dolomite. These substances, however, are present in altered igneous rocks as well as in limestones and dolomites; but as the regional geology is imperfectly known, the significance of this percentage cannot as yet be determined.

The smaller particles in the 2.38 mm to 0.59 mm range showed, as expected, a greater amount of angular material, but the number of rounded particles increased interestingly to a range of 5 to 25 per cent (Figure 5). As roundness is also a function of size, a reverse relation seems to exist between these particles and the pebbles. The difference is apparently significant but may be partly explained by the different methods on which the results are based. It could indicate that the material is of two different ages, represent the inclusion of stream gravels or imply that the finer fraction had travelled farther.

The shape of included materials

The pebble shape was also determined during the till-fabric work (Holmes, 1941) and was consequently divided into six basic classes: discoid, ovoid, tabular, wedge, rhombohedroid and varihedroid. The last comprises irregular-shaped particles. The proportions of these various shapes, which occurred in the cross-valley moraines, are remarkably constant: wedge-shaped pebbles accounted for 40 to 47 per cent of the 400 stones examined; varihedroids made up between 16 and 30 per cent; the tabular and rhombohedroid classes constituted between 10 and 20 per cent each. Because of the nature of the bedrock, the absence of discoid and ovoid stones, both indicative of transport and abrasion, is not surprising. A study of the fine grains under the microscope indicates that about 54 per cent possess high sphericity (Power, 1953) and 46 per cent low sphericity. At the highest exposure, the percentage with high sphericity had dropped to 18 per cent. This, and the increase in the angularity of the pebbles with elevation, suggests either a change in the erosive capacity with altitude or an altitudinal change in the material that was incorporated into the ice. The first suggests greater movement and transport at depth; the second implies that these characteristics of the pebbles were established by subaerial weathering and transport before glacierization.

TILL SAMPLES FROM RIVER-CUT EXPOSURES OF THE CROSS-VALLEY MORAINES

Many exposures in the cross-valley moraines caused by river erosion were examined in 1961, and several showed crudely stratified material. A comparison of data obtained from them with data from the previously discussed, more elevated exposures should make it possible to appraise any changes in till characteristics along the length of the moraines. Ten samples were collected and sieved. Table 2 shows that these samples are more variable than the till in the excavated pits; the mean size is slightly smaller whereas the standard deviations indicate a greater dispersal about the mean. The mean of the phi means ($\overline{X}_t$) is -0.12 with a standard deviation of 0.96. The student's t test showed that there was no significant difference in the means between these samples and those in group 1. The phi standard deviation, with values ranging from 4.3 to 2.0 and a mean of 3.04 (Table 2) suggests that the till is not so well sorted as in the upper exposures. The measures of first phi skewness, at the 1.0 per cent level, are significantly different. The tendency of till near the river to be more skewed toward the larger particles is therefore probably due not to chance but either to a change that occurred during deposition of the till or to an original difference in its constituent materials. Very little work has been done on the causes of regional changes in skewness values or their implications (Mason and Folk, 1958). In this case, however, the increase in the negative skewness could be caused by the washing out of fine material or by a change that took place across the axis of the valley before the last glaciation. This possible change must also be considered, along with the morphometric analysis, which indicated an increase of angularity with elevation.

Table 2

Analysis of river-cut exposures

Sample number	1	2	3	4	5	6	7	8	9	10	$\overline{X}_t$	S_t
$\bar{x}\phi$	–0.93	1.50	–0.20	0.70	–0.45	–1.70	–0.90	–0.40	0.82	0.33	–0.12	0.96
$s\phi$	2.05	4.30	4.07	2.00	2.42	2.05	4.07	3.70	2.80	2.80	3.03	0.93
First skewness	0.14	—	—	–0.11	–0.14	–0.83	–0.29	–0.21	–0.08	0.09	–0.179	0.029
Per cent silt/clay	0.7	15	5	3	1.1	7	8	7	10	8	8.5	

The possibility that water moved down the valley side parallel to the cross-valley moraines during their period of formation might be judged from the variation in the silt and clay content. There is little difference, in fact, between the two series (Tables 1 and 2). Two samples with 15 per cent and 10 per cent silt and clay were taken from bands in which a marked increase of these fractions was readily apparent. It seems that there is no significant change in the percentage of fines along the axes of the moraines. Differences in the various parameters probably reflect preglacial factors. It was noticeable that many of the pebbles were rounded in the lower cross-valley moraines, and this again suggested the importance of the distribution of interglacial or interstadial deposits in glacial drift.

Certain exposures in the river-cuts, however, did vary from those in the excavated pits. They often showed the following sequence: a 2-inch layer of silt-impregnated sand or gravel overlying a coarse, sandy till, which became more compact and finer toward the base of the moraine. Other moraines such as RVIII* are composed of sandy till for the full length of the exposure. In RII and MRI (Andrews, 1963) stratified layers were observed. In the face of RII the surficial lag gravel is underlain on the proximal side by a lens of bedded sands and rounded gravels, which dips 5 degrees to the north, or downglacier. This in turn is underlain by a loose bed of unsorted angular fragments in a sandy matrix. Beneath this again is a sandy till with occasional silty beds, which dip north at 30 degrees parallel to the contact between the till and the overlying material.

In the river-cut face of MRI, which is a massive ridge some 50 to 70 feet high, the clearance of about 8 feet from the top section revealed slump gravels overlying sandy till (Figure 6). The till in turn overlies a regular sequence of banded clay and silt that dips upglacier at 35 degrees. The clay and silt bands are approximately 3 inches thick and become coarser near their base. Implanted in the moraine at this level (Figure 6) was found a large boulder, which truncated the bands but did not affect the structure. The lowest part of the pit was composed of the normal sandy till. The sequence just described contains two distinct, though physically similar, tills that are separated by clay and silt bands dipping steeply upglacier. The bands show no deformation, and their regularity strongly suggests a seasonal deposit. It is strange, however, to find such parallel bands deposited on a slope of 35 degrees, especially as the glacial silt that settled over the present cross-valley moraines lenses out on the moraine crests and forms a deposit at least 2 feet thick in the intervening swales. One explanation is that the material was moved and deposited while in a frozen state. If so, the whole of the underlying till had also to be transported, as the large included boulder was obviously present before the deposition of the clays. The evidence suggests that the clays were laid down over a till sheet and later incorporated into a moraine through basal pressure. If this reasoning is correct, a period of initial till deposition was followed by a short period—five years if the varves are annual—of lake conditions before the final deposition of till. This could have resulted from a small oscillation of the ice front.

Reference must also be made to two exposures in which two tills were noted, both separated by fluvial or glacio-fluvial material. The first is on the south bank of the Isortoq River at 70°43' N, 74°42' W. As the river

*The notations RVIII, MRI, etc. are used for convenience to refer to specific cross-valley moraines. Figure 7 (page 61) in the earlier companion paper should be consulted (Andrews, 1963).

could not be forded at this point, the exposure was examined through binoculars from a distance of 150 feet. The bottom section is composed of a grey sandy till, above which is a horizontal bed of large rounded boulders and gravels (Figure 7) 4 to 6 feet thick. Finally, above this is a thick bed of grey till 20 to 30 feet thick, which represents the cut face of a large

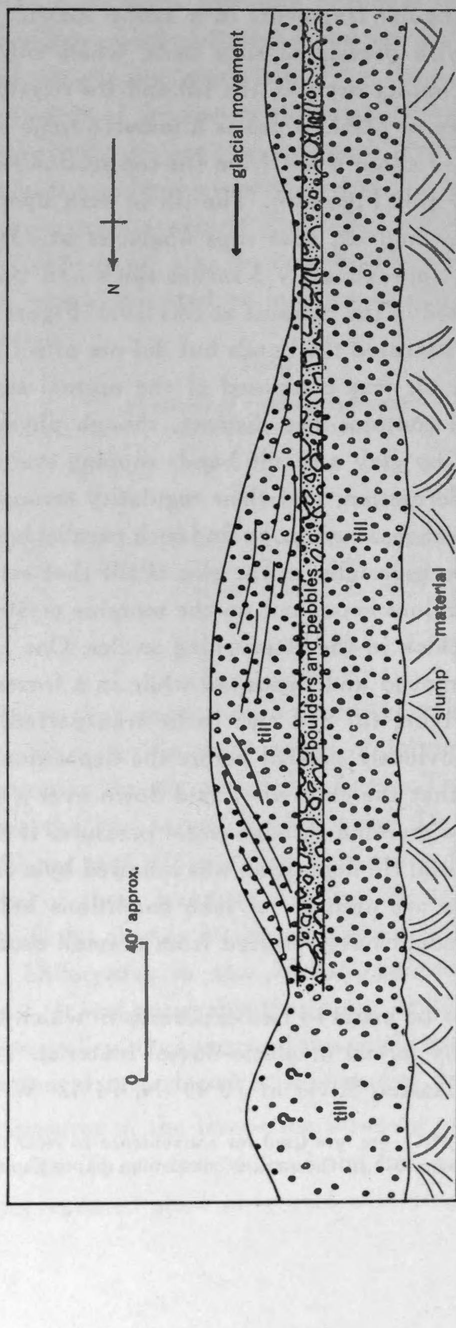

FIGURE 7. A sketch drawn from field notes and photographs of a river-cut exposure through a series of cross-valley moraines along the Isortoq River. The exposure consisted of two tills separated by a horizontal bed of rounded fluvial material. Structures in the upper till were inclined toward the crest on either side of the cross-valley moraine. The exposure is about 40 feet high.

cross-valley moraine. This top layer has distinct structures. A series of curved planes, for example, meet at the centre of the moraine and are also quite noticeable in adjoining sections (Figure 7). Two tills, separated by 10 to 20 feet of bedded sands and gravels, were also examined on the east side of the Rimrock River near MR11.

The stratigraphy can be interpreted as implying more than one glacial oscillation, but at the moment nothing can be said of the length of time separating the depositions of the tills. The tills may have resulted from nothing more than a slight fluctuation of the margin, but it is probable that the time interval was longer. It has been suggested (Andrews, 1963) that during the formation of the cross-valley moraines the proto-Barnes Ice Cap was blocking the upper and middle Isortoq Valley and that consequently the moraines are in some way sublacustrine forms. If this is so, it is hard to imagine how the horizontal beds of fluvial material were deposited. The conditions of drainage and deglacierization were perhaps different between the two periods of till deposition, and this difference could represent a major fluctuation of the ice cap.

STRATIGRAPHY AND SEDIMENTARY CHARACTERISTICS OF THE CENTRAL KAMES

The central kames range in size and complexity from small isolated conical mounds of sand and gravel to higher complexes that straddle the cross-valley moraines (Andrews, 1963). Thus they either appear as discrete features in no way related to the moraines, or they grade into, and become intimately associated with, individual ridges. This relationship is the crux of the problem: are the kames related purely by chance to individual ridges, or is the formation of the central kames and the cross-valley moraines a synchronous process operating at a specific locality? At least a partial answer can be given.

Small exploratory pits in the Rimrock Valley indicate that the kames consist of bedded sand and gravel with alternating beds of fine and coarse sand and occasional silty bands. The mean of the sands visually classified as 'fine' is 1.07ϕ with an average phi standard deviation of 1.02. The material is thus well sorted and falls within the indices of sorting common to glacio-fluvial materials (Friedman, 1962). 'Coarse' sands have an average phi mean of -0.17 with an average phi deviation of 1.01. The degree of sorting in both is similar. Exposures along the north bank of the Isortoq show sequences of well-bedded northeasterly-dipping sands, possibly

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FIGURE 8. Photograph of a pit in RI showing the silt bands dipping steeply downglacier. The photograph should be compared with Figure 9, which is a sketch of the east wall of the pit.

deltaic in origin. Some of the units are composed predominantly of fine sands and silts.

In an excavation on the proximal slope and just below the crest of RI it is apparent that the beds dip upglacier by varying degrees. Bed A (Figures 8 and 9) is probably made up of slump gravels that wedge out onto B, where coarse sands and gravels are current-bedded. The contact between B and C dips upglacier at 16 degrees. Bed C is of a brown, fine-grained sand that lies unconformably over the beds in unit D. These are composed of alternating layers of silt and fine sand that dip downglacier at 45 degrees. They are regularly spaced at intervals of 5 inches. Near the base of the pit, immediately above the permafrost level of July 8, 1961, the silt bands become convoluted and the sands become white.

In another excavation on the distal slope of a central kame in the Rimrock Valley the situation is different: the top 11 inches consists of fine-bedded, coarse sand and gravel covering a central 'core' of coarse, well-rounded pebbles 2 to 4 inches long. Finer gravels within the core are weakly bedded. The gravels are about 3 feet thick, and there is sharp contact with an underlying bed of very fine sand, which exhibits micaceous bands that dip upglacier at 18 degrees.

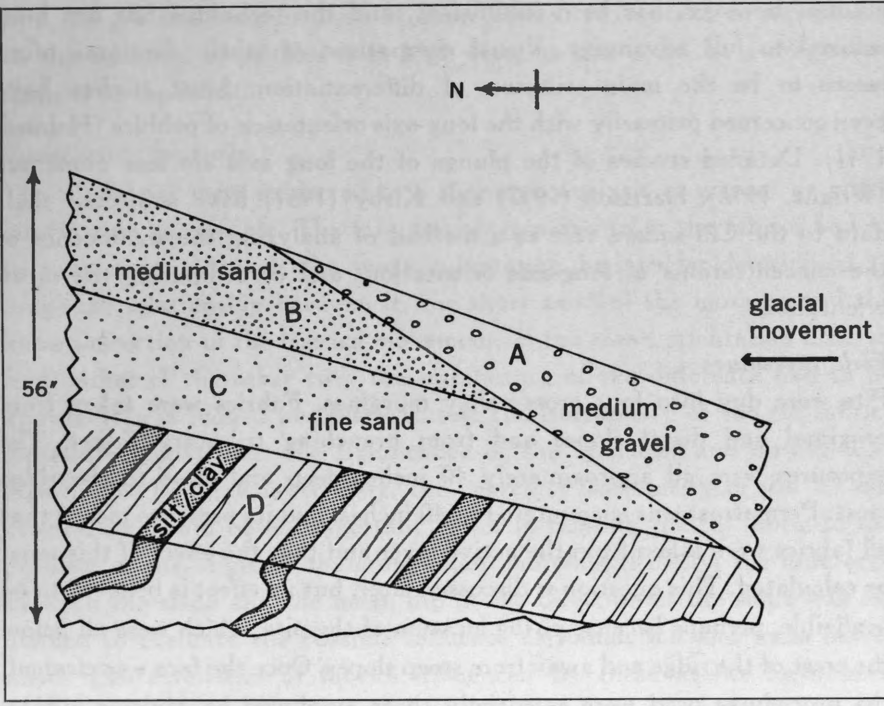


FIGURE 9. Sketch of the east wall of a pit dug on the upglacier slope of RI just below the crest. This figure should be compared with Figure 8. Bed A is slump gravel; B consists of current bedded sand and gravel; C is a fine-to-medium sand which overlies D. Bed D is composed alternately of fine sand and silt bands. Whereas the contacts in the first three beds dip upglacier, the silt bands dip downglacier.

The internal structures of the central kames were caused by the deposition of water-sorted sands and gravels and thus contrast with the composition and structure of the cross-valley moraines. The exposures described in the two preceding paragraphs show important differences, and much more research is needed before these forms can be fully evaluated. To date only one exposure sheds any light on the problem of the time relationship between the kames and the cross-valley moraines. In the Isortoq Valley a river-cut central kame shows a large knob of till surrounded by bedded sands and gravels. The till has a normal appearance and it seems likely that the central kame was laid down after the formation of the cross-valley moraine.

THE TILL FABRICS OF THE CROSS-VALLEY MORAINES

The technique and application of till-macrofabric analysis has steadily developed in recent years. The amount of information obtained from these studies, however, has been insufficient, and the technique has not been utilized to full advantage. Visual comparison of fabric diagrams often seems to be the main criterion of differentiation. Most studies have been concerned primarily with the long-axis orientation of pebbles (Holmes, 1941). Detailed studies of the plunge of the long axis are less numerous (Wright, 1952). Harrison (1957) and Kirby (1961) have subjected their data to the Chi-square test as a method of analyzing the significance of the concentrations of long-axis orientations and of computing the mean orientation.

Field procedures

Pits were dug into four cross-valley moraines. Fabrics were taken from proximal and distal slopes and from branching tributary ridges. The exposures were all approximately 40 inches deep and close to the ridge crest. Permafrost was encountered at 40 inches, and its presence means that all fabrics were taken from the active layer and that the effect of this must be calculated. This question is discussed later, but its effect is believed to be negligible, perhaps because of the location of the pits, which were all below the crest of the ridge and away from steep slopes. Once the face was cleaned, the procedures used were essentially those employed by Holmes (1941), the pebbles being taken from the vertical face. Magnetic north was determined and a north-south guide erected as a reference. Pebbles were gently removed and oriented with respect to the long, or 'a,' axis. The dip of the 'a' axis was also measured. Both the pebble orientation and the dip were measured to the nearest 5 degrees. The determination of the dip and the alignment of the 'a' axis do not fully determine the true spatial position within the fabric. To accomplish this the 'a,' 'b' and 'c' axes must be considered and the maximum and minimum projections determined (Krumbein, 1939; Harrison, 1957). This method, however, although superior to the one used, requires laboratory examination of orientated blocks of till; in no sense is it a field technique.

Only pebbles having a minimum long-to-short axis ratio of 2:1 or more were considered. The average size was 25 mm, with a range of 8 to 100 mm. In six of the exposures 100 stones were taken; in the other two, 50.

The orientation and dip of the 'a' axis have been plotted on a polar equidistant projection, the azimuth representing orientation and the medians the dip. Stones lying in a horizontal position have two possible positions on the projection; in practice they have been placed in the half with the greatest concentration of observations. No restriction was placed on the selection of pebbles with high dips, as this could be a diagnostic element in the fabric.

Quantitative measures

The till fabrics were subjected to a thorough analysis to extract as much information as possible. The information required from the fabrics had to be previously outlined: the mean orientation had to be determined to judge the relationship between it, the short axis* of the moraine and the known direction of the last ice movement. If the mean orientation differed from either of the other two, the significance of the difference had to be known. It was judged necessary to test the isotropicity of the till fabrics for two reasons: first, the significance of the upglacier and downglacier dips had to be known; secondly, the degree of isotropicity of the 'a' axis orientation would be an important factor in relating the till fabric to the problem of the origin of the cross-valley moraines. Finally, the difference between the slope and the mean dip in the direction of the slope was examined to evaluate the possible influence of solifluction and mass movement. Characteristics of fabrics influenced by these agents have been outlined by Lundqvist (1949), Hoppe (1952) and Harrison (1957).

The Chi-square test, one of the most versatile in statistical theory, was used to test the difference between the observed and the expected distributions on the polar equidistant projection. It was *assumed* that the expected frequency would show an equally spaced concentration of both the orientation and the dip of the 'a' axis. In the case of a 360-degree sector this would mean 5.5 per 20 degrees for 100 pebbles. For dips, the expected frequency was considered as the total fabric less horizontally lying pebbles divided by two. Pits where 100 and 50 stones were taken are, of course, not strictly comparable.

The student's t test was applied to the hypothesis that a sample with a mean value of $\bar{x}$ and a standard deviation of s comes from a population whose mean value is $\bar{X}$. The t test is expressed as follows:

$$t = \frac{[\bar{X} - \bar{x}]\sqrt{n-1}}{s}$$

It was used to examine the significance between the slope angle ($\bar{X}$) and the mean dip ($\bar{x}$) of the 'a' axis in the direction of the slope, horizontal

*'Short axis' and 'long axis' refer to orientation direction on the moraines in a two-dimension-plan view.

particles excluded. It was also used to test the significance of the departure of the mean orientation of the fabric ($\bar{x}$) from the short-axis direction ($\bar{X}$) of the cross-valley moraines.

The results of the analysis are shown in Table 3. The terms 'probably significant' (5-per-cent level), 'significant' (1.0-per-cent level) and 'highly significant' (0.1-per-cent level) express the degree of certainty that can be attached to a significance test. It must be emphasized that the results of various tests are valid only within the framework of the assumptions and design peculiar to each.

Lundqvist (1949), Hoppe (1952) and Harrison (1957) have investigated the nature of till fabrics in areas where post-glacial modifications have disturbed the original till. Hoppe (1952) studied the till fabric from an earth flow. His findings can be used to evaluate the pattern of the fabric in the pits and, by comparison, to judge whether the internal structure as shown in the macrofabric is a primary feature of deposition or is due to secondary modifications. In solifluction, the 'a' axes lie on or dip slightly into the slope and are orientated parallel to the flow. The mean dip in his earth flow, however, is 22 degrees and that of the slope is 27 degrees. The difference, which is probably significant, strongly suggests that the stones have been imbricated toward the source of movement and that their dips are consequently less than that of the slope. Caution should therefore be exercised in using the difference between slope angle and mean upglacier dip as a criterion for delimiting unmodified fabrics. Instead, the mean dip of the entire fabric, the number of horizontal and near-horizontal stones, and the strength or frequency of dips into the slope are fundamentally of greater genetic importance. The application of these parameters to Pit 1 gives little indication of post-glacial modification.

Results of the till-fabric analysis, Ridge I

Ridge I* is the last major cross-valley moraine in the middle section of the Rimrock Valley. The fabric was taken from the proximal slope. The long axis of the moraine is at right angles to the last recorded direction of ice movement, which is N to N 10°W. The short axis is aligned N 10°E and the slope is 18 degrees.

Pit 1—The till fabric has a mean orientation of N 13°E; there is no significance between it, the alignment of the short axis and the direction of ice movement. The Chi-square test indicates that the orientation

*Andrews, 1963, Figure 7 (page 61).

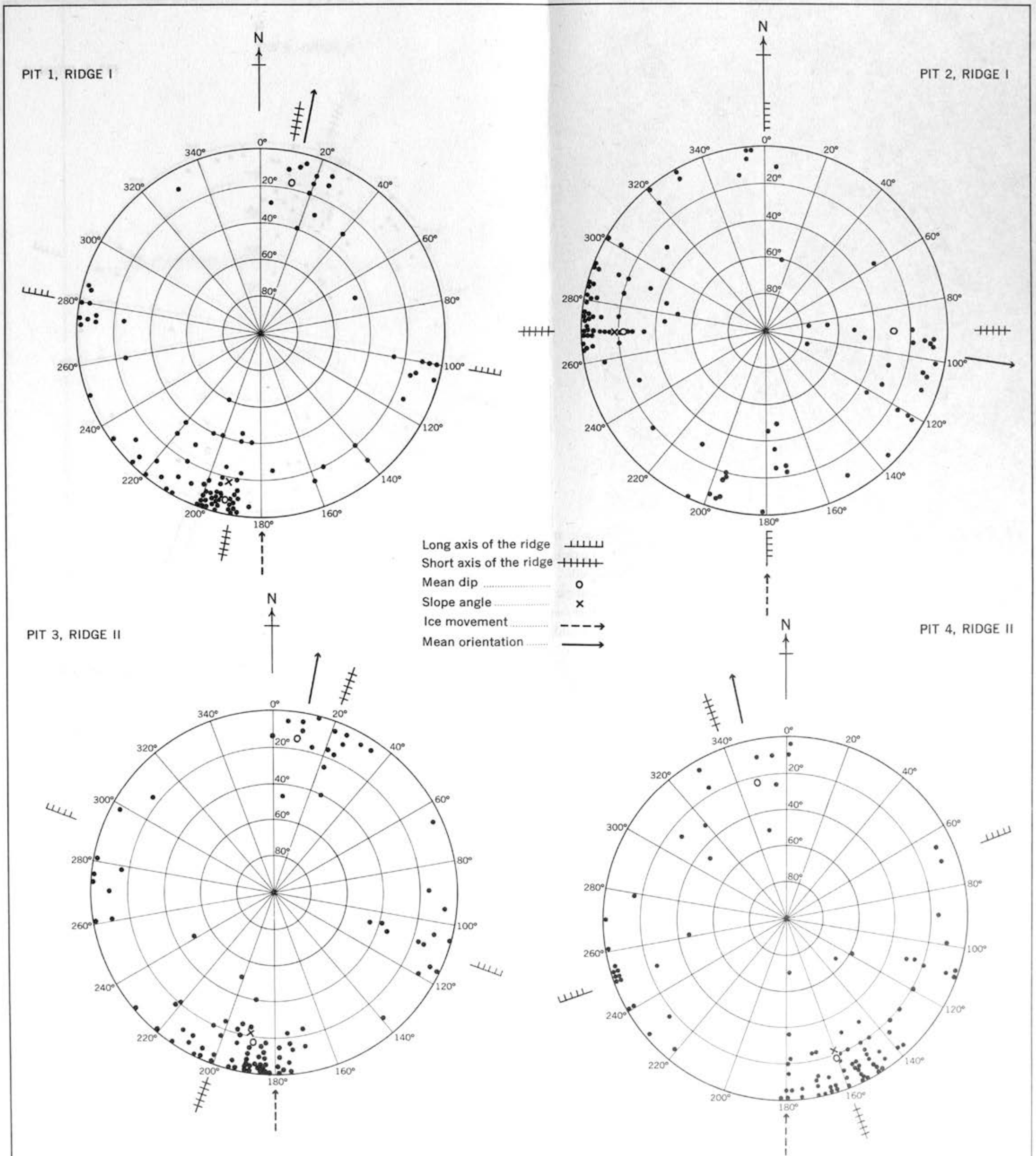
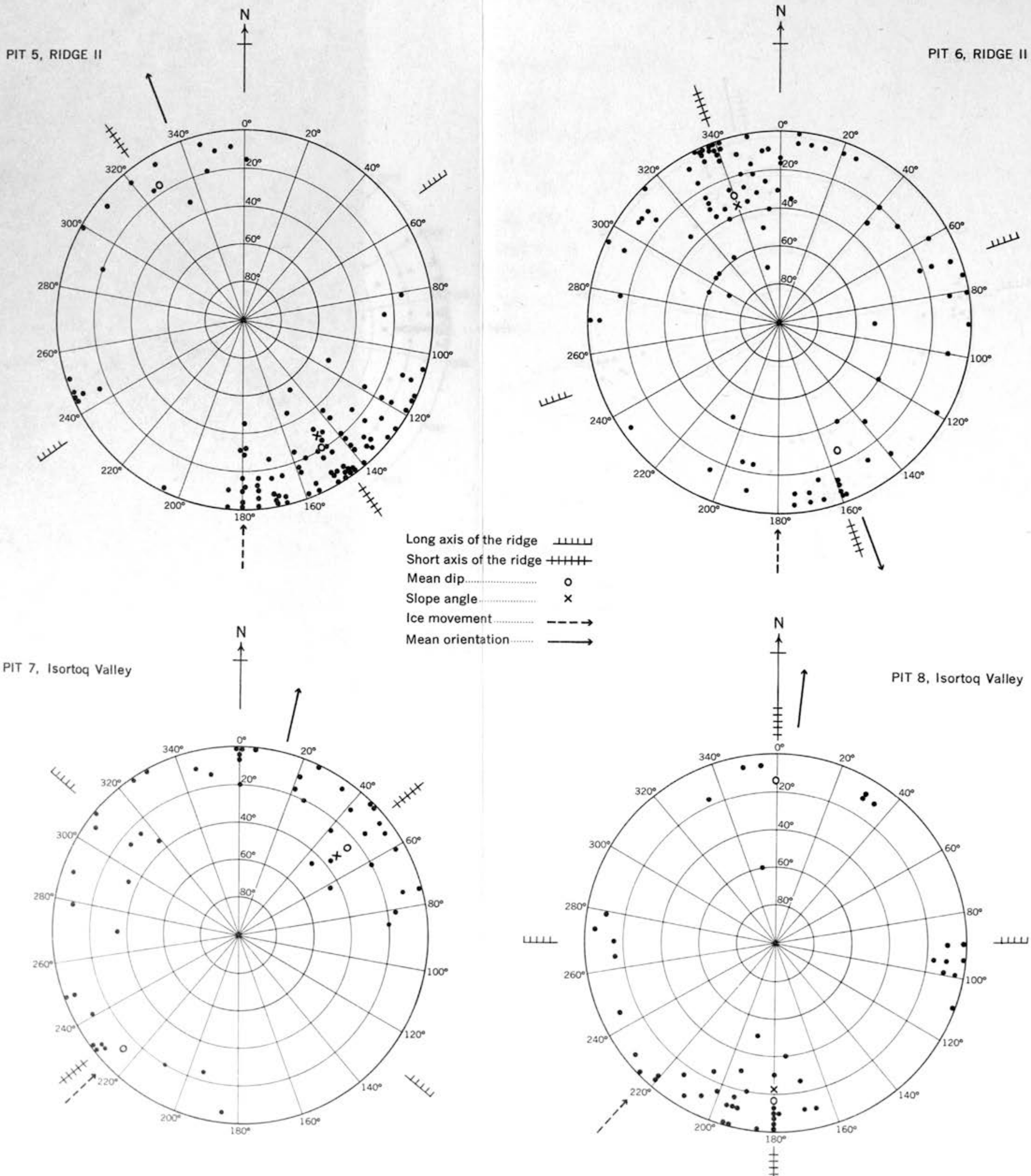


FIGURE 10. Above and on the reverse are shown till-fabric diagrams from the cross-valley moraines in the Isortoq and Rimrock valleys. Fabrics 1 to 6 consist of 100 pebbles; fabrics 7 and 8 of 50 pebbles.


PIT 5, RIDGE II
PIT 6, RIDGE II
PIT 7, Isortoq Valley
PIT 8, Isortoq Valley
N
Long axis of the ridge
Short axis of the ridge
Mean dip
Slope angle
Ice movement
Mean orientation

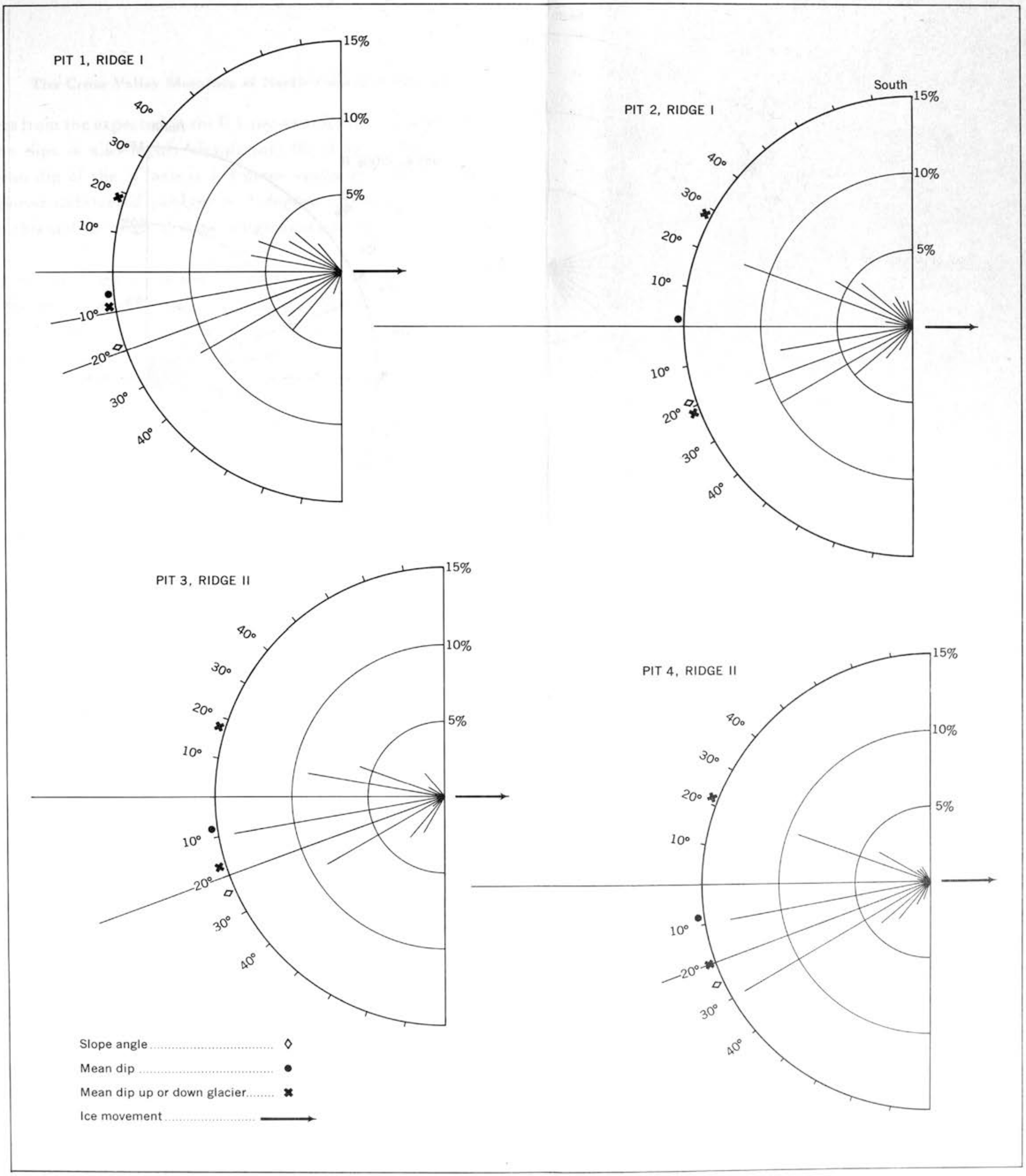
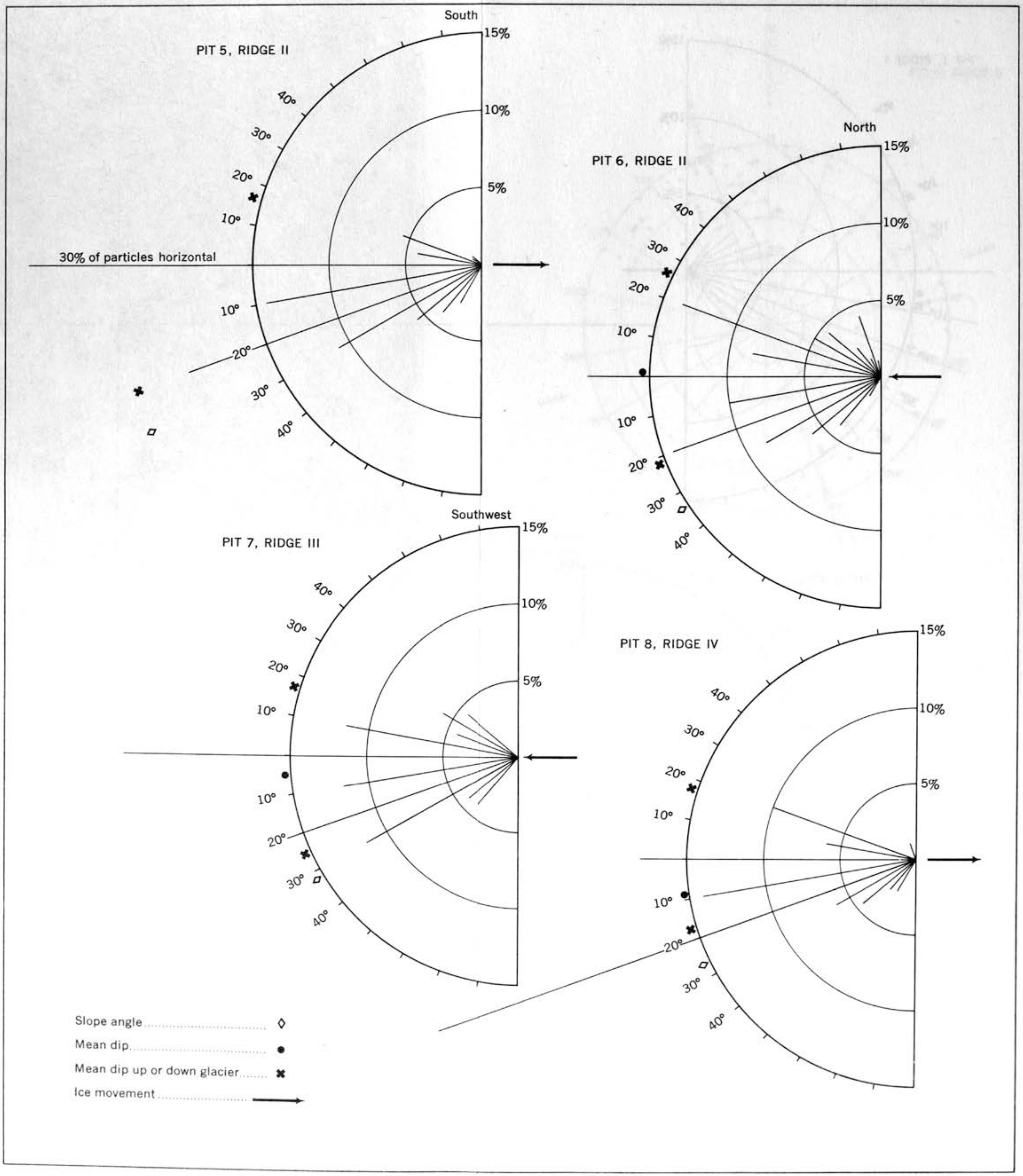


FIGURE 11. Above and on the reverse are shown dip diagrams from till-fabric pits. The half-circle represents a vertical section through each pit and the dips, either upglacier or downglacier, are represented in the same manner as they are classified during the till-fabric analysis. Note especially the horizontal particles and strong maxima about the slope angle.



PIT 5, RIDGE II
South
15%
10%
5%
40°
30°
20°
10°
30% of particles horizontal
10°
20°
30°
40°
PIT 6, RIDGE II
North
15%
10%
5%
40°
30°
20°
10°
10°
20°
30°
40°
PIT 7, RIDGE III
Southwest
15%
10%
5%
40°
30°
20°
10°
10°
20°
30°
40°
PIT 8, RIDGE IV
15%
10%
5%
40°
30°
20°
10°
10°
20°
30°
40°
Slope angle
Mean dip
Mean dip up or down glacier
Ice movement

of the 'a' axis differs from the expected at the 0.1-per-cent level. The observed distribution of the dips is also highly significant: 60 of the pebbles dip upglacier. The mean dip of the 'a' axis is 7 degrees upglacier, whereas the mean dip of upglacier-imbricated pebbles is 9 degrees (Figure 11). The difference between this and the angle of slope is significant at the 0.1-per-cent level (Table 3).

The particles in Pit 1 show a strong orientation at right angles to the long axis of the moraine and nearly parallel the last ice movement (Figure 10). Moreover, they have a strong preferential upglacier plunge with low dips, though the mean upglacier dip is significantly less than the proximal slope angle and the mean dip of the entire fabric is even less obviously related to it.

The discussion so far suggests that the fabric in Pit 1 represents the original position of the pebbles, which are clearly arranged in a well-defined pattern that is diagnostic of the origin of this form. On this premise the till fabrics are used to explain specific characteristics of the cross-valley moraines. The arguments advanced here for the primary nature of the fabric in Pit 1 also apply to the other seven studies.

Pit 2—This pit was located on the lateral slope of a secondary moraine perpendicular to the main ridge. Figure 10 illustrates the differences between the two fabrics. Both have a strong orientation normal to the moraine crest. The mean orientation, N 81°W, does not differ appreciably from that of the short axis of the moraine. The 'a' axis plunge of the pebbles shows no significant preference. The mean dip was 2 degrees to the west. The dispersion of the dips can be seen in Figure 11. If the particles dipping in the direction of the slope are considered, there is no significant difference between the angle of slope and the mean dip; but if the entire fabric is considered, this difference is highly significant. Thirty-five of the stones in Pit 2 were essentially horizontal; only 20 were so in Pit 1.

The structure of Pit 2, therefore, resembles that of Pit 1 but in other ways is distinctive. The complete break between the mean orientation and the direction of glacier movement implies that some other process or processes caused the strong clustering of the 'a' axis at right angles to the crest of the cross-valley moraine.

Results of the till-fabric analysis, Ridge II

Ridge II, in the Rimrock Valley (Andrews, 1963: Figure 7), was studied in detail. Four pits (Figure 12) were used for till-fabric analysis and numerous others for general examination of the till.

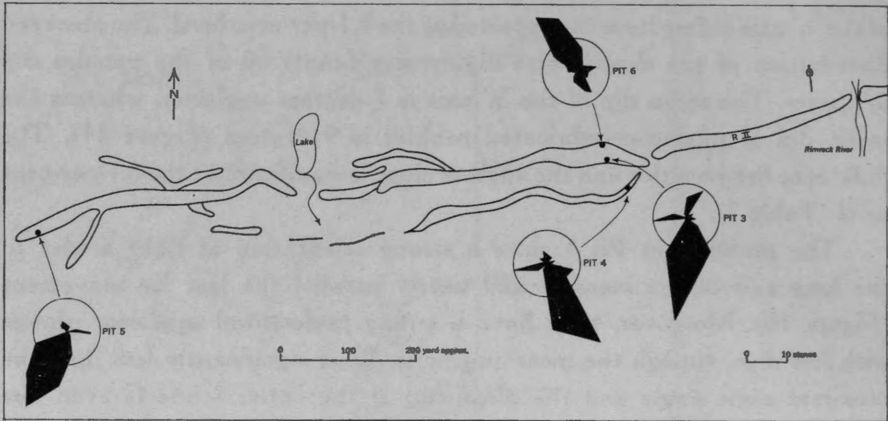


FIGURE 12. A plan sketch of RII with star diagrams of the four pits made in this moraine. Note the relationship between the mode and the known direction of ice movement as indicated by the striations, and the difference between pits on the proximal slope and pits on the distal slope.

Pit 3—This was located on the proximal side of the moraine that was at right angles to the last glacier movement. The proximal slope is 23 degrees. It is probably statistically significant that the mean orientation of the fabric is N 12°E whereas the short-axis direction is N 20°E. The distribution of the dips, of which 48 dip upglacier and 27 lie horizontal, has a 0.1-per-cent level of significance. The mean dip is 7 degrees to the south (upglacier); the mean upglacier dip is 18 degrees and differs from the slope angle at the 5-per-cent level.

In many respects, therefore, the fabric is similar to that in Pit 1, which was in a similar position on a cross-valley moraine. The orientation of the 'a' axes is nearly at right angles to the crest of the moraine but is displaced toward the direction of ice movement. The observed orientation of the long axes differs from the expected at the 0.1-per-cent level, and the clustering of the observations about the mean is very noticeable. In both there is a well-marked secondary maximum at right angles to the mean (Figure 10).

Pit 4—Pit 4 was located on the proximal slope of a secondary ridge (Figure 12). The till in the exposure was more clayey than usual. In the area of Pit 4 the short-axis orientation of the ridge diverges by 40 degrees from the main moraine. The slope of the proximal face is 24 degrees. The mean orientation is N 12°W, which differs at the 5-per-cent level from that of the short axis, and the distribution is non-isotropic. The number of pebbles dipping upglacier is highly significant. The mean dip, 7 degrees upglacier, differs very noticeably from the slope angle, but there is no

Table 3

Results of till-fabric analysis

	1	2	3	4	5	6	7	8	9	10	11	12	(dip) 13	14	(slope) 15	16
Ridge I Pit 1	N100°E	N10°E	100	18°	S–N	N13°E	156	7°U	20	61	9°	19°	0.1%	0.1%	0.1%	—
Pit 2	N	N90°E	100	21°	S–N	N81°W	99	2.1°D	35	35	21°	28°	—	0.1%	—	—
Ridge II Pit 3	N100°E	N20°E	100	23°	S–N	N12°E	103	7°U	27	48	18°	17°	0.1%	0.1%	5.0%	5.0%
Pit 4	N70°E	N20°W	100	24°	S–N	N12°W	78	7°U	30	50	20°	22°	0.1%	0.1%	—	5.0%
Pit 5	N55°E	N37°W	100	25°	S–N	N21°W	73	10°U	30	58	20°	15°	0.1%	0.1%	5.0%	0.1%
Pit 6	S110°E	S20°E	100	34°	S–N	S22°E	67	0.5°U	19	28	22°	26°	—	0.1%	0.1%	—
Ridge III Pit 7	S130°W	S50°W	50	32°	SW–NE	S15°W	20	5°D	13	13	16°	26°	—	5.0%	5.0%	0.1%
Ridge IV Pit 8	N	N90°E	50	24°	SW–NE	N15°E	42	9°D	9	33	17°	17°	0.1%	0.1%	1.0%	—

1. Long-axis orientation of moraine.
2. Short-axis orientation of moraine.
3. Number of stones in till-fabric.
4. Slope angle.
5. Direction of last ice movement.
6. Mean orientation of fabric.
7. Strength of orientation, χ^2.
8. Mean dip: U = upglacier; D = downglacier.
9. Number of horizontal stones (i.e., 5°U to 5°D).
10. Number of stones dipping upglacier.
11. Mean dip upglacier.
12. Mean dip downglacier.
13. χ^2 test of dips in direction of slope.
14. χ^2 test on orientation.
15. t test on slope and dip in slope direction.
16. t test on short-axis orientation and orientation of fabric.

significant difference between the mean upglacier dip and the slope. Thirty of the stones lie horizontal or nearly so (Figure 12, Table 3).

Pits 2 and 4 can be compared, for both are oblique to the predominant east-west trend of the cross-valley moraines. For both there is a strong concentration of readings at right angles to the ridge crest, and this suggests that their orientation bears no relations to the known direction of ice movement. Both fabrics have a mean dip in the slope direction, though the over-all mean is much less. In Pit 4, however, there is a definite upglacier plunge in the fabric. In Pit 2 the dip was at right angles to the glacier movement.

Pit 5—This was the only excavation attempted on the higher, elevated margins of the cross-valley moraines. It was situated on the proximal side of Ridge II (Figure 12), which at this point has a slope of 25 degrees. The short axis of the moraine is N 37°W. There is a highly significant difference between the expected isotropic distribution and the actual plots of the 'a' axis orientation. The mean is N 12°W, which represents a difference at the 0.1-per-cent level from the direction of the short axis. The distribution of the dips is also highly significant, their mean being 10 degrees in the upglacier direction. Fifty-eight of the pebbles dip in this direction. The fact that the upglacier readings have a mean of 20 degrees seems to imply a significant relationship between this mean and the slope angle.

Pit 6—The first pit studied on a distal slope, this was selected because it was opposite Pit 3. The moraine, like most of those studied, is asymmetrical in cross-section, for the distal face slopes at 34 degrees, and the proximal slopes at 23 degrees. It was expected that the till fabric from Pit 5 would help explain the asymmetry of the moraines and would perhaps answer the question posed by Andrews (1963): is the asymmetry a primary effect caused by the original depositional agent, or is it secondary and due to periglacial activity?

The results of the study (Figures 10 and 11) indicate that the spatial position of pebbles on distal slopes is radically different from that on proximal slopes. The mean orientation of the fabric in Pit 6 is S 22°E, and the short-axis direction is S 20°E (the difference in orientation of the short axis between Pits 3 and 6 was caused by the curvature of the moraine crest). The Chi-square test showed that the pattern of the 'a' axes orientations was highly significant but that the distribution of the dips was not significant. The mean dip is 0.5 degrees upglacier, but Figure 11 illustrates the isotropic character of the plunge of the 'a' axis. The fabric appears unaffected by the steepness of the distal slope, and the difference between the slope angle and the mean downglacier dip (in the slope direction) is highly significant. The secondary maximum at 20 degrees might, however, be related to the slope (Figure 11).

The mean orientation of Pit 6 is therefore at right angles to the ridge, but the distribution, even though not isotropic, is decidedly less concentrated about the mean than the fabric in Pit 3. The outstanding characteristic is perhaps the lack of any definite direction of the dips; this is also a feature of the fabric in Pit 2.

Results of the till-fabric analysis, Ridge III

Pit 7—The third cross-valley moraine chosen for study was located near the junction of the Isortoq River and Rockland Brook.* Striations near the Isortoq River indicate that the last ice movement was directed along the axis of the valley toward N 50°E. The majority of the moraines, therefore, lie at right angles to this final movement. The fabric was taken from the distal side of a typical asymmetrical ridge with a slope of 32 degrees.

The mean orientation of the fabric is N 15°E, which, however, does not coincide with any maxima. It represents a highly significant departure from the direction of the short axis, which is very nearly transverse to the striations. The Chi-square test for isotropicity indicated that there was a significant difference between the observed and the expected distributions for the orientation at the 5.0-per-cent level but that the dips were isotropic. The mean dip of the fabric is actually 5 degrees downglacier.

The polar-equidistant diagram shows a dispersed pattern that in some ways compares with that of the Pit 6 fabric, which is also from a distal slope. Both fabrics lack pattern in their long-axial dips, but the orientation of their 'a' axes differs in intensity. The lack of a definite dip preference, however, makes a contrast between these distal fabrics and the proximal fabrics.

Results of the till-fabric analysis, Ridge IV

Pit 8—The fabric in Pit 8 was taken from the proximal side of a moraine near the junction of the Isortoq River and Rockland Brook, immediately northeast of Ridge III. The moraine is about 8 feet high in this sector. The crest strikes N 90°E and the side slopes at 24 degrees. The exposure revealed a sandy till passing into a slightly more clayey till near the base.

*Andrews, 1963: Figure 15 (page 70).

Figure 10 shows that the mean orientation is slightly displaced from the short-axis trend and differs significantly from the direction of ice movement. The fabric has a very strong upglacier plunge (Figure 11). The mean dip is 9 degrees upglacier, whereas the mean upglacier dip is 16 degrees. This divergence indicates a difference at the 1.0-per-cent level between the fabric and the angle of the proximal slope.

Interpretation and comments

The eight till macrofabrics represent only a few of the studies that will have to be made before generalizations can be applied. They do, however, provoke some tentative conclusions and portray a series of definitive characteristics that require comment. In all pits except 5 and 3 the mean downglacier plunge of the 'a' axes is steeper than the upglacier plunge. In all fabrics from moraines lying approximately transverse to the last ice movement, the mean orientation tends to be displaced away from the short-axial trend and toward the direction of this movement; in four cases this had varying degrees of significance. Finally, most fabrics have a second maximum at right angles to the mean orientation.

Statistical tests put the comparison of the salient elements of the fabrics on a firm foundation. The till-fabric diagrams, revealing the spatial positions of particles lying within the cross-valley moraines, are potentially the most powerful means of explaining and interpreting the genesis of these peculiar glacial forms. The well-defined fabric patterns revealed by the studies imply that a mechanical force in some way helped to determine the orientation and imbrication of particles. How this happened is the key to the problem of the moraines. Most attempts to explain stone orientation advance causes connected with the ice itself, such as gliding (Holmes, 1941) or differential shear (Glen, Donner and West, 1957; Harrison, 1957). In general, the papers cited deal with the orientation of particles in ground moraine. A preferred orientation could be produced, however, independent of the ice, and would involve flow within the till, either under pressure or even under gravity. With a flow of this type, the long axis of the particles would become parallel to the flow and dip into the current. This would be their most stable position (Rusnak, 1957). These points should be borne in mind in any discussion of the significance of the fabric studies.

The location of each pit relative to the last recorded direction of ice movement results in a threefold division. There are: first, on proximal slopes, those fabrics that strike approximately at right angles to the glacier movement; second, the fabrics from proximal slopes that lie at a considerable angle away from this movement; and, third, the fabrics taken from the distal slopes of the moraines.

The first group, Pits 1, 3, 5 and 8, have a mean fabric orientation that lies approximately at right angles to the moraine crest and is about parallel to the final ice direction. The distribution of the particles is non-isotropic and clusters closely around the mean. The mean dip is always upglacier, and most pebbles are imbricated in this direction.

In the second group, Pits 2 and 4, the mean orientation is also approximately at right angles to the moraine crest, but this position differs very widely from the direction of striations. The difference implies that the force or forces acting upon the pebbles were independent of either the gliding of stones along the base of the glacier or the deposition of material from a series of shear planes. Another mechanism for the orientation and spatial location of the material is therefore required. Both the fabrics under discussion have a dispersed pattern with strengths of orientation of 99 and 78. The corresponding strengths for the first group are 156 and 103 (Table 3). This pattern is marked in Pit 2, where there is no significant difference between the observed distribution of the dips and the theoretical isotropic distribution. The mean dip in this exposure is downglacier, whereas in Pit 4 the concentration of particles imbricated upglacier is significant at the 0.1-per-cent level.

The third group consists of two samples from the distal slopes of the asymmetrical cross-valley moraines. In both Pit 6 and Pit 7, the mean orientation of the 'a' axes is approximately at right angles to the crests, but there is no statistically preferred direction to the dips. In one, the mean dip is slightly upglacier; in the other it is downglacier. The plunge of the 'a' axes in these fabrics is steep in the direction of the slope (downglacier). The t test suggests that the fabrics have not been produced by secondary periglacial action, but at the same time, all fabrics except those in Pit 2 show maxima at or about the slope angle. The fabrics are primary features of the original deposit. The strengths of orientation—67 and 20—are lower than in all other fabrics.

If all the groups are taken together, it is apparent that basal ice motion did not determine the fabric. In the moraines transverse to this movement there is a predominant upglacier imbrication and a strong, horizontal component. In the ridges at angles to these, the strength of the upglacier dip becomes weaker, and on the distal side there is no preferred dip direction. This information has an important bearing on the origin of the cross-valley moraines.

THE SPACING OF THE CROSS-VALLEY MORAINES

Air photographs along the upper and middle course of the Isortoq River indicate a closer spacing of the cross-valley moraines with increasing distance from the watershed. To verify this, counts were made from the vicinity of the watershed to the junction of the Lewis and Isortoq rivers. Air photographs on a scale of 1:60,000 and enlargements on a scale of 1:30,000 were used. A magnifying glass was also used, with the result that the actual scale from which the determinations were made was approximately 1:5,000 and 1:10,000. Points weer selected at 5-mile intervals along the course of the river, and the cross-valley moraines each 2 miles along a line drawn at a standard distance from the river were counted by two persons separately. In all cases the two estimates were very similar and an accuracy of ± 10 per cent is claimed. During the field season one estimate was checked and the actual field count fell within the limits of error previously established. The data were plotted on a graph (Figure 13), which related the number of moraines in each 2 miles to distance from the watershed. The positive linear correlation is striking.

Four of the selected points stand apart. Observations made at one point showed a group of 20 moraines 8 miles from the Isortoq watershed, whereas in a 2-mile stretch 17 miles from the headwaters of the Rangifer River there are only 11. At the other three, situated in the downstream part of the Isortoq Valley immediately above the Lewis River, observations indicated a sharp decline and a subsequent rise in the number of moraines per unit of distance. The line of least squares was calculated for all points (1) and then for all but these four eccentric points (2) (Figure 13). Finally, a line was drawn by hand through the three points along the lower Isortoq (3), and the equation of y on x was approximated. These three are above the junction of the Isortoq and Lewis rivers and correspond to a change from a proglacial lake at 1,658 feet above sea level to one at about 1,420 feet.

To test the degree of association between the number of moraines and the distance from the watershed, Pearson's product-moment coefficient of correlation, r, was calculated from the data in (1) and (2) (Figure 13). The results show a strong positive correlation between the x and y variables, r being equal to 0.91 and 0.94 respectively; 1.0 would indicate a

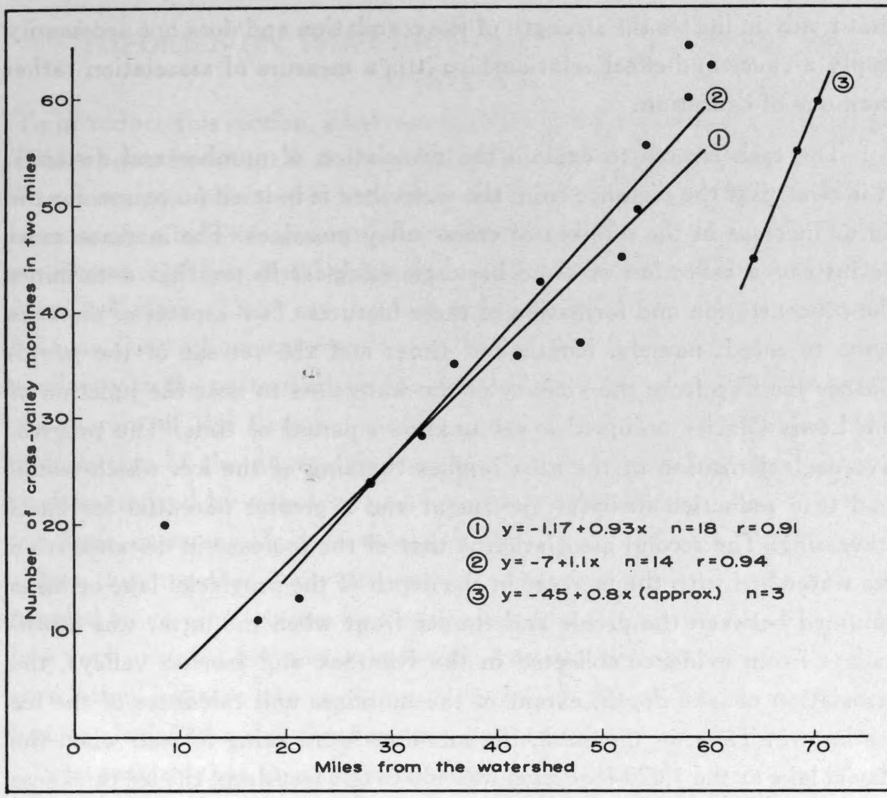


FIGURE 13. A graph relating the number of cross-valley moraines, as determined from air photographs, to distance from the watershed in miles. Lines of least squares have been drawn for (1) all points on the graph, (2) all points less four eccentric points and (3) a line drawn by hand through three of these points which lie below a point where the glacial lake fell by 240 feet. Coefficients of correlation have been calculated for the first two lines

perfect correlation. In other words, it can be said that 83 per cent* and 88 per cent of the variations in the number of cross-valley moraines are accounted for and are directly related to the increase in the distance from the watershed. For associations (1) and (2) (Figure 13), a null hypothesis was established of no correlation between numbers and distance, and this was then tested by the use of the sampling distribution of r. In both cases, the null hypothesis had to be rejected; it was found instead that these two associations were significant at the 1-per-cent level.† It should be stressed

*Determined from 100 r^2.

†Reject the null hypothesis if $r < \frac{-2.58}{\sqrt{n-1}}$ or $r > \frac{+2.58}{\sqrt{n-1}}$ where n equals the number of associations used in the calculation of y and x.

that r only indicates the strength of the correlation and does not necessarily imply a cause-and-effect relationship; it is a measure of association rather than one of causation.

The task is now to explain the association of number and distance. It is clear that the distance from the watershed is in itself no reason for the linear increase in the number of cross-valley moraines. The increase must be instead a reflection of some basic glaciological factor that determines the concentration and formation of these features. Two aspects of distance come to mind, namely, length and time; and the retreat of the proto-Barnes Ice Cap from the vicinity of the watershed to near the junction of the Lewis Glacier occupied a yet unknown period of time. The progressive deglacierization of the area implies thinning of the ice, which would lead to a reduction in basal movement and a greater potential for basal crevassing. The second association is that of the increase in distance from the watershed with the increase in the depth of the proglacial lake or lakes dammed between the divide and the ice front when the latter was downvalley. From evidence collected in the Rimrock and Isortoq valleys, the association of lake depth, extent of the moraines and thickness of the ice are known. Thus, in this area, the moraines were being formed when the glacial lake at the 1,820-foot level was 400 to 600 feet deep, the ice thickness and the lake depth being about the same. It seems, therefore, that the downvalley increase in water depth would lead to an increase in hydrostatic pressure that would cause seepage and buoyancy of the ice. Thus the number of moraines increases.

This hypothesis receives additional support from the location of the three eccentric points north of the Lewis River. Field studies indicate that in their vicinity the proglacial lake fell from the 1,658-foot to the 1,420-foot level. Thus there was a sudden lowering of lake level as the snout of the receding glacier exposed a lower spillway, and air photographs indicate a change in the lake level, which controlled moraine formation in this area. The moraines in the Isortoq Valley show a sudden fall in number per unit area accompanied by a gradual increase farther downstream. A line through the corresponding points (3) is nearly parallel to the lines of least squares for (1) and (2).

Further studies in selected field areas should permit construction of a formula to relate the number of moraines to water depth.

THEORIES ON THE ORIGIN OF THE CROSS-VALLEY MORAINES

To introduce this section, what was said in the companion paper (Andrews, 1963) about the salient features of the cross-valley moraines will be repeated. The moraines increase in height toward the valley bottoms, possibly because of an increase in material in a downslope direction; they are notably asymmetrical, their distal slope being some 10 degrees steeper than their proximal slope. They can be distinguished from normal end moraines because they are concave to the former ice front, showing a remarkable similarity to the pattern of the present-day calving bays established around the margin of the Barnes Ice Cap, notably in Conn and Nivalis lakes. The pattern of the ridges, however, is not simply linear or continuous: it is characterized by tributary and distributary ridges that enter and leave the main moraine, which in many places forms a series of slightly offset ridges that together form the broad arcuate pattern. The moraines are covered to varying degrees by coarse angular boulders. Many of these are in a very unstable position, some perched on end. Finally, the 100-per-cent correlation between the occurrence of the moraines and the presence of former glacial-lake shorelines cannot be overstressed. This and the broad lobate pattern that is concave toward the former glacier centre imply that their formation was connected with the retreat of an ice cap behind a series of proglacial lakes.

The five hypotheses of the origin of the cross-valley moraines

In this section it is proposed to re-examine the validity of each of the hypotheses presented in the previous paper (Andrews, 1963) in the light of the foregoing quantitative data.

Hypothesis I—The proposal that the ridges are subglacially engorged eskers, though it agrees with a superficial visual impression, has very little to recommend it. Although the ridges have a certain sinuosity, they are composed of till that has the mean orientation of the included particles lying at right angles to the ridge crest. No fluvial or glacio-fluvial material was noticed in any of the exposures except those overlain by a later till, and the only attribute that could be related to water action is the increase in the negative skewness of the grain-size distribution with increasing proximity to the valley bottom. The percentage of silt and clay, however, is approximately similar. This hypothesis can be discounted.

Hypothesis II—The second hypothesis is that they are frontal sublacustrine forms. They could be formed in one of two ways: either by the accumulation of material from the face of the ice cliff or by being squeezed up into a ridge at the base of the cliff. In the first alternative, the material might originate in shear planes and would be exposed by calving and ablation of the ice front. The material would be released and would sink at varying rates. Deposits of this type would be coarse-grained and roughly sorted. Material in the pebble range would fall through the lake waters and would not acquire a preferred orientation except possibly when it came into contact with the ground. It would sink heavy end down and, on touching, would pivot and take up a position either parallel to the surface configuration or at right angles to it. It should dip at an angle parallel with that upon which it finally came to rest. The pebbles would not show the patterns that are present in the cross-valley moraines, and the tills should show some sorting. The second alternative requires more careful appraisal and is linked with hypotheses IV and V, those concerning push moraines and basal squeezing. The suggested origin is similar to that upheld by Hoppe (1959) for De Geer moraines. The till fabrics are considered as supporting a squeeze mechanism, but whether this would occur at the actual ice front is doubtful. The crevasse pattern behind the calving bays of Conn and Nivalis lakes indicates that the glacier is being lifted and that its base is not in contact with the ground moraine. Further back, the ice would exert static pressure on the ground moraine. This is discussed in greater detail in the appropriate section.

Hypothesis III—The third hypothesis, that of deposition in shallow water along shear planes, is not applicable to the area of the field studies because here the proglacial lakes were 400 feet or more deep. In the watershed area, however, it is a feasible explanation, and the present-day occurrence of cross-valley moraines, seemingly being formed by this process immediately south of Bieler Lake, indicates that field work is necessary there.

Hypothesis IV—The marked asymmetry of the moraines prompts the suggestion that they are a form of sublacustrine push moraine, whose mode of formation is similar to that assumed as the second alternative for hypothesis II. Analysis of the till-fabric diagrams shows that the asymmetry is a primary feature, a reflection of a difference in the internal structure. A push, however, would produce a fabric pattern different from that observed. The forward motion of the ice against the material would make the fabric orientation primarily parallel to the ridge, which is at right angles to the observed pattern. The situation is analogous to that reported by Lundqvist (1949), who found that at the front of solifluction lobes the pebbles turned at right angles to the flow. The push mechanism, although it accounts for the cross-profile of the moraines, could not have caused the particular till-fabric pattern nor the distributary and tributary arrangement of associated minor ridges. Thus, though basal movement of the glacier might have some bearing on the formation, it can be dismissed as the primary process.

Hypothesis V—The final hypothesis is that the moraines were formed by the squeezing of water-soaked ground moraine into a series of basal crevasses behind the ice front. Before this can be examined further, it is necessary to establish that the ground moraine beneath the ice front was in an unfrozen state and was capable of being forced into crevasses by the weight of the overlying ice. It is not known for certain when deglacierization of the upper Isortoq Valley began, but it might have been 3,000 to 5,000 years ago (Ives and Andrews, 1963), and the mean annual temperature might well have been similar to that prevailing today. The present mean annual temperature at 3,600 feet above sea level on the ice cap (Sagar, 1963: personal communication) is −14°C. There seems little doubt that the Greenland (Robins, 1955) and Antarctic ice caps are cold-based, with subzero temperatures at the ice/ground contact and Weertman (1961) has argued that at least the marginal zone of the Barnes Ice Cap may also be frozen to its bed. Mathews and Mackay (1960) point out that, if preglacial temperatures approximated those of today in the Mackenzie Delta (−10°C) and if the area were then overriden by a cold-based glacier, permafrost 100 to 200 m thick would still be present after 10,000 years. It is probable that a thick layer of permafrost was present in north-central Baffin Island before the last glaciation. Terzaghi (1952) has shown that the decrease in thickness of permafrost from basal melting due to the geothermal influx is relatively slow, amounting to 2 cm a year or less. Radiocarbon dates from a peat deposit buried beneath glacial materials 10 miles west of the Barnes Ice Cap indicate that the last glacial phase began less than 25,000 years ago* and lasted perhaps 20,000 years in the interior areas.

*Peat, interbedded with silt and overlain by glacial deposits, has a minimum thickness of 15 feet in the Isortoq Valley. A sample from the top of the section (J.T.A. 62-IP; I-731) has been dated by Isotopes Incorporated as 24,600 ± 500 years old. Radiocarbon testing shows a second sample from the lowest accessible part of the section (15 feet below I-731) to be 30,000 ± 1,200 years old. (J.T.A. 62/2P; I-839.)

If permafrost existed on Baffin Island to a depth comparable with that at Resolute, Cornwallis Island, it probably survived beneath the ice until deglacierization began. Thus it is important to estimate the basal temperatures of the retreating ice cap because, if the basal-squeeze hypothesis is correct, it must first be possible to define the method by which the ground moraine reached a suitable physical state.

With a series of parameters defined, it is possible to take the examination still further: it is postulated that temperatures during deglacierization were similar to those of today (−14°C at 3,600 feet above sea level) and that the retreat westward from the watershed was accompanied by the formation of proglacial lakes. At the 1,820-foot lake phase in the Rimrock Valley the water was 400 feet deep and the adjacent ice 400 to 450 feet thick. Taking into account the effect of friction from glacier movement, Ward has calculated that the temperature gradient through ice in the lower part of the ablation zone is about 1°C per 22 m (Ward, 1952). When Ward's result is applied—and this result is a maximum for the thermal gradient—the basal temperature in the Rimrock Valley is found to have been −3°C to −6°C, depending upon allowance for the effect of altitudinal difference on mean annual air temperature. The static pressure exerted on the floor by the glacier would be roughly 12 atmospheres and consequently the ice would not be at the pressure-melting point. Thus the ground moraine would remain frozen.

What mechanism or mechanisms would produce a rise in the temperature of the ground moraine immediately behind the ice front? Two possibilities exist: either the ice is buoyed up by the lake, thus allowing water to penetrate under its sole and eventually to thaw the ground, or water percolates under the glacier foot by seepage pressure. The first mechanism was proposed by Thorarinsson (1939) to explain the drainage of certain ice-dammed lakes in Iceland. When the water depth equalled 9/10 of the ice thickness, the ice would be lifted and the lake could drain underneath. Glen (1954) and Carey and Ahmad (1961) have pointed out drawbacks. The principal objection is that in most cases the glacier would be frozen to its base and would require a greater depth of water to lift it. Before the glacier could be lifted, water would begin to percolate beneath its sole under the influence of seepage pressure. This process can be explained as follows (Glen, 1954): the hydrostatic pressure of water at a point z_w below the surface of a lake will be $p_w g z_w$ where p_w is the density of water and g is the acceleration due to gravity; this is the normal stress that acts on the ice front. The vertical compressive stress component (static pressure) acting on the ice at this point will be $p_i g\ z_i$ where p_i is the density of the ice and z_i the depth below the ice surface. If z_w is equal in depth to z_i, the horizontal force is greater than the vertical; if it is great enough to cause flow, water will spread under the base of the glacier owing to the excess hydrostatic pressure component. For the middle Rimrock Valley it is possible to estimate with fair precision that the hydrostatic pressure at the base of the ice cliff would be 13 kg/cm^2 and that the vertical pressure component would be 11.7 kg/cm^2. The extent to which the hydrostatic pressure in the water at depth z_w is greater than the compressive vertical stress component is calculated as follows:

$$\Delta p = (p_w - p_i)\ gz$$

z equalling 131 m in the present case. The effective stress at this depth is therefore obtained from the equation Δ p = 1.4 bars, and there will be shear stresses of the order of Δ p/2 on planes 45 degrees to the horizontal. The conditions thus ascertained are close to those necessary to establish flow within the ice. But even before the shear stress was sufficient to cause flow in the ice, the excessive hydrostatic pressure would lead to a slow seepage under the glacier base. The first effect would be to raise ground temperatures. Glen (1954) concludes by remarking that this effect will occur whenever the depth of water at an ice face is sufficient. The seepage of lake water with a temperature of about +1°C would result in the thawing of the underlying ground moraine. This would lead to a lack of adhesion between the moraine and the glacier, and the ice would become buoyant. The buoyancy in turn would result in crevassing of the bottom and surface. Assumed that 3 m of permafrost existed beneath the ice, it would require 1.6 × 10^5 litres of water at 1°C to melt the ground ice.* In the actual vicinity of the lake the basal temperatures will be determined by the rate of calving relative to the seepage flow; if the retreat is slow, as it seems to be today around the ice cap, the ground temperatures near the ice cliff will be close to or above 0°C.

Carey and Ahmad (1961) have drawn several interesting comparisons between cold- and wet-based glaciers. They point out that in the former the entire weight of the ice rests on the ground while in the latter the weight is supported by interstitial meltwater. Thus at the point of buoyancy

*Assuming a porosity for the material of 33 per cent, a basal temperature of −6°C and an equal heat loss to the glacier.

there is a hinge line, where the glacier can bear down and squeeze the water-soaked ground moraine into a series of basal crevasses. If the ice is 400 feet (131 m) thick, the static pressure on the ground moraine will be 13.0 k/cm², which is 10 times what Terzaghi and Peck (1948) give as the maximum bearing pressure allowable for soft clay and wet sand. This mechanism, therefore, seems realistic. A flow diagram for seepage water shows that behind the ice front there is a tendency for the water to rise; when it does, it lifts the soil grains because of the friction between the water and the grains (Terzaghi and Peck, 1948) and so reduces the internal cohesion of the material. If, however, the hydraulic gradient i becomes equal to

$$i_c = \frac{p_s}{p_w}$$

i_c becomes the critical hydraulic gradient because the average seepage pressure becomes equal to the submerged weight of the soil p_s. A weight resting on this material would sink as if in a liquid. The cross-valley moraines are probably formed by this mechanism—the thawing of the ground moraine by seepage water and the squeezing of water-soaked material into basal crevasses.

Ward (1952) assumed that the Barnes Ice Cap was frozen to its base in the vicinity of Generator Lake, but he noted that a stream disappeared beneath the ice some 600 m from the ice cliff. A study of air photographs also indicated a similar phenomenon at Conn Lake, where meltwaters disappear beneath the ice surface 3 miles behind the ice front. Glen (1954) uses a mechanism similar to the one just described to explain how meltwater streams penetrate to the base of a glacier. The initial penetration is along crevasse lines. The possibility that the streams find their way to the area where the cross-valley moraines are formed is important because of the relationship between the central kames and the moraines. Examination of the materials indicates that two dissimilar processes were in operation, one connected with the deposition of water-laid sands and gravels, the other with formation of the moraines. In places, the two processes seem to have been synchronous, but in one exposure it was apparent that the moraines were the older of the two forms.

It has been emphasized that the curvature of the calving bays is similar to the broad lobate pattern of the moraines and that the general crevasse pattern behind the ice front bears many similarities to the ridge pattern.

From a mechanical viewpoint it seems that the basal-squeeze hypothesis is applicable: the method allows for the thawing of the moraine, the formation of crevasses and the reduction in the strength of the tills. It is now proposed to examine the data shown in the till-fabric diagrams and other data to ascertain whether the field evidence supports or contradicts the hypothesis. Several factors support it. The unstable position of the angular surficial boulder cover suggests that it dropped onto the moraines and is not a primary feature. This would imply that ice covered the ridges even after their initial formation and that they are decidedly a subglacial form. The boulders were probably an englacial or basal load. All the evidence, including temperatures at the base of existing ice caps and the nature of the fragments in the ridges, indicates that the till was not transported far. As the ground temperatures rose toward the pressure-melting point, the interstitial ice would be replaced by meltwater and the till would separate from the glacier.

It has been shown that the static pressure at the base of the glacier would have exceeded the bearing strength of clay and wet sand. The data used were for the middle Rimrock Valley, but they apply even more directly to the middle Isortoq, where ice thickness and water depth were both greater. The bearing strength of the soil is even further reduced in areas where the seepage is directed toward the surface. It is suggested that the actual formation of the cross-valley moraines occurs when the critical hydraulic gradient is reached. If the base of the ice were fractured, the ice would settle and the till, which would flow as a liquid, would be forced into the crevasses. The tills should then show fabric patterns consistent with movement under liquid flow; they do reveal these characteristics. The pressure would result in an upglacier-to-downglacier flow that would bear no relationship to the ice movement but would be controlled by the point of origin of the pressure. This would vary but would be related to the crevasse pattern. The fabrics from the proximal slopes all have maximum orientation at right angles to the ridge crest, although the orientation is often displaced toward the centre of the valley. The fabrics also show a strong statistical tendency to be imbricated upglacier, which indicates flow from this direction (Rusnak, 1957). On the distal slopes it appears that the flow 'tumbled' and was no longer controlled. Only in this way can the lack of a clear dip pattern be explained. Perhaps material flowed into a crevasse and was forced to tumble down by the retaining downglacier crevasse wall. This could be taken as the cause of the asymmetry of the cross-valley moraines; the steep distal slope then becomes an ice-contact slope.

The exposure on the south side of the Isortoq River (Figure 7) can also be used as supporting evidence, though here the conditions are different. The exposure shows an upper till bed with arched bands leading toward the crest of the ridge. These structures could be caused either by the release of the containing pressure or by the response of the flow structure to frost or other agents. The structure of this cross-valley moraine can be compared with the fabric data. The moraine has an upglacier imbrication on its proximal slope and a downglacier dip on the distal slope; the mechanism seems to be nearer that suggested by Hoppe (1952), in which the pressure is equal on either side of the crevasse.

The origin of the central kames has to be linked to that of the cross-valley moraines even though it is certain that the formation of the two forms is not fully synchronous. The key to the problem lies in the comments of Ward (1952) that water appears to penetrate beneath the ice surface in front of Generator Lake and in the disappearance of streams behind Conn and Nivalis lakes. It is proposed that the kames are formed at or near the immediate ice edge. They represent sorted water deposits and probably form where moulins and crevasses reach the subglacial surface. Many of the kames are typically conical, thus being suggestive of deposition by falling water. The occurrence of regular silt and sand layers seems to indicate alternating summer and winter deposits, which in turn imply that a water table of some description existed. The central kames probably represent deposition over a number of years.

Finally it is worth recalling that the change in the linear spacing of the cross-valley moraines near the junction of the Rimrock and Isortoq valleys occurs at a point where the level of the proglacial lake fell 240 feet. Because of this, fewer moraines were formed, but as the ice front retreated downvalley, the depth of the lake would automatically increase and so likewise would the number of cross-valley moraines.

Table 4 provides the first approximation on the relation of the moraines to the lake depth at the time of their formation. On the assumption that z_w equalled z_i the effective stress exercised by the hydraulic pressure at the base of the ice has been calculated (see page 119). The altitudes of the former lake shorelines and the valley floor are taken from topographical maps prepared at 1:50,000 with a 25-foot contour interval. The figures for the lake depths are considered accurate to ± 25 feet (Figure 1). The number of moraines in 2 miles has also been included in Table 4.

Table 4

*Relationship of moraines to lake depth at the time of formation**

Location	Elevation of lake shoreline (feet)	Elevation of valley bottom (feet)	Lake depth (feet)	Δ p (bars)	Number of moraines per 2 miles
1	2,075	2,025	50	0.15	40
2	2,075	1,825	250	0.76	60
3	2,000	1,875	125	0.33	18
4	2,000	1,875	125	0.33	26
5	1,875	1,725	150	0.47	24
6	1,875	1,600	275	0.78	28
7	1,850	1,300	550	1.7	56
8	1,650	1,200	450	1.4	60
9	1,820	1,400	420	1.3	62
10	1,650	1,300	350	1.1	—
11	1,650	1,100	550	1.7	55
12	1,420	700	720	2.2	60

*See Figures 1 and 14.

Only the highest shoreline in each area was considered. Figure 14 shows the relation between the effective stress and the number of moraines per 2 miles. The coefficient of correlation, r, indicates a positive correlation with $r = 0.74$; thus 55 per cent of the variation of x is associated with the variation in the effective stress. This correlation is lower than that obtained in the earlier analysis (Figure 13), and the reason is the inclusion of two sets of data from Rogen Valley, where the values of Δ p were low in comparison with the large number of cross-valley moraines. The association is significant at the 5.0-per-cent level, even with these data included. If, however, they are excluded from the calculations, r equals 0.94, and 90 per cent of the variation in the number of moraines is associated with an increase in the effective stress. It is interesting to observe that in all cases but one, $\Delta p/2$ is less than 1 bar, the limiting condition for ice flow. It seems either that limited flow occurs before this limit is reached or that the effective hydrostatic pressure is sufficient to cause seepage under the glacier. Why the moraines in the Rogen Valley have such significant development while the effective stress is low, is difficult to explain. The very high degree of correlation obtained from the Isortoq Valley compares well with the earlier values obtained there from the number of moraines and the distance

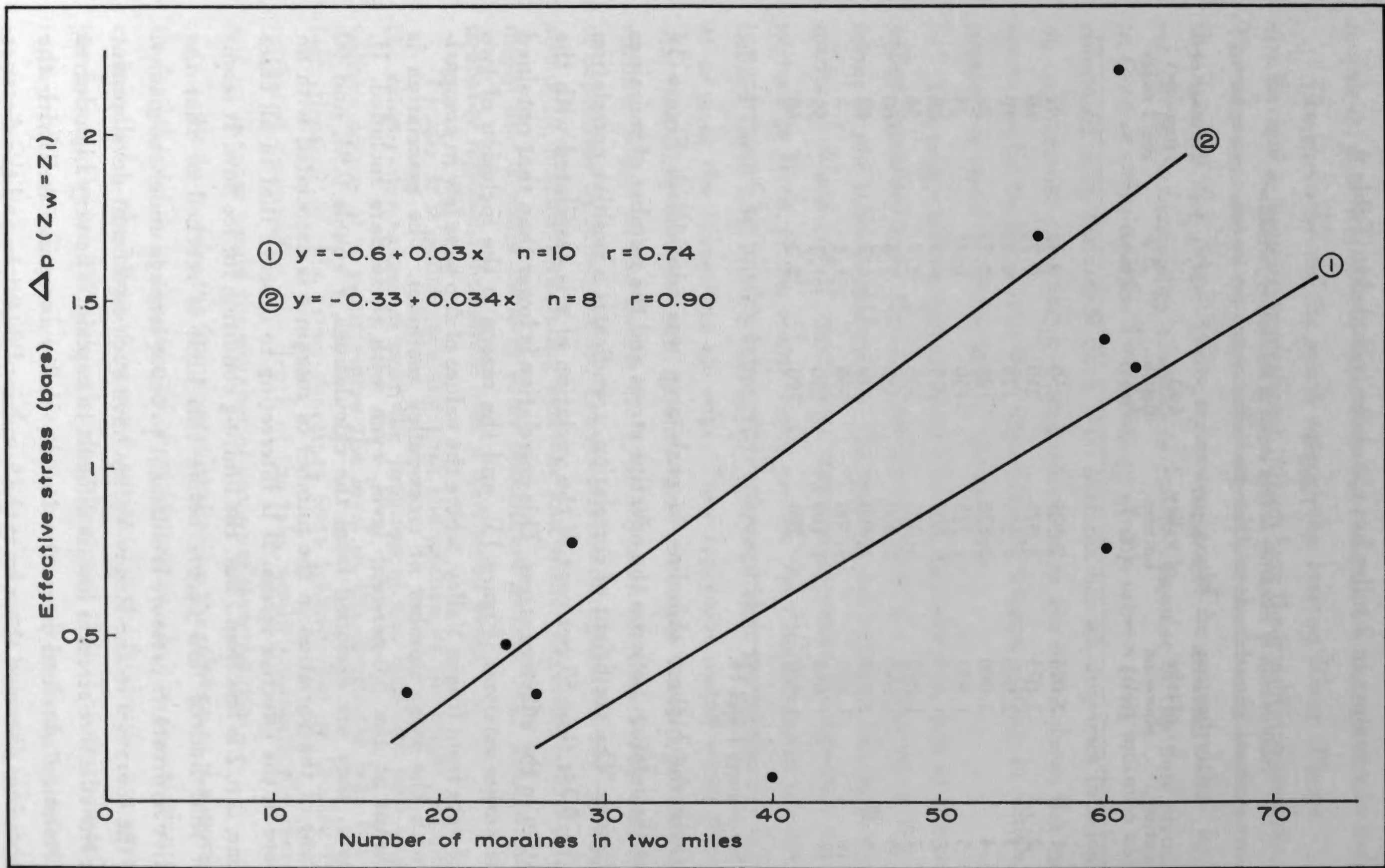


FIGURE 14. A graph relating the number of moraines per 2 miles to the effective stress exercised at the base of a glacier, it being assumed that Z_w, the depth of the glacial lake, equals Z_I, the thickness of the ice at its front. Lines of least squares for these data have been calculated and the coefficients of correlation determined.

from the watershed. Thus the degree of correlation is related to the increase in water depth and the increase in Δ p, the effective stress.

These statements are based primarily on the study of good-quality air photographs and topographical maps. The system of sampling the numbers of cross-valley moraines was established on an objective basis, but it must be emphasized that any sampling system can create or obscure other pertinent details. Further research in other areas where cross-valley moraines occur is still necessary. Indeed, further studies are planned on these and other cold-glacier morphological features about the margin of the Barnes Ice Cap. It is hoped that they will assist in the general interpretation of Pleistocene glacial forms.

RELATION OF THEORIES FROM OTHER STUDIES

Hoppe (1957) discussed the origin of washboard, or De Geer, moraines and noted that the preferred orientation of the pebbles bore no relation to the former direction of ice movement. In this and a subsequent paper (Hoppe, 1959) a theory of formation is outlined similar to that now proposed for the cross-valley moraines of north-central Baffin Island. According to Hoppe, the De Geer moraines were formed at or near a steep ice front that was calving into the sea. The till flowed when the hydraulic gradient reached a critical value. Hoppe envisaged a higher hydrostatic head in the glacier than that produced by the sea so that flow would be directed toward the ice front. The excess pressure would cause water to seep through the till. Abrupt shortening of the ice front by calving would lead to an increase in the hydraulic gradient, and flow would be induced.

These proposals were made before the work on the cross-valley moraines was undertaken, and by elimination a similar origin can be envisaged for the De Geer and cross-valley moraines, with some differences. In a cold arctic glacier it is difficult to establish conditions under which the water pressure within the ice is much greater than that of the proglacial lake. Even the disappearance of one or two streams behind the ice cliff cannot be taken as an indication that a glacial water table exists, especially when theoretical considerations indicate how these meltstreams can find their way to the glacier base. Since the initial loci of these moulins are likely to be a crevasse system and since they probably will not constitute such a system unless the temperature of the ground moraine is raised to the melting point, it is certain that the initial conditions must include these factors. The only condition under which this inclusion can occur is seepage of water under the glacier due to the excess pressure of the frontal water body. Once the ground has thawed, it becomes possible for the ice cliff to float if there is sufficient water depth.

The essential difference between temperate and arctic glacial conditions is that in the former the seepage pressure is directed toward the ice front under the glacier while in the latter it is directed away from this ice front. It is possible that at a later date, if enough meltwater penetrates to the base and through the ice, the seepage conditions will be reversed and the situation will become similar to that described by Hoppe (1957). Behind the Conn Lake ice cliff the meltwater streams disappear at 2,300 feet, whereas the elevation of the lake is 1,820 feet above sea level. There is an effective pressure difference of 13.3 kg/cm^2 between these two points. In Nivalis Lake the meltwaters disappear only half a mile behind the ice cliff. But how far does the water penetrate the ice, and is enough meltwater present to cause a seepage flow toward the ice?

In Canada as early as 1936, Mawdsley noted the relation between linear till ridges and former proglacial lakes in the Opawica-Chibougamau area of Quebec. His description of the ridges is essentially similar to that of the cross-valley moraines in the Rimrock Valley, but the till-fabric patterns support a pressure hypothesis whereas Mawdsley suggested that the morainic material might have been washed into a system of cracks and fissures. Elson (1957) suggested that a series of parallel, discontinuous till ridges (washboard moraines) in Manitoba was formed by the lodgment of till along a junction between active and stagnant ice. Till-fabric studies indicated a preferred orientation parallel to the ice motion and not perpendicular to ridge crests. The washboard moraines of Mawdsley appear similar to the cross-valley moraines, but those of Elson were probably formed by a different mechanism.

CONCLUSIONS

The cross-valley moraines are formed by the squeezing of water-soaked ground moraine into basal crevasses behind a proglacial lake. This conclusion is based only on the first year of quantitative study, but an analysis made in 1962 of till fabrics from another area supported it. In Baffin Island there is clearly a unique opportunity to relate process to morphology. Cross-valley moraines, revealed by a drop in lake level, appear to be forming in Generator Lake and in a small water body south of Bieler Lake. It would be interesting, and is indeed vital to further studies, to know whether cross-valley moraines are being formed under the ice cap at Conn, Bieler and Nivalis lakes today. It would be necessary to examine the drainage areas behind the present ice cliffs and to ascertain the temperature conditions at the base of the ice and the movement of meltwater through the ice. If, as has been suggested, the central kames are either younger than the cross-valley moraines or contemporaneous with them, the till must have been in a suitable condition to flow before the penetration of surface streams.

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COLOR AND DESIGN IN THE BRITISH COLUMBIA AND MANITOBA ATLASES AND THE ATLAS OF CANADA

Gerald Fremlin

Abstract: Color and design characteristics of maps in three Canadian atlases are analyzed by identifying visual phenomena on the maps and by the use of the Munsell color system. The method of analysis may, with development, make it possible to improve the terms of discussion of map design.

Résumé: L'auteur analyse les caractéristiques des couleurs et de la présentation de trois atlas publiés au Canada en identifiant les phénomènes visuels sur les cartes et en recourant au procédé chromatique de Munsell. Une fois perfectionné, ce procédé d'analyse pourrait permettre d'améliorer la présentation visuelle des cartes.

INTRODUCTION

The symbolism used on maps is highly standarized, but the effectiveness of different maps varies a great deal. Frequently the legibility of individual symbols, such as they appear in the legend, is not the factor that makes the difference between an effective and a less effective map. From this it is evident that legibility and cognition, by means of which symbols are meaningful, are not the only factors affecting communication by visual media. In contrast to other graphic arts, cartography has depended heavily on cognitive symbols to attain communication, and relatively little systematic consideration has been given to the non-cognitive factors. Advertising is clearly very dependent on these factors in communication, and the many different type faces used in typography, differing is design but not in cognitive function, may be considered as evidence of the importance of non-cognitive factors. The control of these to attain specific purposes in communication by visual media is here called 'design.'

The body of this paper consists of notes taken while preparing "An Analysis of Canada's Provincial Atlases" (Nicholson and Fremlin, 1963). This circumstance accounts for the paper's greater attention to the provincial atlases (*British Columbia Atlas of Resources*, 1956 and *Economic Atlas of Manitoba*, 1960) than to the *Atlas of Canada* (1957). There is no attempt at continuity between the notes nor at development of a theme or theory. The approach is that of phenomenological observation guided by identifications of visual phenomena given in the literature of experimental psychology. Although this approach can hardly be said to give a wholly objective assessment of the efficiency of the maps, it does get away from the subjectivity of 'taste.' The approach is susceptible of development, and it seems possible that with observations and terminology borrowed from experimental psychology a good deal could be done to improve discussion of map design.

Although map design, in the sense used here, has received little systematic study, it is axiomatic that design must have at least two goals: (1) to create an attitude favorable to the map regardless of its particular subject material; (2) to supplement and support the communicative powers of cognitive symbols. The first may be thought of as a matter of "opening the channels of communication by pleasing the eye"; the second as a matter of visual efficiency, assuming the symbolic conventions to be understandable. The aesthetic qualities and the strictly visual qualities are, of course, not wholly separable, since they obviously affect each other. In the present state of knowledge aesthetic judgment is notoriously unobjective, although recently, by the device of the 'sematic differential,' Osgood (1957) has approached a solution of this problem. Judgment of visual efficiency must ultimately be based on what is known of visual perception, on which there is a large body of psychological literature with great relevance to cartography. The findings, however, have made almost no entry into cartographical literature.

In the following notes no attempt is made to assess the aesthetic factor. Some of the measurable color characteristics of three representative maps are compared, and the discussion is otherwise directed to factors of visual efficiency on particular maps. Some additional comments on miscellaneous visual phenomena of interest in cartography are included.

COLOR

An exhaustive analysis of color in the Canadian atlases is not feasible for this paper; and no analysis, however exhaustive, would adequately convey the over-all color effects as they meet the eye. Among the three atlases there are nevertheless distinctive differences in color treatment, the gross characteristics of which may be pointed out. To summarize, it may be said that a 'bold' appearance is characteristic of about half the plates in the British Columbia atlas, pastel effects are typical of the Manitoba atlas, and pale pastels are characteristic of the *Atlas of Canada*. The geology maps in the provincial atlases and Plate 52, "Aboriginal Population," in the national atlas may be considered as typifying the differences in color use, and have therefore been chosen for analysis. The criterion for selection of the maps was the general similarity in the disposition and relative size of color areas. The analysis was made with the *Munsell Book of Color* (1929). The results are represented diagrammatically as Figures 1, 2 and 3. A brief description of the Munsell color system is given in the Appendix.

The chief conclusion of the analysis is that the difference in the color effects among the maps chosen is to be found in the values and saturations of the colors that occupy the major areas. In the British Columbia map, four of the five colors that occupy these areas have saturations of 6, 8, 9

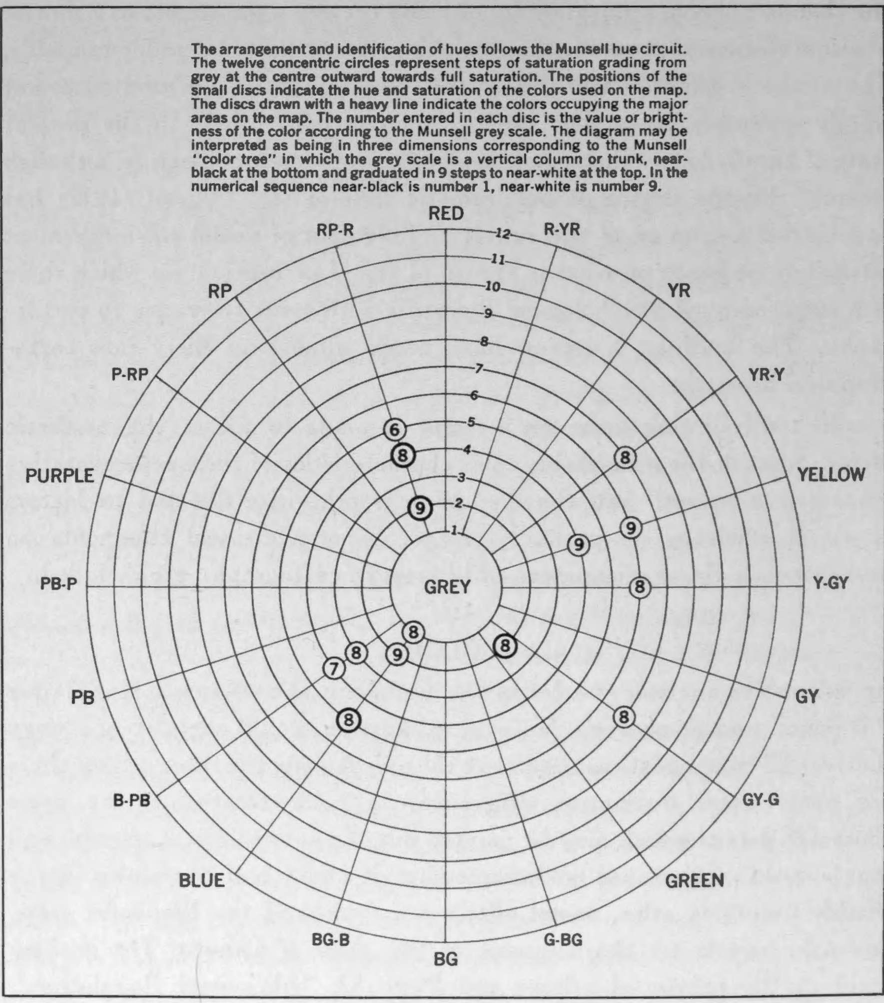

FIGURE 1. Color characteristics, Plate 4, *Economic Atlas of Manitoba.*

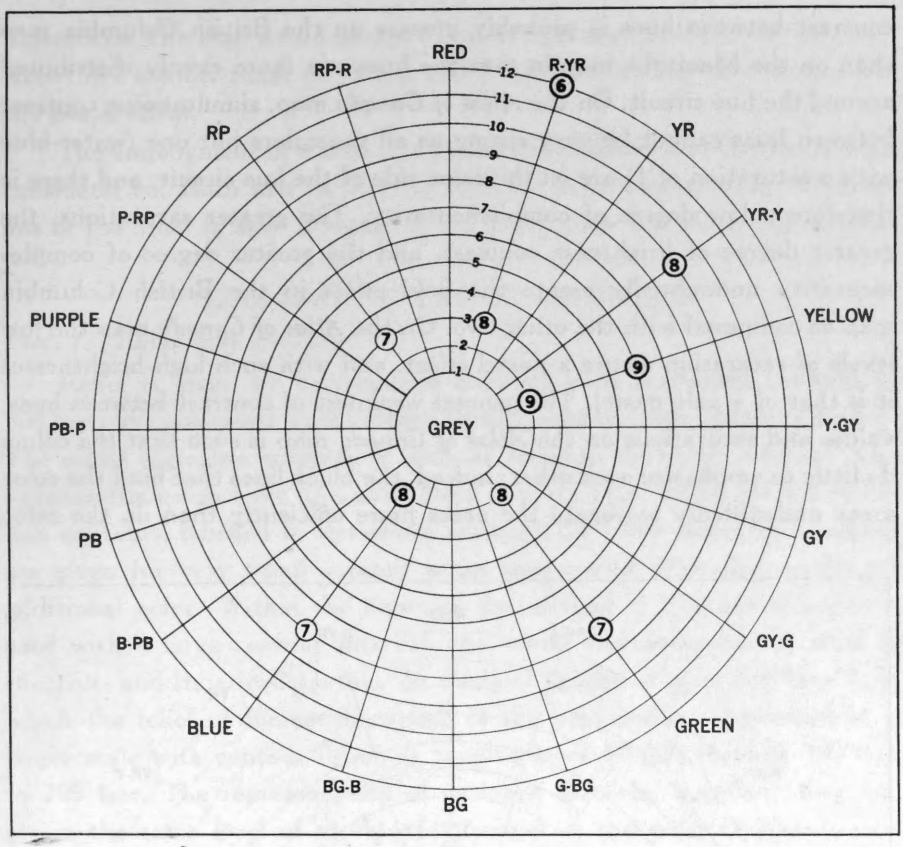

FIGURE 2. Color characteristics, Plate 3, *British Columbia Atlas of Resources.*

and 12 in the Munsell scale; the equivalent range for the Manitoba map is 2, 2, 4 and 5; for the *Atlas of Canada* it is 1, 2, 2, 2, 2, 3, 3, 3, 3, 4, 4, 4 and 6. These figures indicate that the major color areas on the Manitoba and *Atlas of Canada* maps are significantly more faded or desaturated than those on the British Columbia map and, other things being equal, may therefore be considered as having correspondingly less visual impact. The values or brightnesses of the five major colors on the British Columbia map are 6, 7, 8, 8 and 9; equivalent values for the Manitoba map are 8, 8, 8 and 9; for the *Atlas of Canada* map, seven of the chromatic colors have a value of 9 and the other six a value of 8, and the white of the paper shows within the map frame. These figures indicate that brightness contrasts between the major colors of the British Columbia atlas tend toward mutual emphasis and differentiation to a greater degree than those on the other two maps, where brightness contrast tends to be minimal. The effect of simultaneous contrast between hues is probably greater on the British Columbia map than on the Manitoba map in that the hues are more evenly distributed around the hue circuit. On the *Atlas of Canada* map, simultaneous contrast between hues cannot be very strong as all the colors but one (water-blue with a saturation of 1) are on the same side of the hue circuit, and there is therefore a low degree of complementarity. The greater saturations, the greater degree of brightness contrast, and the greater degree of complementarity undoubtedly create the bold effect in the British Columbia map as compared with the other two. On the *Atlas of Canada* map the low levels of saturation assure a pastel effect, and with such high brightnesses it is that of a pale pastel. The general weakness of contrast between hues, values and saturations on the *Atlas of Canada* map is such that the colors do little to emphasize each other; indeed, the black lines that bind the color areas undoubtedly segregate the areas more efficiently than do the color

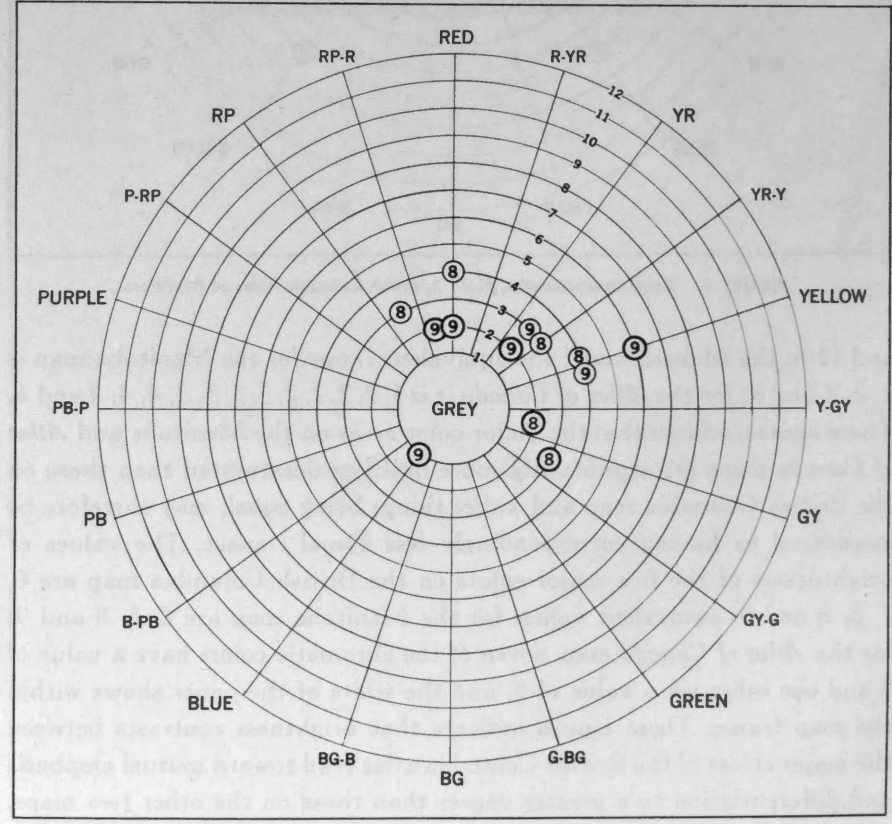

FIGURE 3. Color characteristics, Plate 52, *Atlas of Canada*.

differences. The map would obtain a livelier appearance, if that is desirable, were there a wider range of values, and would not thereby need to sacrifice the pastel effect.

The employment of a bold or a pastel composition is of course a design consideration. Both can be equally efficient in communication. Whether one or the other is more pleasing in the use of color is a matter of opinion.

ECONOMIC ATLAS OF MANITOBA

Plate 1, "Relief and Drainage"

Relief is given by hypsometric coloring with a contour interval of 500 feet; five colors are used grading from greens through yellow to brown. The colors segregate adequately without recourse to strong contrast. The hypsometric colors have fine, solid black binding lines, which are the elevation contours, labelled in feet above sea level. In a few places spot heights are given for very small summit areas that would otherwise require an additional color. Within the limits of the method of hysometric coloring used with a large contour interval, the visual representation of relief is effective, and its adequacy may be checked against a map on Plate 3, in which the relief of the southern half of the province is represented at a larger scale with contour intervals ranging from 50 feet through 100 feet to 200 feet. The representation of drainage features, however, does not attain the same level of visual effectiveness as the relief representation, a point of some importance when the close integration and causal relationship between the two elements is taken into account. The following factors seem to contribute to this deficiency: (1) the weakness of the binding line for lakes; (2) the treatment of bathymetry; and (3) the weakness of the lines used for rivers.

(1) The binding line used for lakes is a narrow, screened black line, grey in effect, much weaker than the solid black line used for elevation contours. The strength of the elevation lines is further increased by their function as the contours of color areas. Many or most of the numerous lakes are of complex configuration, and where they lie within, or interdigitate with, complex configurations of relief contours, there is a poor segregation of the lakes as entities. A stronger binding line for the lakes would probably improve this situation.

(2) For the three large lakes (Winnipeg, Manitoba and Winnipegosis) and for Hudson Bay, bathymetric data are plotted by using the hypsometric color method, with white for the first depth interval and tints and shades

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of blue for successive intervals. The numerous other lakes, for which bathymetric data are not given, are in the blue used for the interval from 50 to 100 feet. Under this system, the lakes with bathymetric data have a ribbon of white adjoining the shoreline and enclosing areas of blue. The bathymetric contours, like the elevation contours, are fine, solid black lines, and the binding line of the entire water body is, as mentioned, a rather weak screened line. The ribbon of white adjoining the shoreline becomes something of a 'ghost' that prevents the lake from being visually comparable to the other lakes. Thus the larger lakes appear to lose size in relation to the smaller one. This effect is due not only to the weakness of the binding line for lakes, but also to the strength of the depth contours that enclose areas of blue comparable to the blue of the other lakes. Although Hudson Bay also has a ribbon of white like the lakes, it segregates as an entity very clearly. This is due to the simplicity of its shape, the contrast between the ribbon of white and the green that is used for the lowest land elevation, and the representation of the shoreline by a line which, although screened, is considerably wider than that used to bind lakes.

(3) Screened black lines are also used for rivers, with the result that all but the major streams are visually weak. The major rivers, being of good width, stand out clearly, but are interrupted by lakes which, for reasons already given, are visually weak, and consequently break the continuity of the rivers.

The over-all result of the foregoing factors is that the drainage pattern lacks unity and does not appear clearly as a system. It would be rash to predict that black lines rather than screened lines would give immediately satisfactory results. This type of problem requires experimentation.

Plate 2, "Physiographic Diagram"

On this map the landforms of the province are represented by pictorial symbols that give a realistic impression of terrain. There are 10 landform classifications with 10 symbols, many of which are similar in appearance, thus reflecting the character of the terrain. Within the provincial boundaries the background is white; outside these boundaries it is grey. The landform depiction extends outside the provincial boundaries. The very numerous rivers are in dark blue; the equally numerous lakes in a tint of the same blue.

The blue occupies a very considerable area of the map and apparently, by simultaneous contrast, induces a chromatic effect over most of this area, giving it a vague pinkish cast that suggests odd or unexpected illumination. There is nothing necessarily wrong with this effect except that where the viewer 'expects' white, he sees something of a chromatic off-white. There is little doubt that the effect is traceable to simultaneous contrast induced by the blue.

What is more serious is that the strength of the blue makes the drainage pattern by far the strongest figural element on the map, with the result that the landforms are 'forced' to become a background that is vague over wide areas. Much of the potential effect of the map is thus lost. It seems that the density of the line work by which the landforms are built up is insufficient to resist the influence of the blue. The effects on the Manitoba map may be compared with those on the British Columbia physiographic diagram. In the latter the drainage is in a light tint of blue that is adequately dominated by the relief shading, the shading being much denser, with many shadow areas in solid black. The strong relief of British Columbia, of course, permits or requires very strong shading.

Plate 12, "Urban Settlement"

The map shows all the hamlets, towns and cities, incorporated and unincorporated, of 50 or more inhabitants. There are seven size classifications of urban centres distinguished one from another by typography, color of typography or town symbol. The base map shows only the drainage pattern, and there is a finely divided graticule with black lines. The graticule is calibrated for latitude and longitude and has a letter and number system referable to the gazetteer in the atlas.

Although the colored typography is eminently readable, and there is no serious difficulty in locating places, the map has a vagueness that is worthy of analysis. This quality seems attributable to a depth illusion inadvertently introduced. The place names seem to attach themselves not to a single surface but, as it were, to several planes at different frontal distances. There are apparently several contributing causes. (1) The place-name typography is in five sizes and five colors, which possibly introduces the phenomenon of size constancy in which objects of the same shape but different objective size appear to be of the same size but at different distances. The phenomenon of advancing and retreating colors conceivably may also have an influence. (2) The town symbols are small and in the same colors as the typography of their place names, and are visually dominated by the place names, so that if the place names tend to establish themselves in different planes, the town symbols do likewise. (3) The base map (i.e. drainage map) establishes a surface, but place names 'stick' to this surface only when the town is on a drainage feature. (4) The strong graticule, which joins into the map frame, overprints the entire map surface and has the visual effect of a grating through which the map is seen.

The problem of this map seems to be to establish a single visual surface to which the various elements will 'attach' themselves. The transportation pattern would probably perform this function, particularly if the town symbols were attached to it.

Plate 25, "Water Resources"

On this map it is possible to observe some influences of composition on color. A number of drainage basins are represented by colored ruling, cross-ruling of different colors, and solid colors. On the map the color effects are noticeably different from those in the legend box, this apparently being a case of the phenomenon of color change with change in area, although contrast effects have an influence. The map patterns appear to be of greater saturation or of lower value than those in the legend box. One classification that is a light grey in the legend box has a distinct chromatic cast on the map, while a light solid yellow undergoes chromatic changes that vary with the degree of influence of adjacent colors.

BRITISH COLUMBIA ATLAS OF RESOURCES

Plate 1, "Relief and Oceanography"

This, the first map of the British Columbia atlas, suffers from some of the difficulties outlined for "Relief and Drainage" in the Manitoba atlas and, in addition, has a particularly serious problem of land-water separation along the very complex fiorded coast with its offshore islands. The lines used for rivers, as in the Manitoba atlas, are screened lines that fail to compete with the fine, solid, black binding lines of the hypsometric colors and consequently fail for the most part to build up a drainage system complementary to the intricate relief system. The numerous large, elongated lakes of British Columbia are printed in a very dark blue and stand out very clearly; but, since the rivers are so weak, the lakes do not easily appear as units in the drainage system and are 'mystery shapes' on the map.

The weak land-water separation along the coast can be traced to several factors: the weak binding line for the shore, the method of representing bathymetry, and the poor segregating qualities of the lowest hypsometric color. Given the intricate configuration of the coastline, the weak grey binding line has little 'chance' against the frequently close succession of solid black contour lines and the strong hypsometric colors they bind. The bathymetric contours, which along the coast have intricate configuration, are composed of dots in solid black, which in the complex configuration have little lineal unity. Where the dot-lines interfinger into land areas, they tend to 'fuzz' the configuration of the shoreline. In some areas the dots create stipple patterns of indeterminate shape, crowded close to the land. The lowest hypsometric color that marks the coastlands in a blue-green which, in the terminology of Koffka (1935), is one of the 'soft' colors; that is, its powers of shape-segregation are less than the 'hard' colors in the red and yellow family. The phenomenon of hard and soft colors is conveniently illustrated by comparing the plate under discussion with Plate 3 "Geology," in which the coastlands are in red.

An extremely complex configuration, the adjacent sharp delineation of hypsometric colors by solid black lines, the weak coast binding line, the 'fuzzing' effect of the bathymetric contours, and the poor segregating qualities of the land color that directly adjoins the weak coast binding line—all these combine to create a very poor land-water separation.

A composition factor that may also influence the land-water separation involves the bathymetric colors used for deep water. The slope from the British Columbia coastal shelf to deep water is very abrupt, and the configuration of the front of the shelf is simple. The bathymetric colors used for deep water are shades of purple and blue close to saturation. Thus, offshore there is a strong, simply configured color area that to a degree 'begs' the eye not to look at the confusing coastal configuration.

One further comment on "Relief and Bathymetry." In this, the first map in the atlas, it seems of some importance that the boundaries of the province should be sharply delineated. There is recognition, however, that particularly for a subject like relief, it is important to show the continuity of the system beyond the data area, as on this map. The solution seems to be to mark the political boundaries boldly. For this purpose the screened line for the boundary notably fails; in many places, particularly along the crestline of the Rocky Mountains, it is, in effect, lost.

On a number of maps in the British Columbia atlas, census divisions are identified by large white numbers having a screened orange binding line. In many instances the orange line is sufficiently similar to the background colors to have little function, the visibility of the number being dependent chiefly on the contrast between the white of the number and the color of the background. Frequently there is a low level of contrast, and the number is consequently difficult to see. The orange binding line is used consistently from map to map, regardless of its varying efficiency. A black or grey binding line for the numbers would have made their visibility consistent from map to map and from place to place on any particular map. On Plate 27, "Forest Administration," solid black numbers are used effectively and without undue distraction to identify forest districts.

Many maps in the British Columbia atlas show the land outside the province in grey, as opposed to the chromatic colors within the provincial boundaries. The grey of the Alaska panhandle, although objectively the same as the grey elsewhere on any particular map, frequently appears to be different in value from the main body of grey. It is, of course, separated from this main body and consequently can be separately affected by adjacent colors. The effect is perhaps most noticeable on Plate 10, "Climatic Regions," but it can be seen on many other maps, varying with different color combinations. It is not deleterious to the maps but is of interest in cartography.

The vignetted shoreline on many of the British Columbia maps, on which the water blue is designed to fade out to a white, seldom appears white, presumably owing to simultaneous contrast. Apparently the water blue is most influential, and the 'white' area usually has an orange or yellow cast. This varies, however, from map to map, probably because of the varying influence of different colors on the land area. It is possible that this effect could be controlled or eliminated by a strong coastal binding line, for it is well known that a strong contour around a color area will resist the effects of simultaneous contrast.

NOTES ON THE ATLAS OF CANADA

Comments on the appropriateness of particular colors to particular subjects are frequently not objectively defensible; but the selection of colors for Plate 48 of the *Atlas of Canada*, "Density of Population," promotes misinterpretation. In the gradation of colors signifying the gradation of density, one segment in the scale is, for all visual purposes, repeated at different levels in the scale. Specifically, the 4–10 and 10–20 persons-per-square-mile ranges are practically indistinguishable from the 40–100 and 100–300 ranges. The result is a very erroneous impression.

On many maps in the *Atlas of Canada* there is a weak land-water separation. To put it another way, the shape of the land has a weak figural quality that is particularly unfortunate where configurations are complex, as, for example, in the Arctic Archipelago. The weakness of figure may contribute in some cases to a vagueness of color; for a strongly contoured figure can lend emphasis to a contained color, the converse being true where there is a weak contour. The line that delineates the land area is a pale grey on most maps. It is not a screened black line, as in the provincial atlases, but rather a solid line in grey ink, 'broken black' in the parlance of the printers.

Throughout the *Atlas of Canada* standard base maps in several scales are used, the number of background data increasing with scale. In the larger scales, the base data, particularly rivers and place names, create a complex articulation capable of conflicting with the subject data, thereby seriously reducing the visual impressiveness of the subject material. This is particularly noticeable on Plates 77 and 78 which show generating stations and power lines, as well as on some of the isarithm maps in the climatic series.

APPENDIX

The color analysis in this study conforms to the Munsell system of color description. The color dimensions measured in this system are hue, value (or brightness) and saturation (or chroma).

Hue is the quality signified by the common color names. Red is a hue and yellow is a different hue, but a dark red and light red have the same hue. In the Munsell hue circuit, the major hues are Yellow,* Red, Purple, Blue and Green. Intermediate hues are identified in terms of the major hues. The hue midway between Blue and Green, for example, is Blue-Green (BG), and the hue midway between Blue and Blue-Green is Blue Blue-Green (BG-B). In the Munsell system a numerical notation is also used for the identification of hues, but its use was not considered necessary for this study.

Value may be described as the degree of darkness or lightness a hue shows when compared with gradations of grey between black and white. In the Munsell grey scale, there are nine gradations between black and white; number 1 in the scale signifies a near black, number 9 a near white.

*Initial capitals indicate colors as coded in the *Munsell Book of Color*.

Saturation may be described as the degree of 'fadedness' of a hue, the steps of saturation ranging from a neutral grey in which all hue is 'faded out,' to the full color. In any particular gradation of saturation, value remains the same; that is, each step of saturation is equatable to the same grey in the value scale. Different hues reach full saturation in differing numbers of steps. In the Munsell system up to 16 steps of saturation are employed. Purple-Blue reaches full saturation in 16 steps, Red in 14, Yellow in 12, Green in 8, and so on.

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MAP NOTES—FICHES CARTOGRAPHIQUES

CANADIAN LAND-USE SERIES. GEOG. BR., DEPT. MINES & TECH. SURV., OTTAWA

Since November 1962, seven more multicolored land-use maps have been published: three of southern Ontario at the scale of 1:50,000; two of southwestern British Columbia at the scale of 1:50,000; one of south-central Saskatchewan at the scale of 1:500,000; and one of Prince Edward Island at the scale of 1:126,720.

Ontario (1:50,000)

Welland East (30L/14)

The Welland East sheet is the sixth large-scale (1:50,000) map to be published in the series of land-use maps covering the Niagara Peninsula. The legend is unchanged from that of earlier maps in the series and shows 12 land-use categories. The map includes the flat, poorly drained clay plain southeast of the City of Welland, where large acreages of idle and abandoned agricultural land are shown by the two grassland categories. A narrow band of summer cottages and private parks occupies almost the whole length of the Lake Erie shoreline. In the vicinity of Crystal Beach the cottages extend 2 miles back from the water's edge. The industrial cores of Port Colborne and Welland are also shown.

(J.M.)

Essex East (40J/2) and Pelee East (40G/10, 40G/15)

The Essex East and Pelee East sheets are the first in a series of large-scale (1:50,000) land-use maps that will eventually cover the area bordering Lake Erie from the Niagara Peninsula in the east to Windsor in the west. The legend for these sheets shows 22 land-use categories; it differs from the legend used on the Niagara sheets only in the addition of sugar beets and soy beans as separate categories. The Essex East sheet shows the intensive agricultural use of land on the Essex clay plain. Woodland remains only as tiny, scattered bits and pieces. The sandy deposits around Leamington stand out clearly as areas of fruit- and vegetable-growing. The Pelee East sheet shows Pelee Island and Point Pelee, a sand spit jutting out into Lake Erie from the mainland. Fields of soy beans cover most of the surface of Pelee Island. On the Pelee spit there is a sharp contrast in land use along the boundary of Point Pelee National Park. Outside the park the marshland has been drained and is used for vegetable-growing; within the park the natural vegetation of swamp and marsh remains.

(J.M.)

British Columbia (1:50,000)

Victoria (92B/ 6 W) and Shawnigan (92B/12 E)

The Victoria and Shawnigan sheets are the first land-use series maps to be published of British Columbia. They are two of four sheets being produced at the scale of 1:50,000 to portray land-use patterns in the densely populated area of southeastern Vancouver Island. The Victoria sheet is essentially an urban land-use map, as almost all the area covered by the sheet is occupied by Greater Victoria. On the Shawnigan sheet are illustrated the constrasting types of land use found in two of the major physiographic divisions of British Columbia. Within the map area are lowlands of the Coastal Trough and mountainous zones of the Outer Mountain area. The areas of agricultural land use, restricted to the lowland, contrast sharply with the large expanse of woodland occupying the mountain area. Settlement in the mountain zone is discontinuous and non-agricultural; it shows strong orientation to transport routes and water fronts, both coastal and lake.

(J.W.M.)

Saskatchewan (1:500,000)

Moose Jaw-Watrous (72 N.E.)

The Moose Jaw-Watrous sheet is the first published map of the 1:500,000 Prairie land-use series. The legend used in this series is more general than those for British Columbia, Ontario and the Maritimes. This legend includes 13 categories: two urban and one each for cropland, horticulture, improved pasture, two grassland, four woodland, unproductive, and one each for swamps and marshes. The boundaries of community and cooperative pastures are also shown.

Although the predominant category shown on the map is cropland, there are several other interesting features that stand out. The most striking of these are the belt of open grassland that marks The Missouri Coteau, the predominance of forest and grassland on the sand deposits west of Dundurn, the concentration of woodland in the Touchwood Hills, and the scattering of small areas of forest and grassland throughout the morainic deposits in the northeastern part of the sheet.

(J.H.L.)

Prince Edward Island (1:126,720)

Prince County

The Prince County sheet is the first in a series of three land-use maps to be published of Prince Edward Island. The scale permits a detailed presentation of the Island's agricultural land use with very little generalization and allows direct comparisons with the soil-survey maps published at the same scale. The 21 land-use categories differentiated include five urban, seven agricultural, two abandoned-grassland and four woodland categories, as well as unproductive land, swamps and marshes, and areas leased for oyster culture on the bottom of the shallow bays and river estuaries. Among other variations in the land-use pattern, the sheet discloses the contrast between the Island's most specialized potato-growing area, which is southeast of Summerside, and the more marginal, ill-drained areas of widespread land abandonment toward the northwest.

(C.W.R.)

BOOK NOTES—FICHES BIBLIOGRAPHIQUES

LIFE NATURE LIBRARY, Time Incorporated, New York, comprising:
The Sea, 1961, by L. Engel and the editors of *Life*. 190p.
The Poles, 1962, by W. Ley and the editors of *Life*. 192p.
The Desert, 1961, by A. S. Leopold and the editors of *Life*. 192p.
The Mountains, 1962, by L. J. Milne and M. Milne and the editors of *Life*. 192p.
The Forest, 1961, by P. Farb and the editors of *Life*. 192p.
The Universe, 1962, by D. Bergamini and the editors of *Life*. 192p.

The *Life* Nature Library consists of a series of books, each of them a lively introduction to the knowledge of the universe, the earth, or the earth's environmental units, such as the desert, the mountains, the sea, the poles and the forest.

The series is not a scientific treatise, although it offers a good text supplemented by valuable scientific tables and lists and splendidly illustrated with photgraphs, diagrams and drawings. It is a spectacular pictorial presentation that will be an asset on the bookshelves of anyone interested in the world he lives in. It is also an example of the successful teamwork of scientists, writers and artists. By giving not only a summary of the achievements of various sciences but also their current trends and future possibilities, the whole series shows the dynamism of the 'new frontier.'

Although each book is limited to about 190 pages, the texts are clear and concise; thus, while short, they present a full account of their topics. The photographs, whether black and white or colored, are original, carefully selected and of an artistic and technical level difficult to equal. The text is supplemented by colorful drawings representing scientific data in imaginative pictures, but the cartographic illustration of the *Life* Nature Library series seems to have been neglected. The maps are few, and even the ones included are much below the general level of the publication.

The unity of the series is based on the affinity of topics. Otherwise each book is a separate work by a different author.

The first volume concerns the environment where all life probably evolved. The sea, which covers over 70 per cent of the terrestrial surface and makes the earth unique in the solar family, has been explored for some 4,000 years—since the time of the Phoenicians (2,000–1,000 B.C.); but the knowledge so acquired was related to the surface of the sea, and the second era of discovery began with the echo sounder, which revealed the underwater landscape and the permanence of sea basins. Here the reader of *The Sea* finds a remarkable drawing representing the topography of the ocean bottom, which was prepared by the cartographer Kennet Fagg and incorporates, among other data, the findings of the International Geophysical Year. The reader is also introduced to Heezen's theory of expansion, to the Ewing and Donn hypothesis and to J. Tuzo Wilson's work. The ancient life of the sea is represented by photographs of famous fossils and by imaginative drawings. The chapter entitled "Sharks and Other Killers" will fascinate both young and adult readers with its original photographs and vivid details of noted attacks. The economic prospects of sea management constitute the topic of the final chapter.

The Poles is an introduction to the history of exploration and the regional geography of the polar zones. The history of the conquest of the poles, from the Greek, Pytheas (395 B.C.), to Nautilus, is enlivened with drawings and well-chosen pictures. The photographic coverage of Scott's tragic expedition is remarkable. Also remarkable is the pictorial presentation of polar plant and animal life. The chapter on Arctic peoples describes Eskimos and Lapps, their life, traditions and problems. The final chapter deals with the achievements of modern man in polar regions. The Antarctic is a great laboratory; the

Arctic "for better or worse . . . is central to the 20th century world." In 1961 a nuclear power plant was installed at McMurdo Sound, Antarctica; and transpolar submarine traffic, commercial cargo routes under the ice cap, and cities dug in the ice do not seem distant.

Three books on the desert, the mountains and the forests offer rich material organized much as in previous volumes. The description of desert landforms, which is illustrated by diagrams, drawings and photographs, is of particular geographical interest. Clearly presented theories on the origin of mountains, together with the classification of mountain types and volcanoes and the presentation of their erosional cycles, form an apt introduction to geomorphology. *The Forest*, which introduces ecology, depicts plant and animal communities of each environment by means of magnificent photographs combined with an illuminating text. The stress is on the marvel of adaptation and the relations of wildlife.

Throughout the series, man's relation to different natural environments is shown as it changed during historic time. The most inaccessible mountain tops have been conquered, and the desert is no longer an abandoned land. The forest, one of man's future 'land banks,' which protected, fed and clothed him in early times, was later fought by burning and destroyed by exploitation; but wherever agricultural lands replaced the major part of the forest, the need for conservation and proper management became urgent and gave rise to scientific forestry.

The last volume of the series enlarges the scope of interest from particular environments to the whole earth and the universe. Like the others, it is not a scientific treatise but an introduction to earth science and the place of the earth in the universe.

Through the history of the development of various branches of knowledge, the reader is led to newly discovered facts and new theories; and it is a point in the book's favor that such subjects as the nature of supernovae, the processes of photosynthesis and the mysteries of living cells are explained and illustrated clearly enough to be understood by non-professionals.

There is a certain amount of repetition from book to book, especially in the last two volumes. The point of view and the amount of information vary, however, according to the main topic in each, and all seven combine to make the earth and its life more understandable.

(I.J.)

Gazetteer of Canada Series, Canadian Board on Geographical Names, Ottawa, comprising:

Prince Edward Island, 1960, 19 p., map. Price 75 cents.
Nova Scotia, 1961, 192 p., map. Price $2.
Ontario, 1962, 614 p., map. Price $4.

Previous volumes in this series (*Southwestern Ontario, British Columbia, Manitoba, Alberta, Northwest Territories and Yukon, New Brunswick* and *Saskatchewan*) have been described in Geographical Bulletins 4, 7, 9, 13 and 14. The names of physical features and settlements are listed alphabetically in each of the above gazetteers and are followed by their designations, locations and geographical coordinates. End-paper maps are included.

Supplements to the Alberta gazetteer for 1960, 1961 and 1962 have been published by the Alberta Board on Geographical Names, from which copies may be obtained on request.

(J.K.F.)

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