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GLACIAL FLUTINGS IN CENTRAL AND NORTHERN ALBERTA[1]

C. P. GRAVENOR and W. A. MENELEY

ABSTRACT. An examination of vertical air photographs covering about 175,000 square miles of northern and central Alberta has revealed the presence of large fields of glacial flutings. The flutings show two dominant trends, one in a south to southwest direction and the other in a southeast direction. Although the majority of the flutings are formed in till, in northeastern Alberta the flutings are erosional in character and developed in Precambrian granite gneiss. Striae on the Precambrian flutings are roughly parallel to the ridges. Till fabric determinations made on the southeast flutings of the North Battleford, Saskatchewan district show that there is a marked change in fabric with depth in the ridges. Fluting development apparently bears little relationship to topography. It is believed that the flutings originated from alternating high and low pressure zones at the base of the ice.

INTRODUCTION

The word "fluting" has been used to describe parallel shallow grooves on till plains (e.g. Chapman and Putnam, 1951, p. 15). In this report the term fluting is used in its widest possible sense and except where specified includes low-lying drumlins and giant grooves as well as parallel shallow grooves. The fact that drumlins—of a variety of form—and flutings are gradational (plate 1) has been pointed out by several geologists (e.g. Smith, 1948; Gravenor, 1956; and Lemke, 1958).

An examination of vertical air photographs and mosaics of Western Canada shows that flutings are very common and in the absence of striae and well-developed end moraines, provide a good clue to the direction of glacier movement. There are two major ice-movement directions in northern and central Alberta, one to the south and southwest and the other to the southeast. The significance of these two directions is as yet rather obscure but there is preliminary evidence to suggest that certain flutings which trend in a southeasterly direction were created by minor readvances of the retreating ice.

Most of the flutings examined are composed of sandy to clayey till except in northeastern Alberta where they are formed in Precambrian granite gneiss and porphyritic granite. Unfortunately exposures in fluting are extremely rare and the possibility exists that many of them contain incorporated stratified material.

FLUTING DIRECTIONS IN NORTHERN AND CENTRAL ALBERTA

Vertical air photographs covering about 175,000 square miles of northern and central Alberta have been examined and fluting directions recorded. The results of this study are shown on figure 1. Other glacial features, such as crevasse fillings and a variety of minor end moraines, can be confused with poorly developed flutings and consequently such doubtful features have been carefully excluded from this study. Undoubtedly as more detailed mapping of surficial deposits is carried out in northern and central Alberta more ice-movement directions will be added. Most of the measurements were made on the shallow-groove type of fluting but in some instances—for example in the area

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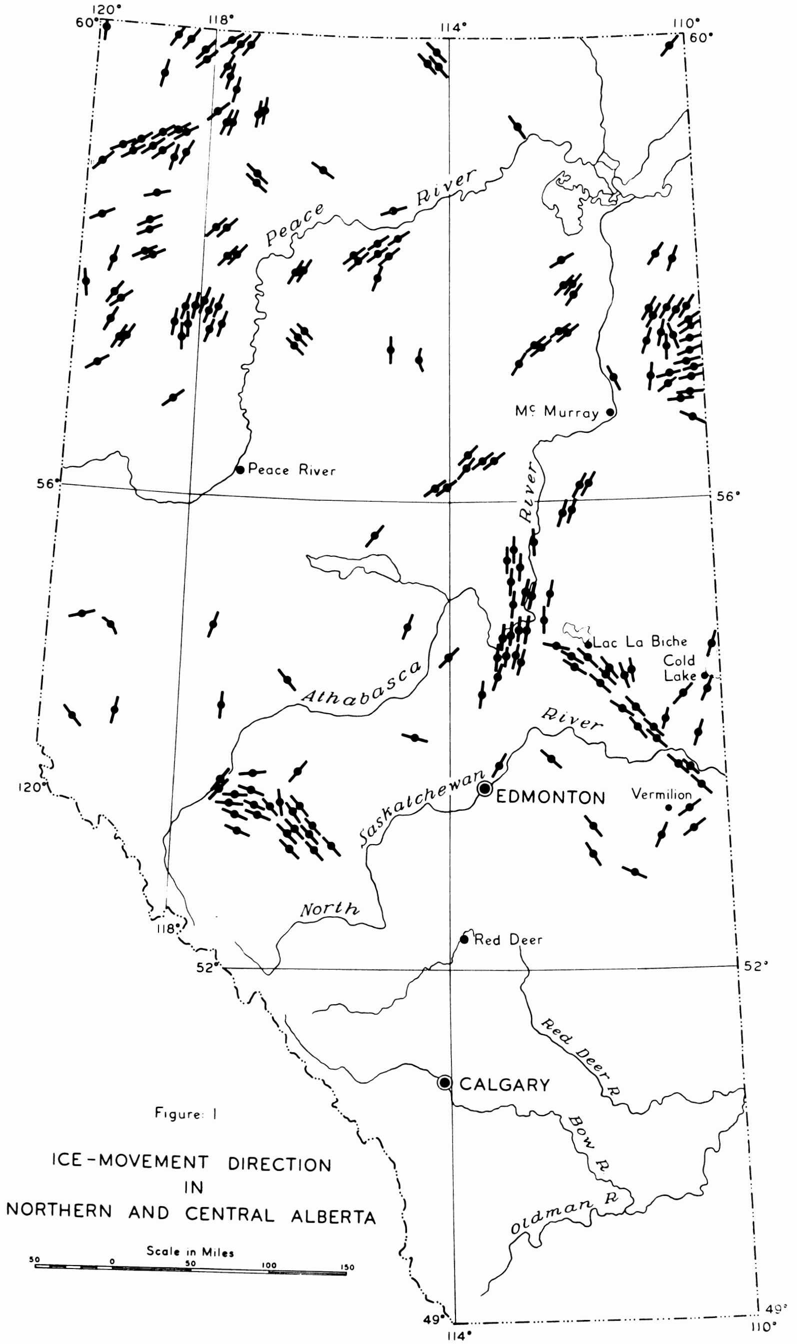
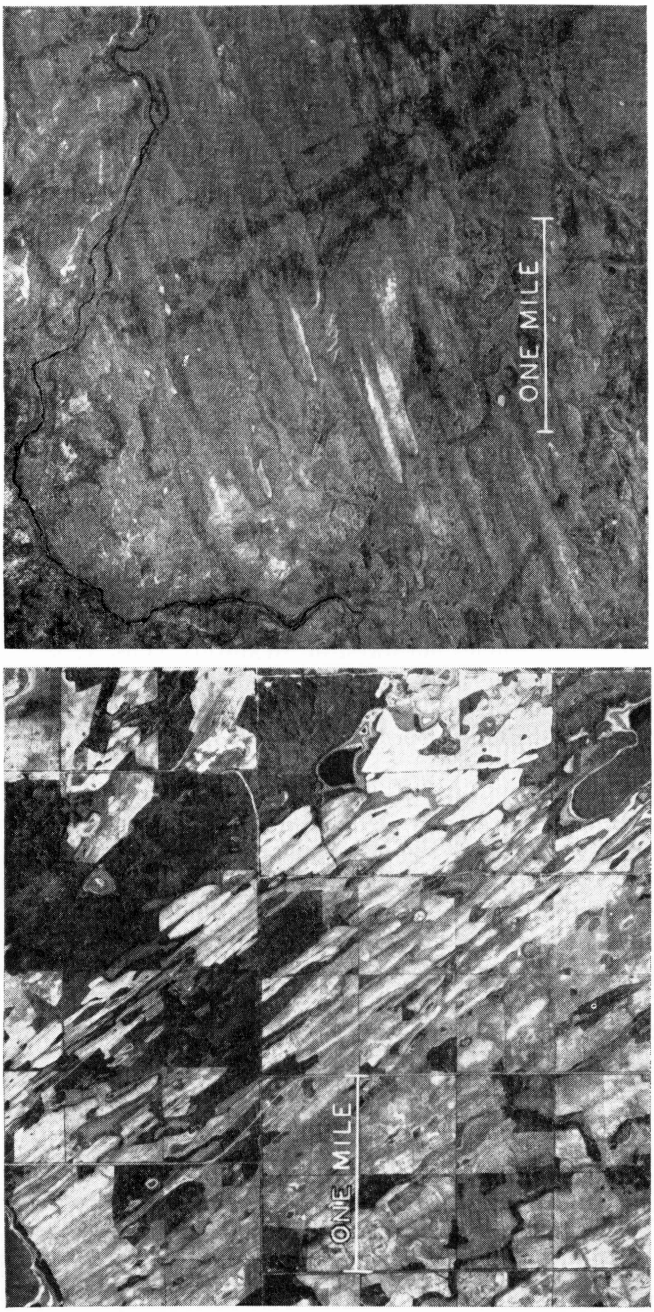

120°
118°
114°
110°
60°
60°
Peace River
Mc Murray
Peace River
56°
56°
River
Lac La Biche
Cold Lake
Athabasca
River
120°
Saskatchewan
EDMONTON
Vermilion
North
118°
Red Deer
52°
52°
Red Deer R.
CALGARY
Bow R.
Oldman R.
Figure: I
ICE-MOVEMENT DIRECTION
IN
NORTHERN AND CENTRAL ALBERTA
Scale in Miles
50
0
50
100
150
49°
114°
49°
110°

Fig. 1.

northeast of McMurray (plate 1A)—many of the measurements were made on drumlins.

PLATE 1



A

Loc.—Tp. 96, R. 1, W. of the 4th Meridian, Firebag River, 60 miles N.E. of McMurray.

B

Loc.—Tp. 58, R. 9, W. of the 4th Meridian, St. Paul, 70 miles N.W. of Vermilion.

Both of these photographs show flutings which are gradational to drumlins. In general drumlinized flutings do not display the extreme parallelism or length of the shallow groove type of fluting (plate 2). (Photographs reproduced by courtesy of the Technical Division of the Department of Lands and Forests, Edmonton.)

Most of the ice-movement directions shown on figure 1 were developed from continental glaciers which advanced in a west to southwest direction from the Keewatin ice center. An exception is found in the area west of Edmonton between the North Saskatchewan and Athabasca Rivers where it is believed that the flutings resulted from Cordilleran ice which flowed in a northeast direction out of the foothills and then swung to the southeast more or less parallel to the foothills of the Rocky Mountains.

The majority of the ice-movement directions over northern and central Alberta are towards the south and southwest and are in reasonably good agreement with the ice-movement directions predicted from the use of indicators (Gravenor and Bayrock, 1956). There are, however, a significant number of directions toward the southeast (Plate 1B)—particularly in the Lac la Biche-Vermilion area. The Lac la Biche flutings extend in a southeasterly direction to a point 30 miles southeast of North Battleford, Saskatchewan. From the fact that southwest directions exist north and south of the Lac la Biche southeast trend it might be suspected that these two sets of directions are of different age. There is some data—which is presented under fabric studies—which suggests that the Lac la Biche southeast flutings were probably developed during deglaciation of east-central Alberta and have no relationship to the direction of regional ice advance.

LOCAL DISTRIBUTION OF FLUTINGS

Effect of topography.—Although topography may have been an influence on the direction of ice movement in central and northern Alberta the relationship of topography to fluting development is rather obscure. In the Birch Mountains (plate 2B) 70 miles northwest of McMurray (Ells, 1932) and in the Naylor Hills 100 miles northwest of Peace River the flutings are developed only on the tops of highlands. In the Red Deer district (plate 2A), on the other hand, the flutings are best developed in a sidehill position of a preglacial valley.

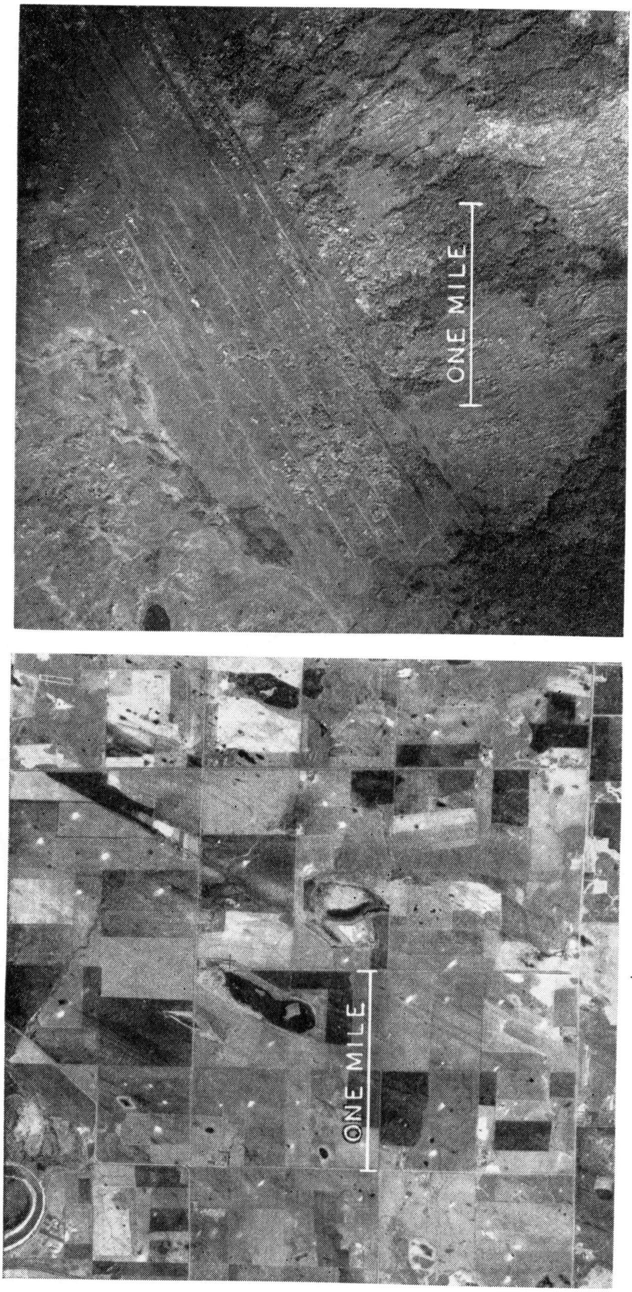
In the Stettler district (fig. 2) the flutings were developed from the glacier ice which moved uphill in a southwesterly direction. The fan-like distribution of these flutings suggests that the ice spread laterally as it was advancing to the south. It is difficult to visualize how such a distribution of flutings could originate from a regional ice flow and it is suggested that the Stettler flutings were created by a minor readvance of the glacier. The last glacier probably retreated well to the north of Stettler and then readvanced, locally, sending a small ice lobe into the Stettler district. It is interesting to note that linear trends visible in the hummocky dead-ice moraine five miles north of Stettler show the same orientation as the flutings. Although the age of the morainal ridges is post-fluting it appears that the same stress distribution in the ice which gave rise to the flutings in part controlled the positioning of some of the dead-ice features.

In summary, flutings are found on the tops of highlands, on sidehill positions in lowlands and on uphill positions. Thus it appears that while the ice movement may have been affected by topography, fluting development is independent of topographic control. A similar conclusion has been reached by Smith (1948) in his study of giant glacial grooves.

EROSIONAL FLUTINGS ON THE PRECAMBRIAN

The area north of Lake Athabasca in the extreme northeast corner of Alberta is underlain by massive granites and metasediments of Precambrian

PLATE 2



A

Loc.—Tp. 38, R. 27, W. of the 4th Meridian, Red Deer.

B

Loc.—Tp. 96, R. 17, W. of the 4th Meridian, Birch Mountain, 70 miles N.W. of McMurray.

These photographs show the extreme parallelism and length (up to several miles) of the shallow groove type of fluting. The Red Deer flutings are developed on a sidehill position and the Birch Mountain flutings are on a topographic high. (Photographs reproduced by courtesy of the Technical Division of the Department of Lands and Forests, Edmonton.)

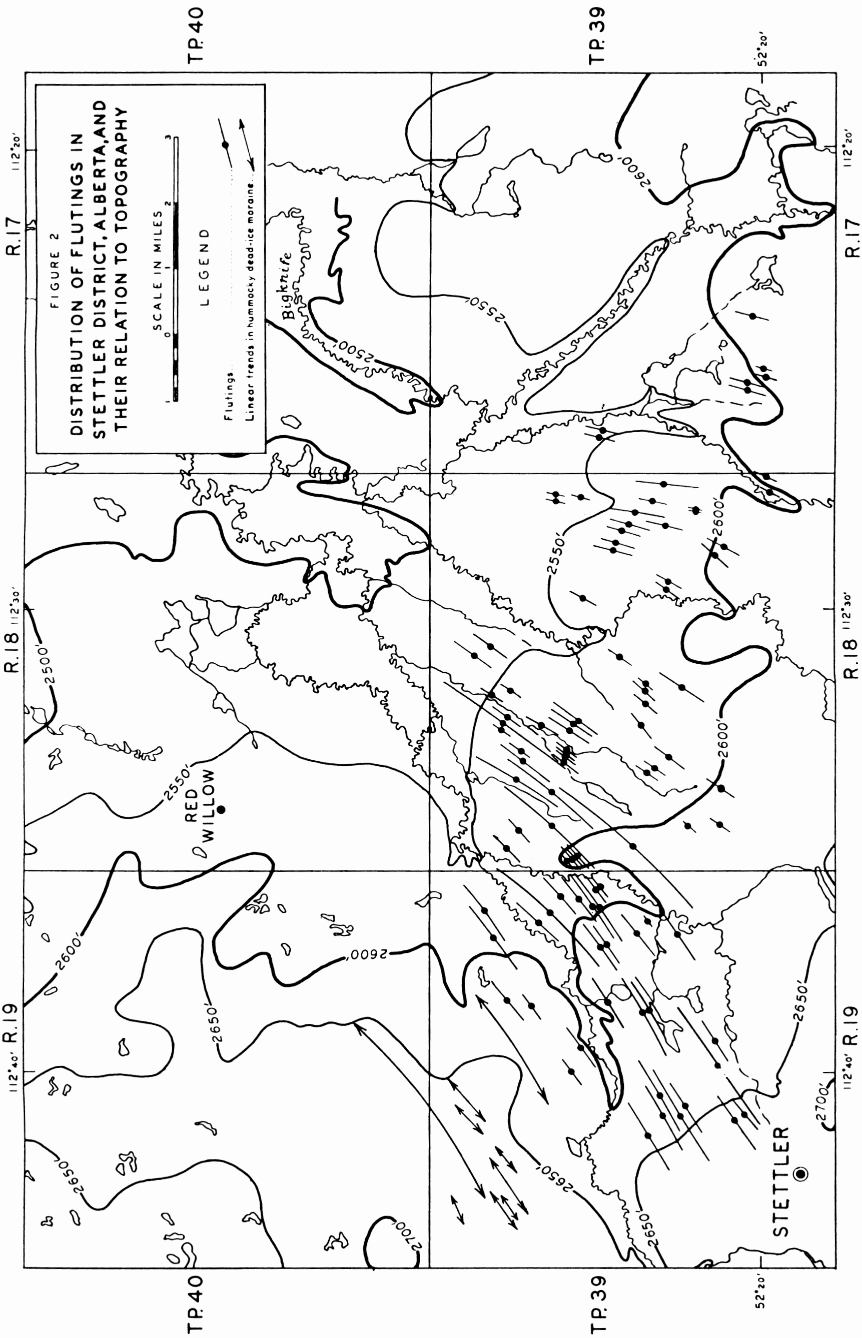


FIGURE 2
DISTRIBUTION OF FLUTINGS IN STETTLER DISTRICT, ALBERTA, AND THEIR RELATION TO TOPOGRAPHY
SCALE IN MILES
LEGEND
Flutings
Linear trends in hummocky dead-ice moraine
TP. 40
TP. 39
R. 17
R. 18
R. 19
112°20'
112°30'
112°40'
52°20'
RED WILLOW
STETTLER
Bigknife
2500'
2550'
2600'
2650'
2700'

Fig. 2.

age. The surface of this portion of the Canadian Shield is gently rolling and broken, locally, by ice-scoured valleys and fault scarps. In the Andrew Lake district (fig. 3) glacial erosion on the Precambrian rocks produced a field of flutings which trend north 60 degrees east. To the east in northwestern Saskatchewan the erosional flutings are gradational to a drumlin and fluting field. The flutings in the Andrew Lake area transect the bedrock structures (fig. 3) and hence differential erosion through variation in lithology has been insignificant. In many instances feldspathic pegmatite dykes which cut across several flutings have been eroded to the same depth as adjacent softer meta-sediments.

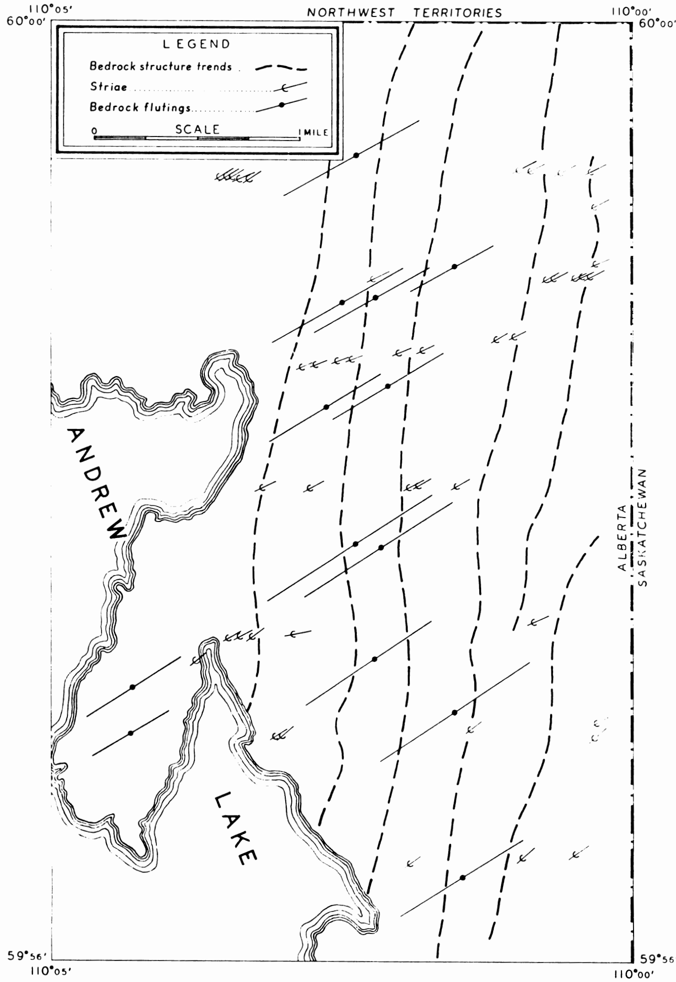


Fig. 3. Flutings, striae, and bedrock structure trends in the northeast corner of Alberta.

These erosional flutings are similar in size and shape to the giant grooves developed on sedimentary rocks in the Mackenzie district—described by Smith (1948). In general, the fluting ridges lie about 10 to 25 feet above the adjacent grooves and the individual ridges are spaced about 300 feet apart. Some of the fluting ridges can be traced for a distance of several miles, but most are considerably shorter.

Many hundreds of stria measurements made on the sides and tops of Andrew Lake flutings show a parallelism to the ridge orientation (fig. 3). Thus it is reasonably certain that the flutings were developed parallel to the direction of ice movement, although it should be kept in mind that the striae were developed at a later date than the flutings and perhaps under different ice conditions to those which actually created the flutings. The fact that the Andrew Lake flutings are gradational to drumlins and are similar in size, shape and spacing to till flutings would suggest that the erosional process is an important factor in the development of flutings of all types.

FLUTING WAVELENGTH

The term fluting wavelength as used in this report is defined as the distance between the crests of adjacent ridges or troughs of adjacent grooves, measured perpendicular to the long direction of the flutings. Fluting wavelength measurements were made on air photographs along lines drawn two-thirds to one mile apart normal to the fluting trend. In most cases wavelength measurements were made between adjacent ridges but in some cases the grooves were used in order to get the best values. The wavelengths of all visible flutings which crossed each line of measurement were recorded. Wavelengths greater than one mile are rare and are not reported.

Wavelengths of flutings in five districts of Alberta and Saskatchewan were measured. The results were plotted as histograms (fig. 4) with the wavelength the abscissa and the frequency of occurrence the ordinate. Statistical tests show that the histograms have a significant deviation of wavelengths from a normal distribution. There is a preferred wavelength of 300 to 400 feet present in all cases and a secondary preferred wavelength of 600 to 700 feet in all cases except for the North Battleford flutings. The secondary peak is best developed on the Cold Lake flutings and may be related to the fact that a portion of these flutings is composed of elongate drumlins (plate 1B).

The similarity of fluting wavelength developed under widely differing conditions of topography and lithology suggests that wavelength is essentially independent of topographic or lithologic control. The wavelength must therefore be controlled by some physical property of the glacier ice which gives rise to periodic variations in erosive capacity in a direction transverse to the direction of flow. Until more is known about the physics of ice flow it is impossible to suggest a reason for periodic variation of the erosive capacity in ice.

MICROFABRICS[2]

Macrofabric studies made on drumlins generally show a prominent lineation parallel to the long axis of the drumlin (e.g. Donner and West, 1955;

[2] The method of preparation, analysis and interpretation will be the subject of a further paper which is now in the preparation stage.

Wright, 1957). Due to the absence of deep exposures it was decided to study the fabric of flutings by microfabric techniques. According to Seifert (1954) and Harrison (1957) microfabric studies give similar results to those obtained

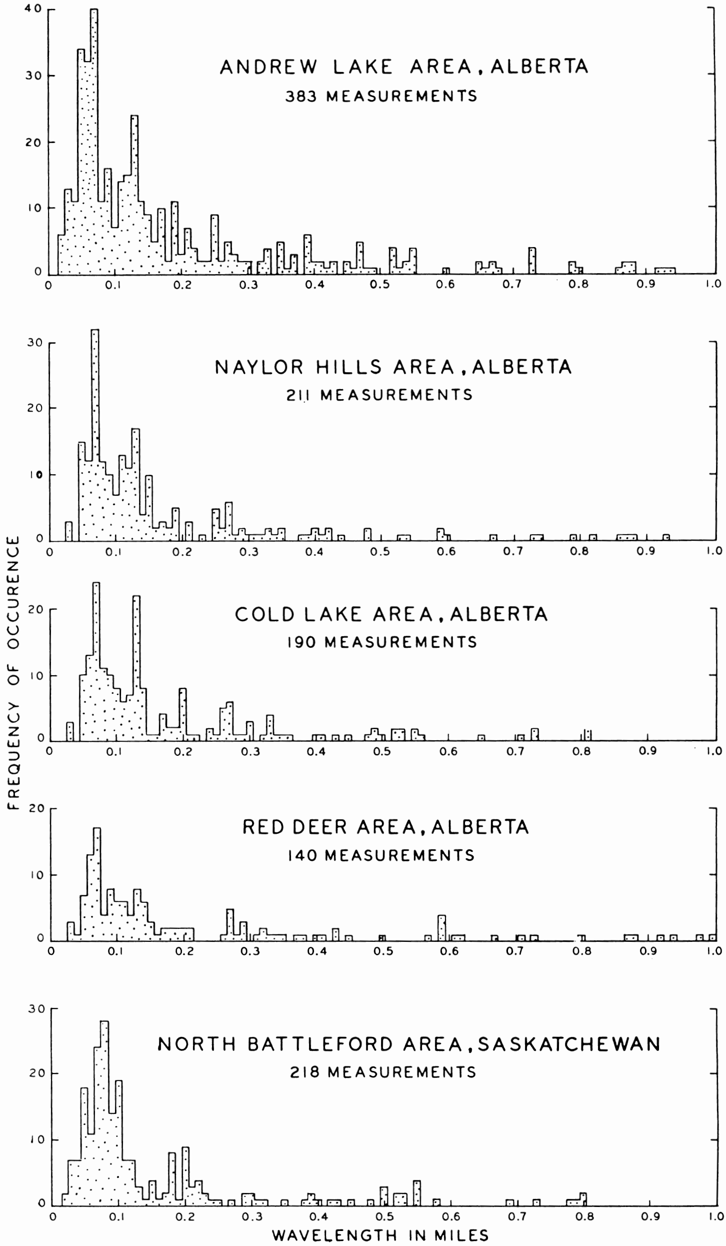


Fig. 4. Fluting wavelength distribution.

by macrofabrics and hence appear to be a reliable technique in the study of till fabric.

Microfabric analyses were carried out on oriented undisturbed samples of till obtained from auger holes in a fluting at North Battleford, Saskatchewan. Shelby spoon samples of three-inch diameter were used to take samples at intervals below the crest of a fluting ridge. The samples were impregnated with a thermosetting plastic and a minimum of three mutually perpendicular thin sections was cut from each sample. The least projection elongation direction (Dapples and Rominger, 1945) of the apparent shape of about 200 particles

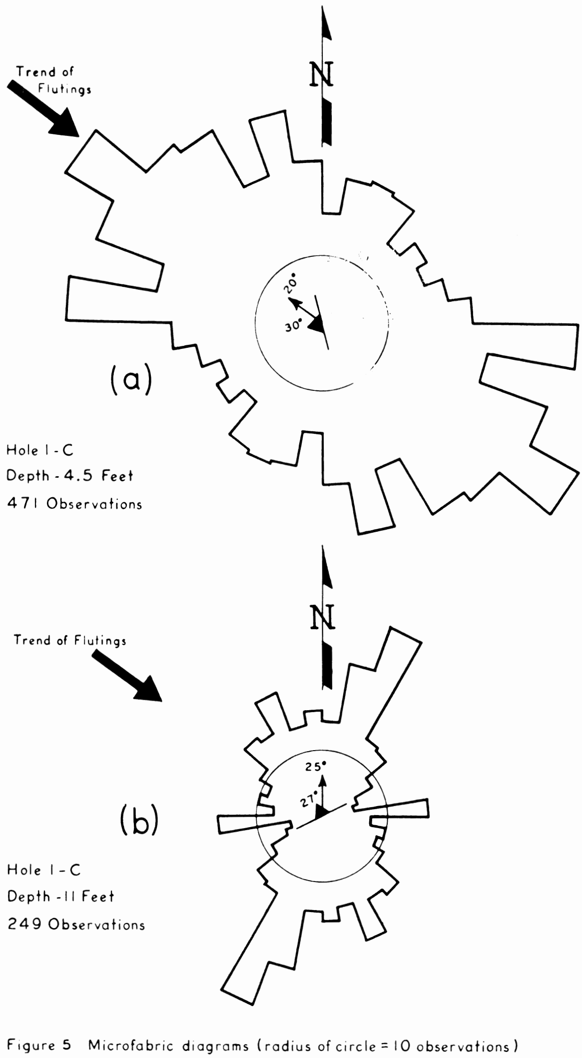


Fig. 5. Microfabric diagrams (radius of circle = 10 observations).

was measured in each thin section and plotted on rose diagrams. Microfabric diagrams of two typical samples are shown in figure 5.

In order to define the attitude of any particle in space it is necessary to measure the orientation of two shape parameters—the long axis and the plane of maximum projection area. In this study the preferred orientation of the long axis and the plane of maximum projection area are described by the standard structural symbols for lineation and foliation respectively.

The interpretation of the two-dimensional orientation data is based upon graphic analysis of the relationships between the two-dimensional apparent shape in thin section and the long axis and maximum projection area of the particles. If the foliation dips less than 45 degrees then the preferred orientation determined from a thin section cut in a horizontal plane approximates the strike of the lineation. The preferred orientation directions determined in two vertical thin sections may be considered as the apparent dips of the plane of foliation. The strike and dip of the foliation and the plunge of the lineation may then be determined by the methods described by Billings (1954, p. 442-443).

At a depth of four to five feet below the crest of the fluting ridge, microfabric determinations (fig. 5) show a prominent lineation which strikes parallel to the long direction of the fluting—northwest—and plunges northwest at 20 degrees. The foliation dips west at 30 degrees. A similar microfabric is present at a depth of 10 feet with the exception that lineation plunges at a very small angle—two degrees—to the northwest and the foliation dips eight degrees southwest.

At depths greater than 10 feet the microfabric changes markedly although there is no apparent change in the mechanical composition of the till or no evidence to suggest that more than a single till is present. At 11 feet the microfabric (fig. 5) has a lineation which strikes a few degrees east of north and plunges at 25 degrees to the north. The foliation dips north-northwest at 27 degrees. At 13 feet the microfabric (not figured) has only a lineation striking north.

The till constituting the upper 10 feet of the fluting ridge is interpreted as till which was eroded from the neighboring grooves. The till was transported obliquely from the grooves and deposited to form the ridge by ice advancing parallel to the trend of the flutings. It is believed that the till was not transported far before being deposited on the ridges.

The North Battleford flutings on which this microfabric study was made form a continuation of the southeasterly-trending flutings of the Lac la Biche area of Alberta (fig. 1). It is interesting to note that the south to southwest lineation found below a depth of 10 feet in the North Battleford flutings is almost parallel to the southwest-trending flutings found north (Cold Lake) and south of the North Battleford-Lac la Biche flutings (fig. 1). Although more data are required it might be speculated that the southwest Cold Lake flutings were developed by a regional ice advance[3] and later during deglaciation the southeasterly Lac la Biche trend was produced by a local readvance or succes-

[3] This hypothesis is supported by the regional southwest fluting and drumlin trends over northern Saskatchewan shown on the Glacial Map of Canada (1958).

sive readvances of the ice—perhaps flowing parallel to the retreating ice front. If such is the case the data cast some doubt on the validity of flutings as indicators of regional ice-movement direction and suggest that fabric determinations made at depth might prove more reliable for this purpose.

ORIGIN OF FLUTINGS

It is not the purpose here to discuss the many hypotheses which have been proposed for flutings and allied features. As more data are collected, however, it becomes apparent that erosion has played a significant role in the development of such forms. The fact that flutings are well developed in sedimentary and metamorphic rocks and that such flutings are gradational to drumlins and flutings developed in bedrock or in sandy till make it certain that flutings and drumlins can be produced through erosion.

In dealing with such materials as clayey till, factors other than erosion may have a bearing on the production of flutings. Clayey till, when water saturated, is highly plastic and can be moulded and shaped quite readily. If unfrozen, water-saturated clayey till exists at the base of a glacier it could readily be pressed into tunnels or other openings at the base of the ice. Dyson (1952) has suggested that small-scale flutings could be formed in this way. The regularity of spacing, the parallelism and length of the flutings found in Western Canada all make it appear unlikely that tunnels or other basal-ice openings were responsible for fluting development. At least it is difficult to visualize how such openings could be created at regular intervals and maintained in an open state under a thick, moving ice cover.

Lemke (1958) believes, with some reservations, that those flutings (narrow linear drumlins) which contain stratified materials, " . . . were formed by glacier ice advancing over stratified deposits, eroding and shaping the deposits into ridges and then plastering a layer of till over the deposits". With the exception of the layer of plastered till the explanation given by Lemke is quite similar to that suggested by Gravenor (1953) for the origin of drumlins.

Any proposed origin must take cognizance of the following factors.

(1) Flutings and drumlins are gradational features
(2) Flutings are formed of till, stratified drift and bedrock
(3) Flutings are regularly spaced, show well-developed parallelism and are quite long (up to several miles)
(4) There is some evidence to suggest that many flutings were created by a local readvance of a glacier which overrode existing glacial deposits
(5) Preliminary fabric data show that there is lineation parallel to the ridges and foliation which dips away from the ridge tops.

From the fact that flutings are found in bedrock and in some cases contain stratified materials (Lemke, 1958) the writers believe that erosion has played a significant role in the development of such forms. The preliminary fabric data suggests that till which is found on the tops and sides of flutings was placed there, partly, through the component of ice flow perpendicular to the long trend of the ridges. Considering both of these factors—erosion and fabric—a picture can be built up of an actual process of formation. It is suggested that flutings have been developed through the action of alternating parallel high and low pressure zones at the base of the ice. Figure 6 shows a hypothetical cross-section through the base of a glacier perpendicular to the direction of ice flow. Material eroded from below the high pressure zones is incorporated with the ice and moves downstream in a curved path toward the

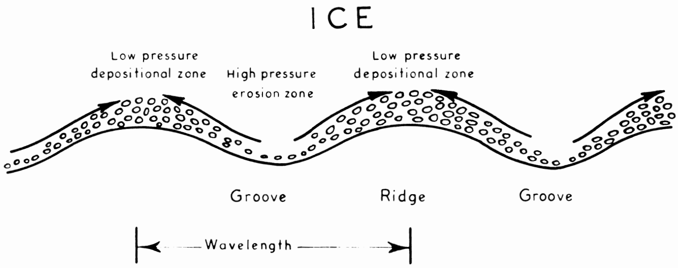


Fig. 6. Hypothetical cross-section through the base of a glacier to illustrate a possible mode of formation of flutings. Arrows indicate the lateral component of glacier flow.

low pressure zone on the sides and top of the fluting ridge. By this mechanism the ice between the grooves becomes debris-clogged and till is deposited over the core of undisturbed material. This mechanism presupposes that flutings were created from pre-existing glacial deposits—an assumption which must be made in any erosional hypothesis and is proven in the case of flutings formed in bedrock.

It is believed that this mechanism of fluting formation acounts for the erosional character of flutings, diverse composition and observed fabric. It might be argued that instead of the till being eroded from the grooves it was simply squeezed from the high pressure to the low pressure zone. Such a process necessitates unfrozen water-saturated till at the base of the ice. While this is a possibility it nevertheless enters another assumption which is unwarranted at this time. Additional work on microfabrics is now in progress at the Research Council of Alberta and it is hoped that such studies will result in a clearer picture of fluting development.

ACKNOWLEDGMENTS

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Geological Division
Research Council of Alberta
Edmonton, Alberta