MORPHOLOGY OF PRAIRIE MOUNDS

A DESCRIPTIVE ANALYSIS
OF
THE MORPHOLOGY OF PRAIRIE MOUNDS
IN SOUTHERN ALBERTA

by

DIANNE ELIZABETH JORDAN, B.A.

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree
Master of Arts

McMaster University
May 1968

MASTER OF ARTS (1968)
Geography

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: A Descriptive Analysis of the Morphology of Prairie Mounds in Southern Alberta

AUTHOR: Dianne Elizabeth Jordan, B.A. (McMaster University)

SUPERVISORS: Dr. Allan Straw, Dr. S. B. McCann

NUMBER OF PAGES: viii, 132

SCOPE AND CONTENTS:

Prairie mounds from the general area of Foremost-Cypress Hills, Alberta, have been described. Various morphometric parameters, including relative and absolute altitude of the mounds, depth of their central depressions, orientation of breaches in their rims, angle of the bounding slopes, and distribution of surficial stones were measured. Several characteristics of the mounds were found to be widespread. Firstly, the mounds occur in elongate fields that correspond roughly to the 3,000 ft. contour interval. Secondly, surficial stones invariably have their greatest concentration on the rims of the mounds. Also the mounds are frequently separated by interrupted drainage channels. The bounding slopes of the mounds are asymmetrical, with west and north-west slopes being least steep. Interpretation of these morphological observations and a consideration of the various hypotheses of formation proposed in the literature leads to the conclusion that prairie mounds most likely originated by the differential melting of a stagnant ice mass in a manner proposed by Gravenor in 1955, and have subsequently been modified by mass-wasting processes.

ACKNOWLEDGEMENTS

The present thesis is based primarily on field work carried out in the summer field seasons of 1965 and 1966, while the author was temporarily employed by the Geographical Branch of the Department of Energy, Mines and Resources, Ottawa. The work was carried out under the direction of Dr. M.J.J. Bik to complement his sedimentological-stratigraphical study of prairie mounds carried out within a broader interpretation of morphoclimatic and morphotectonic events in southern Alberta. The writer would also like to acknowledge the field assistance of Miss Diane Coleman.

The author would like to thank Drs. A. Straw and S. B. McCann of McMaster University who provided supervision and encouragement during the writing up of the thesis. The appendix on stone rings has been kindly reviewed by R. Wilmeth of the National Museum of Canada, and C. E. Heidenreich. Thanks are also extended to M. Goodchild who wrote computer programs for the Student's t-test and multiple regression analysis of the slope angle data, and to B. Luckman who lent his photograph of fossil pingoes in Wales.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(continued)

CHAPTER I

INTRODUCTION

In the northern Great Plains region of Canada, a distinctive landform, characteristically a round hill dimpled by a central depression enclosed by a rim, has a widespread occurrence. These forms are ideally quite symmetrical, and though they range from less than 15 to more than 200 meters in diameter, and from 1.5 to 10 or more meters in height, they are most frequently about 100 meters in diameter and 1.5 to 5 meters high. The central depression varies in depth relative to the highest point on the rim from 0.5 to 2.0 meters and is frequently drained by a breach in the broad rim ridge that encircles it. The landform is a "positive" form in that its dominant component is the bounding hill slope rather than the central depression, which is usually quite shallow and very rarely reaches the level of the surface adjacent to the mound. The bounding slopes of the mounds are relatively steep components of the local topography, being in the order of 5° to 10°, whereas the inner sides dip gently towards the centers. When viewed from the ground the expression of the mounds is often subtle and the lower and broader ones in particular can be easily overlooked. The mounds, however, are not merely the result of an arbitrary abstraction of a component of the general terrain, but do exist as discrete landforms. From the air, perspective, and soil moisture and vegetation patterns accentuate and enable one to see readily their arresting "doughnut"-like shape (Plates I to V).

The mounds tend to occur in groups, particularly those which are associated with undulating plains of low local relief interpreted by Stalker (1960) and Westlake (1965) as ground moraine. Mounds that are morphologically similar are also found occurring individually in hummocky moraine topography, where they usually rise to the height of the knobs in the surrounding terrain.

The Literature

Diverse hypotheses have been proposed for the origin of the mounds.

Christiansen (1965) classified similar forms in Saskatchewan as a feature of terminal moraine. The use of this term then suggests that the formation of the mounds was closely related to the margin of the glacier and, moreover, was quite possibly associated with streaming ice conditions.

Others, however, notably Gravenor (1955), Stalker (1960), and Westgate (1965) believe that the features represent a type of dead or stagnant ice morphology. Stalker largely applied and extended the theories of Hoppe (1952) to Alberta and concluded that the mounds or "plains plateaux" are the result of ice-pressing processes acting at the base of a stagnant ice mass. Two prerequesites are necessarily

Plate I. Prairie mound, with a local relief of approximately 5.2 m., about three miles to the south-east of Foremost, Alberta. To the right, a breach in the rim and a channel below it in the bounding slope are apparent. NW$\frac{1}{4}$, Sec. 1, Twp. 6, Rge. 11, W.4.

Plate II. Prairie mound topography near the southern margin of the major belt, about five miles to the south-west of Irvine. Sec. 16, Twp. 11, Rge. 3, W.4.

Plate III. A low altitude oblique of prairie mound topography shown in Plate II. The prairie mound in the foreground is about 5.4 meters high and 120 m. in diameter. This terrain was included in the Ross Creek traverse. Sec. 16, Twp. 11, Rge. 3,W.4.

Plate IV. A low altitude oblique of prairie mound topography from the major belt along its extent towards Lethbridge.

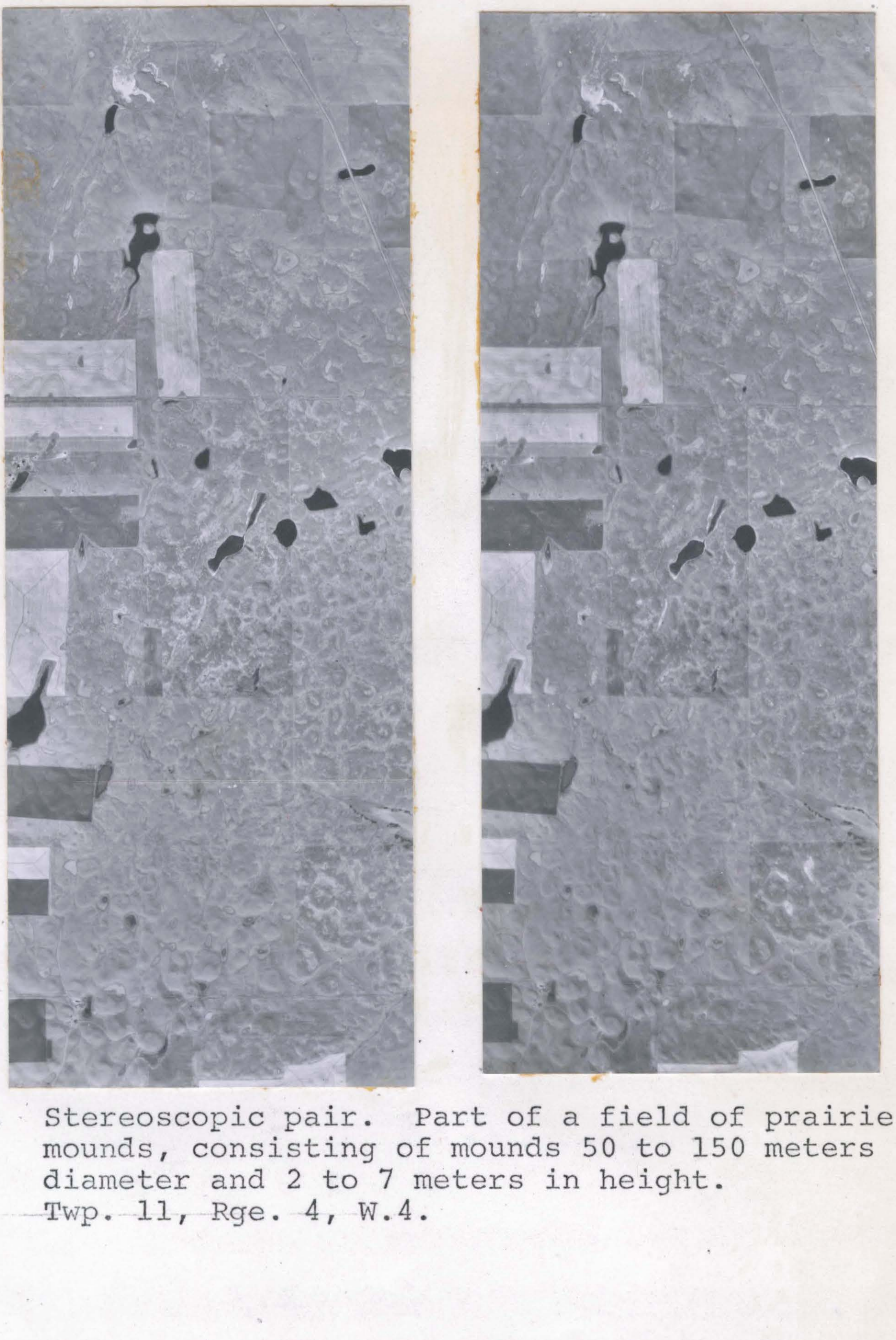


Plate V. Stereoscopic pair. Part of a field of prairie mounds, consisting of mounds 50 to 150 meters in diameter and 2 to 7 meters in height.
Twp. 11, Rge. 4, W.4.

assumed. Firstly, during deglaciation cavities of various types are present in the base of the ice, probably having arisen from water percolating down holes formed at intersections of crevasses along former fractures and shear planes that had been produced in the glacier while it was yet moving. The preservation of the holes requires that the ice-sheet be largely stagnant, and thin enough in order to inhibit plastic flow of basal ice. Also, the climate must be ameliorated enough so that the walls melt back rapidly and filling of holes with ice by calving is prevented. Secondly, the subglacial material must be either not frozen or only partially frozen, and must also contain much water, commonly being completely saturated and therefore in a highly plastic or a fluid condition. When these conditions prevail, then the process of extrusion flow of the basal material operates to form the mounds. The weight of the overlying ice on the plastic till presses it towards adjacent holes where most of the material comes to rest near the margins and only a little near the center. The ridge rises until either the nearby supply of plastic till is exhausted; or the ice margin has melted back from the ridge; or the ridge has reached a height which approximately balances the pressure exerted from beneath the ice. Superglacial streams pouring into the holes, and building deltas at their margins, and depositing fine material over the center of the holes are largely responsible for the center fillings in the plains plateaux.

Gravenor (1955) similarly associated the origin of the mounds with stagnant ice conditions, but, however, attributed them to the deposition of supraglacial and englacial ablation moraine under the control of the topography of the wasting ice surface. He observed generally that stagnant ice zones of continental glaciers reveal a wide variety of deposits and forms, including a superglacial cover of sorted and unsorted debris and large pits which are frequently water filled and contain sediments of a sorted and unsorted nature. The pits are formed either by differential ablation resulting from the heterogeneous distribution of debris on the ice surface and hence varying intensity of insolation effects, or by the collapse of caves formed below the water-table in stagnant ice by the enlargement of crevasses, or even by more rapid solution of those sections in the ice which contain lesser amounts of debris. The pits are deepened by convection-current action as long as debris in the base of the pits is permeable and allows the transfer of heat from the water to the ice. Material accumulates in the pits by mass-wasting and residual accumulation from the melting ice. As debris moves off the high areas, melting becomes concentrated there, and eventually if a considerable depth of ice below the base of the pits is present, an inversion of topography results. An ice core is left in the mound which on melting produces a central depression; if the ice below the pits is quite thin, mounds without central depressions will form as a result of direct melting.

Definition of the moraine systems on the western plains of Canada has been somewhat confused by the lack of uniformity of terminology as well as varying interpretations. Both Stalker (1960) and Gravenor (1955) note that the "plains plateaux" or "prairie mounds" typically occur on ground moraine. Gravenor does observe that the mounds are also found in areas of recessional moraine. Stalker recorded similar morphological features within hummocky morainal tracts, and although he hypothesized that they are genetically related to "plains plateaux", distinguished them on the basis of their different situation by calling them "moraine plateaux". The interpretation by both authors of the associated morainic landforms tends to be based on morphologic rather than lithologic considerations.

Westgate (1965), however, argues that the prairie mound, which he refers to as a closed disintegration ridge, has a sufficient affinity to hummocky moraine to be considered as a component of this type of topography, rather than distinguished as a different landform. This viewpoint is reflected in his mapping of the area to the west and south of the Cypress Hills. Seven types of hummocky disintegration moraine are recognized (Table 1) on the basis of such morphological characteristics as relative degree of local relief, presence of knobs and/or closed disintegration ridges,

TABLE 1

Classification of hummocky disintegration moraine, (mainly till)

(after J.A. Westgate)*

Type	Presence and nature of knobs	Presence and nature of disintegration ridges	Degree of local relief
I a)	well-defined knobs and kettles	closed and linear disintegration ridges	large local relief
I b)	aligned knobs	closed disintegration ridges	large local relief
I c)		aligned closed disintegration ridges	large local relief
I d)	aligned knobs		large to medium local relief
I e)	knobs		large to medium local relief
II a)	knobs	closed and linear disintegration ridges	medium local relief
III a)	knobs often indistinct and blowouts common	(stony surface in places; saline soils)	medium to small local relief

---

*Compiled from the legends of maps accompanying "Surficial Geology of the Cypress Hills Area, Alberta", Research Council of Alberta, Preliminary Report 65-2, 1965.

and alignment of these features. Topography found to be composed dominantly of closed disintegration ridges again occurs beyond the rest of the hummocky moraine fields and Westgate likewise finds the ridges associated with ground moraine plains. Through his morphological classification of the landform, he implies that the mounds are formed in a manner similar to the irregular knobs amongst which they are sometimes located, that is, residual accumulation of supraglacial and englacial debris from stagnant ablating ice.

Henderson (1952), in contrast to the above writers, proposed that the origin of similar mounds in the Watino Quadrangle is related to patterned ground that has been formed in a periglacial environment. Since ice contracts as the temperature is lowered below the freezing point, it is believed that freezing unconsolidated material with an appreciable water content will eventually develop frost cracks of a tensionsal origin which in places will form a polygonal pattern and may be associated with ice veins. Water migrates to the ice wedges by capillary action, the growing ice veins exert lateral pressure, bulging and raising the material within the polygon. Under the arched materials, the iniation and growth of a segregated ice lens is facilitated by a zone of negative overburden pressure. Such an ice core tends to accentuate the upheaval of the plastic till on the frozen substratum and subsequent melting may leave a central depression on the top of the mound. Melting of the ice wedges further emphasizes the relief of the mounds.

Bik (1967) is also hypothesizing a periglacial origin for the mounds,but invokes quite a different mechanism in suggesting that they are the result of pingo formation combined with subsurface displacement of plastic material. His paper is an elaboration on Mathew's hypothesis (1963) to account for similar distinctive mounded topography in the Fort St. John area of northeastern British Columbia on the lacustrine sediments of Lake Peace. The age relationships of the mounds with respect to the deposits of Lake Peace and the wide spacing of some of the mounds in Mathew's opinion precluded respectively the ablation hypothesis and the ice-wedge hypothesis. Rather, the network of intermound troughs between closely spaced mounds suggested permafrost patterns and associated local pond silts suggested some relationship to modern pingos. However, on melting, such features would leave little positive topographic relief. Probably the formation of the Fort St. John mounds involved displacement of water-saturated soil during the development of permafrost, and this soil moved at depth toward points of potential rupture where permafrost was thinnest, as for example beneath the center of shallow ponds.

Bik proposes that an abrupt drop in the levels of large proglacial lakes brought about either by a deterioration in the climate reducing melt-water run-off, or the opening of another outlet by the retreat of the ice-margin, would expose material that was unfrozen to a fair depth due to heat and insulation previously supplied by the lake water. Under periglacial conditions the unfrozen sediment with its high water content begins to freeze when exposed to subaerial temperature extremes. Owing to the probably irregular surface of the emergent zone and lesser moisture content of the topographic highs, penetration of frozen conditions takes place at different rates, being greatest under the higher areas. The varying downward progress of the freezing front towards the underlying permafrost substratum ultimately results in a series of taliks which are essentially closed systems. In any talik the upward growth of a pingo is initiated in the manner hypothesized by Müller for the development of pingos found in shallow lakes or former lake basins in east Greenland. An ice lens forms, heaving up and ultimately rupturing the overlying layers. Preceding and accompanying the process of pingo formation is the displacement of subsurface plastic material caused by pressure exerted by the higher areas of the initial relief where permafrost is established downwards more rapidly, and by volume increase of the water constituent at the permafrost boundary. The pressure gradient decreases towards the center of the depressions where the overlying permafrost layer is thinnest; therefore, movement of the plastic material tends to operate in the same direction and to accentuate the landform resulting from the formation of an ice lens. The result is an inversion of the original topography.

Subsequent melting of the ice core then leaves a symmetrical hill with a deep central depression that is infilled and modified by the deposition of lacustrine, aeolian, and mass-wasted sediments.

The theme of this study is to evaluate the two main contentions. To accomplish this, morphometric analyses of empirical-quantitative descriptions of the surface geometry and surficial materials of the mounds have been assembled. The conclusion is that the mounds most probably originated as a type of ablation moraine deposited by a stagnant wasting ice mass, and later were modified by mass-wasting and aeolian processes.

The Area

The area in which the field studies were conducted was the Foremost-Cypress Hills region in south-eastern Alberta, (Foremost map sheet (72E) 1:250,000), (Figure 1). Previous mapping of the landforms from aerial photographs done in May and June of 1965 indicated that the primary occurrence of these landforms in this area is in an almost continuous belt that extends approximately in an east-west direction from Irvine to Conrad and at an altitude of nearly 3,000 feet A.S.L. It is in this belt where the most distinct and "typical" mounds are to be found. To the north at approximately 2,500 feet elevation occasional fields, that are elongated roughly parallel to the major belt and composed of less conspicuous mounds, are to be found. Also individual features having

TABLE 2

Summary of the literature

Author	Name	Geomorphic Regime	Process
Christiansen (1965)		Streaming ice	Deposition at margin of continental glacier.
Gravenor (1955)	Prairie mound	Dead ice	Differential ablation of ice controlling accumulation of residual till.
Westgate (1965)	Closed disintegration ridge	Dead ice	Ablation; a type of hummocky disintegration moraine.
Stalker (1960)	Rim ridge a) Plains plateau b) Moraine plateau	Dead ice	Extrusion flow of plastic basal till into cavities in base of ice mass.
Henderson (1952)	Till and silt Mound	Periglacial	Arching of plastic till by growth of ice veins in polygonal contraction cracks, and subsequent growth of discrete ice lens in zone of negative pressure.
Mathews (1963)	Mound	Periglacial	Pingo formation with displacement of water-saturated soil to where permafrost thinnest.
Bik (1967)	Collapsed pingo	Periglacial	Arching of plastic till by formation of ice lens in talik, and displacement of till to upper margin of arch by development of permafrost downward from surface.

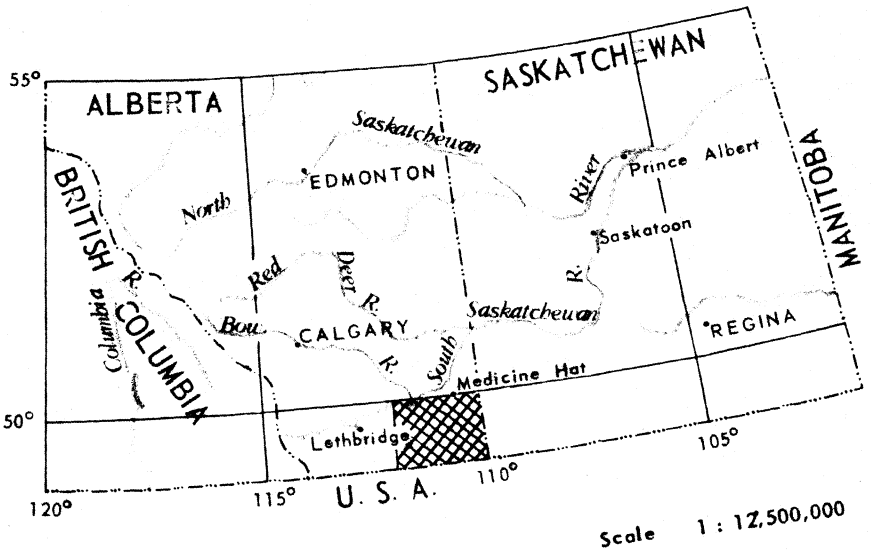


Figure 1 LOCATION OF FIELD AREA

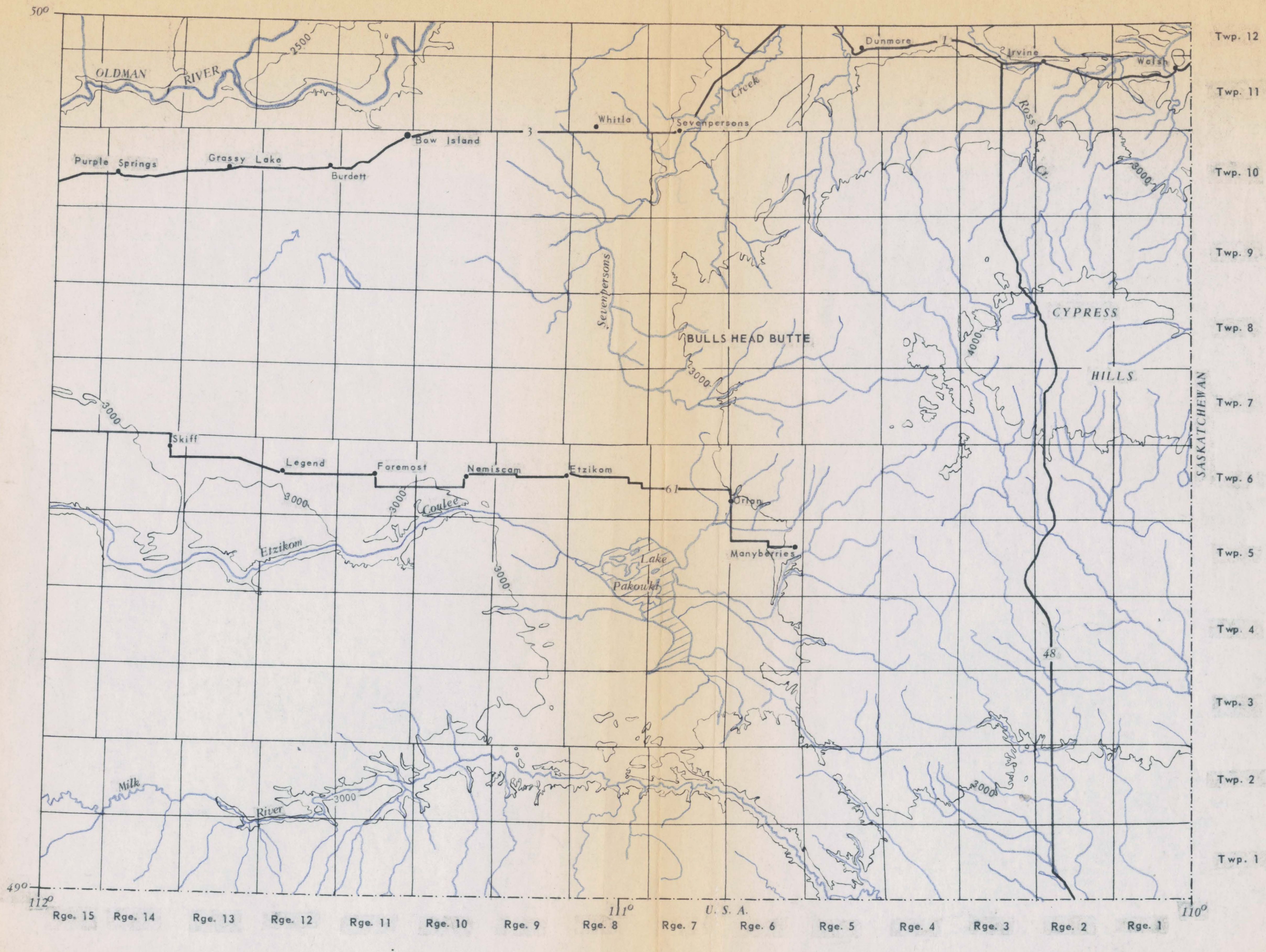
similar morphology and dimensions are situated within areas of irregular hummocky topography characterized by knobs and kettles, pressed up against the northern and southern flanks of the Cypress Hills plateau.

Field Work

Collection of data on morphometric characteristics of the landforms was carried out during eight weeks in July and August of 1966. A total of 160 mounds were measured across ~~g~~five sections of the major belt. The traverses were selected so that possible variance in the morphometry and/or surficial materials of the mounds could be assessed across the belt, over as broad an area as possible, and in relation to different physical features. Therefore, the traverses were chosen so that they extended:

i) west of Hwy 48, in a northerly direction
ii) near Bulls Head Butte, in a westerly direction
iii) near Lake Pakowki, in a north-west direction
iv) near Foremost, in a northerly direction
v) near Skiff, in a north-north-easterly direction (Figure 2).

The landform description was done with a component-characteristic organization with reasonably quantitative procedures in order to establish a degree of repeatability and objectivity of observations that would enable valid comparisons



Scale 1 : 500,000

Figure 2 FIELD AREA

after D.M.T.S.

to be made. Data was systematically collected on the relative and absolute height of the mound, depth of the central depression relative to both the opening and the highest point on the rim, orientation of the opening , angle and azimuth of the bounding slopes, general morphology of the rim, and stone cover.

CHAPTER II

ANALYSIS OF THE MORPHOMETRIC OBSERVATIONS

Preliminary reconnaisance during the summer of 1965 in the general area of Foremost-Cypress Hills suggested several characteristics of the morphology of the mounds that could bear implications regarding their mode of formation.

For example, examination of material in the central depressions of the mounds and on their bounding slopes revealed a loess-like deposit (Bik, in press), suggesting a period of periglacial conditions subsequent to the formation of the mounds. As well, the mounds seemed to have gentler slopes on their south-west aspect, further indicating a periglacial regime.

Secondly, the distribution of stones on the mounds tended to have a distinct concentration on the rims and the south-west quadrants. Such a distribution strongly suggests that the boulders may be, in fact, a lag deposit. Further study of the tendencies in the distribution of stones on the mounds and compositions of the mounds might permit a reconstruction of the original mound form. For example, breaches in the rims generally have very few surficial stones, and hence probably have undergone less erosion. These notches could correspond to and have been inherited from ruptures in debris through which an ice lens had burst (Müller, 1959); therefore, a "collapsed pingo" origin might be likely.

Mapping from air photographs and field observations indicated that the best developed mounds, that is those having the greatest relative relief and deepest central depressions, are located at higher altitudes. If the degree of development of the mounds is thus related to the general terrain, then the mounds might well have formed along the margins of pro-glacial lakes as hypothesized by Bik (1967). In the higher location, the ice lens would have had longer to develop and the resultant mounds could be expected to be larger.

Those breaches in the rim that are lower than the central depressions of the mounds seemed to occur irrespective of the regional slope on which the mounds are located. Either an ice-pressing or periglacial origin is most likely supported here. A tendency for the breaches to be oriented towards the local direction of drainage would probably suggest fluvial erosion during formation, and possibly an origin by the ablation of dead ice.

Morphometric measurements were made of relevant characteristics of the mounds so that any differences in the morphometry and/or surficial materials of the mounds could be assessed across the major belt and over as broad an area as possible. In this chapter the data are analyzed to determine if the suspected relationships occur over a widespread area, and if they are significant.

Angle and Azimuth of the Bounding Slopes

The average inclination of the bounding slope of each mound was measured to the nearest half degree with an Abney level, (which has an expectable accuracy of half a degree), in eight coordinate directions from north, through north-east, east, south-east, south, south-west and west, to north-west, as determined by a Brunton compass.

Qualitative inspection of the data suggested that the degree of slope angle varies with direction. Plotting of the slope angle data in the nature of histograms and graphs did not indicate a simple relationship between slope angle and orientation but the arithmetic mean values of the angles grouped by azimuth (Table 3) did show that in general the slopes from the south-west to the north-west had the least inclination. As well, the angle of the slope tended to increase progressively both clockwise and counter-clockwise to the east and south-east where maximum slopes were encountered.

The Student's t-test was employed to determine the significance of the apparent relationship. Only data from those mounds whose geometry was not influenced by the proximity of adjacent mounds or channels leading down from the breaches was included in the sample. The results are tabulated in Table 4. The highest t-value in the test for significant differences exists between the means of the slope angles grouped by the west and east azimuths. Iso-

TABLE 3

Arithmetic Means of Angles of Bounding Slopes Grouped by Azimuth

Location	Arithmetic Mean of Bounding Slope Angle in Degrees								Regional Slope	
	N	N-E	E	S-E	S	S-W	W	N-W	Direction	Angle
Ross Creek III	6.3	7.1	7.5	7.4	6.3	5.9	5.4	5.5	355°	0°55'
Ross Creek II	6.5	7.6	7.0	7.2	6.3	6.7	5.9	6.0	185°	0°25'
Ross Creek I	7.6	7.8	8.5	8.1	7.7	6.8	6.9	7.2	20°	1°34'
Foremost	10.5	10.8	10.9	10.4	9.4	8.1	8.2	9.3	No distinct regional slope	
Skiff	5.3	6.1	6.0	6.4	6.2	5.5	5.0	4.4	Sample not stratified	

═ Greatest slope angle mean for each sample

— Lowest slope angle mean for each sample

TABLE 4

t-Values to test for significant differences between means of slope angles grouped by azimuth

	N	N-E	E	S-E	S	S-W	W	N-W
N		0.48	0.90	0.08	0.19	1.15	2.12	0.75
N-E			0.41	0.40	0.67	1.59	2.51	1.15
E				0.82	1.12	2.04	2.98	1.54
S-E					0.28	1.24	2.21	0.83
S						0.99	2.01	0.60
S-W							1.03	0.22
W								1.06
N-W								

Significance Levels at 77 Degrees of Freedom

0.85	80%
1.29	90
1.67	95
1.99	97.5
2.37	99.0
2.64	99.5

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\sigma_1^2/N_1 + \sigma_2^2/N_2}}$$

where $\bar{x}$ represents mean

σ^2 σ^2 " variance

N " population

pleths drawn for significance levels then decrease outwards more or less concentrically about the high value. This statistical expression of the variance of bounding slope angle with azimuth verifies the relationship suggested by the subjective interpretation of the raw data, and establishes its numerical significance. For the same population as used in the Student's t-test, a frequency diagram (Figure 3) of the direction the least angle of the bounding slope for any given mound has been drawn, and it can be readily seen that the lowest slope angle faces to the north-west and west most often.

Multiple regression analysis was then employed to determine if the slope angle is significantly related to slope aspect, relative height of the mound, regional slope angle, and regional slope aspect. The hypothesis that the slope S_{ij} of mound j at the i^{th} aspect can be expressed by the model

$$S_{ij} = A_j \sin 0_i + B_j \cos 0_i + C_j$$

where 0_i represents the slope aspect, and A_j, B_j, and C_j are fitted for the mound, and further that

$$A_j = A' + B'\sin\alpha_j + C'\cos\alpha_j + D's_j + E'z_j$$

$$B_j = A'' + B''\sin\alpha_j + C'\cos\alpha_j + D''s_j + E''z_j$$

$$C_j = A''' + B'''\sin\alpha_j + C'''\cos\alpha_j + D'''s_j + E'''z_j$$

where α_j represents aspect of the regional slope, s_j represents the regional slope, and z_j represents the relative height of

Figure 3

Occurence of Lowest Angle of Bounding Slope of any Given Mound by Azimuth

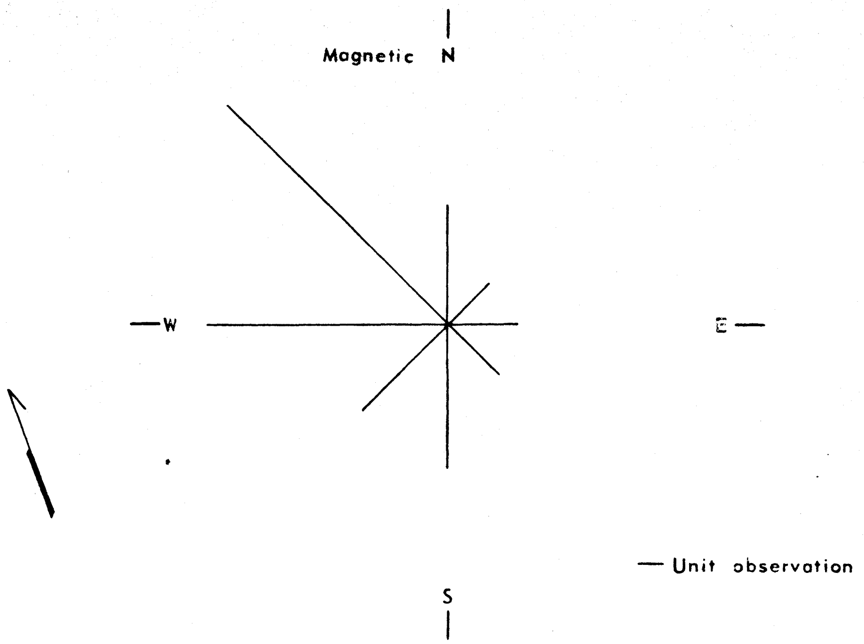
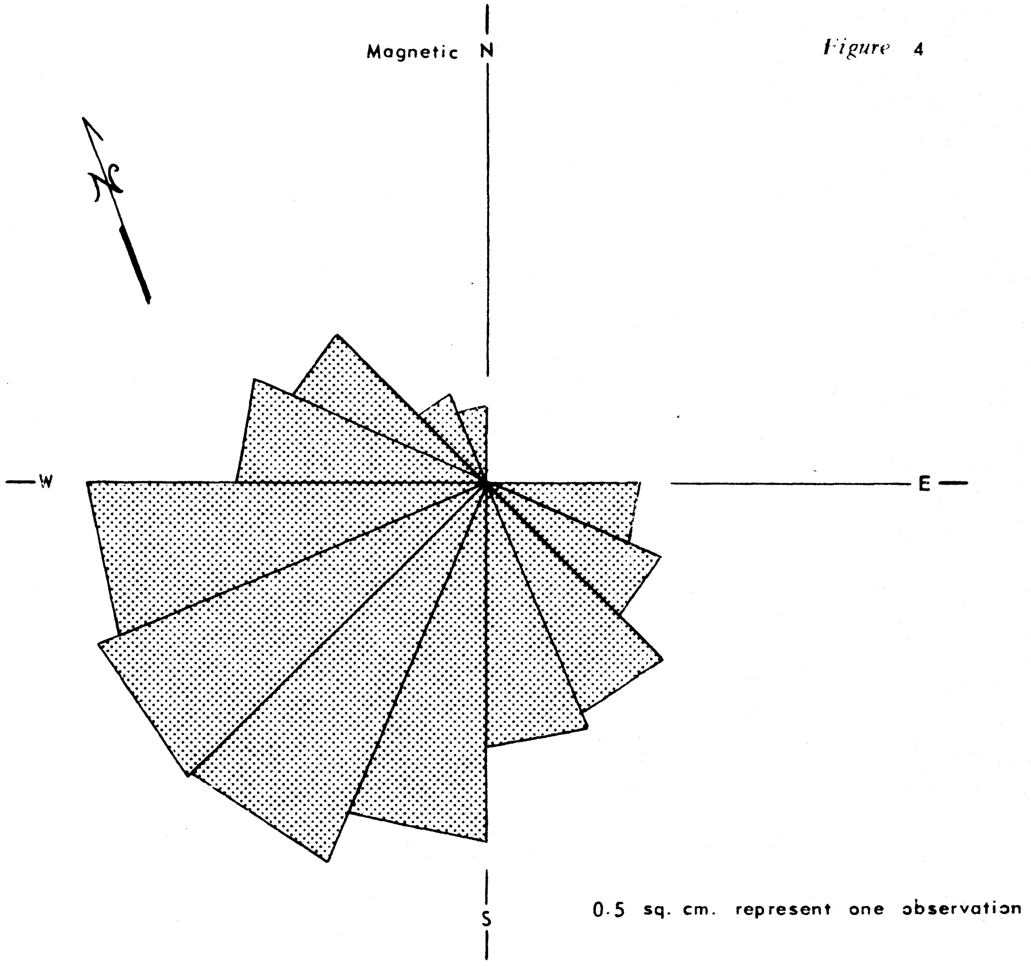


Figure 4



Occurence of Greatest Density of Stones having Furthest Downslope Extent on Bounding Slopes of Mounds with Respect to Slope Aspect the mount was tested. The results are interesting but indicate that the variables chosen and/or the model do not generally provide a very high degree of statistical explanation for the relationship between slope angle and azimuth which is suggested by the significant differences in the slope values when grouped by azimuth. The correlation coefficients for the individual mounds where slope is the independent variable and direction the dependent variable were greater than 0.75 for only thirty-two mounds out of a sample ofseventy. The degree of explanation added by taking regional slope aspect and angle, and relative height of the mound into account was negligible, the coefficient of A_j for the entire sample being 0.08, B_j 0.26, and C_j 0.001.

Distribution of Surficial Stones:

For each of the mounds the distribution and concentration of surficial stones were described, their occurrence being noted in terms of the component slopes of the mound and their density denoted by a somewhat subjective scale ranging from none, through few, minor, and moderate, to abundant. A concentration of few stones describes a distribution of one or less stones per square meter; minor two or three stones per square meter; moderate about four to seven per square meter; and abundant greater than seven. Very abundant is used to describe an almost uninterrupted stone pavement. These descriptions were subsequently mapped on stylized diagrams of the "ideal" symmetrical mound. (Appendix I).

A high proportion of the stones are igneous erratics, probably originating from the Canadian Precambrian Shield area. Many have a diameter greater than fifteen cm. and rocks more than one meter in diameter are not uncommon (Plate VI). The stones on the mounds, except for two mounds studied to the north-west of Lake Pakowki, are invariably imbedded in the sod to varying depths, as well as encrusted with mosses. They range in roundness from sub-angular to sub-rounded, and none appear to have been frost shattered since their deposition.

Visual analysis of the diagrams reveals that several characteristics of the distribution of the stone cover on the mounds remain similar both across the belts and throughout the Foremost-Cypress Hills area. The greatest concentration of stones on any mound is usually on the rim. Frequently the cover of stones on the rim is interrupted or less dense across the breaches, including only minor dips that do not provide surface drainage for the central depression. This relationship between decreased stone cover and notches in the rim is sometimes even carried downslope from the breach on the outer slopes of the mound. When concentration of the stone cover does vary on the rim, the greatest densities are to be found on the highest segment. Stones on the rims of at least thirty-seven of the mounds observed have been

Plate VI. Two boulders, each greater than one meter in diameter, near the crest of the rim of the prairie mound illustrated in Plate I. The boulder to the left is visible in the first plate in front of the channel.

NW.$\frac{1}{4}$, Sec. 1, Twp. 6, Rge. 11, W.4.

arranged into stone circles and small clusters, most probably remnants of tipi-rings and fire hearths left by pre-historic and proto-historic occupants (Appendix 2) , but a comparison of these mounds with those where no rings are found indicates that the distribution and density of the stones has probably not been significantly altered by human agents.

The central depressions are often devoid of stones and even when concentrations do approach "minor" the stones here are generally less than fifteen cm. in diameter. Moreover, they are not imbedded in the sod, but instead are found in shallow saucer-shaped hollows that have no vegetation and are no more than about two meters in diameter and ten cm. in depth.

On the bounding slopes, the greatest concentration of stones and the furthest downslope extent below this concentration lies between south-east and north-west, the extremes of the spread extending from east clockwise to north, and only infrequently coinciding with the north-east quadrant. The correlation of surficial stone concentrations and slope aspect is quite striking in Figure 4 where the occurrence of the furthest downslope extent of the greatest stone concentration, when this has been at least moderate or abundant, has been plotted with respect to the direction of the bounding slope by sectors of $22\frac{1}{2}^{\circ}$. For any one mound where the stones extended equally downslope in more than one sector, as they often did, one occurrence was recorded for each relevant sector. The histogram is based on data accumulated throughout the entire field area but only those mounds whose geometry is not appreciably affected by the proximity of other landforms or channels leading down from the central depression were included. A unit observation is represented areally by 0.5 square centimeters. Where this relationship is not found either the bounding slopes to the south-west lead to the central-depression of an immediately adjacent mound, or else only minor concentrations of stones at most are to be found on the mound. The spread of stones on the bounding slopes thus appears to be strongly related to slope aspect and relatively unaffected by other variables such as direction or angle of the regional slope.

Concentration of surficial stones on the bounding slopes does vary as the slope angle. On Figure 5 the relative density of stones on the south-west exposure of the bounding slopes of those mounds whose geometry had not been complicated by the proximity of other features, has been plotted with respect to slope angle. Both the arithmetic mean and median value of the slope angle for each category of stone concentration increase progressively as the abundance of surficial stones. The degree of significance of the relationship is, however, somewhat lessened since the upper and lower values of each category do not increase regularly.

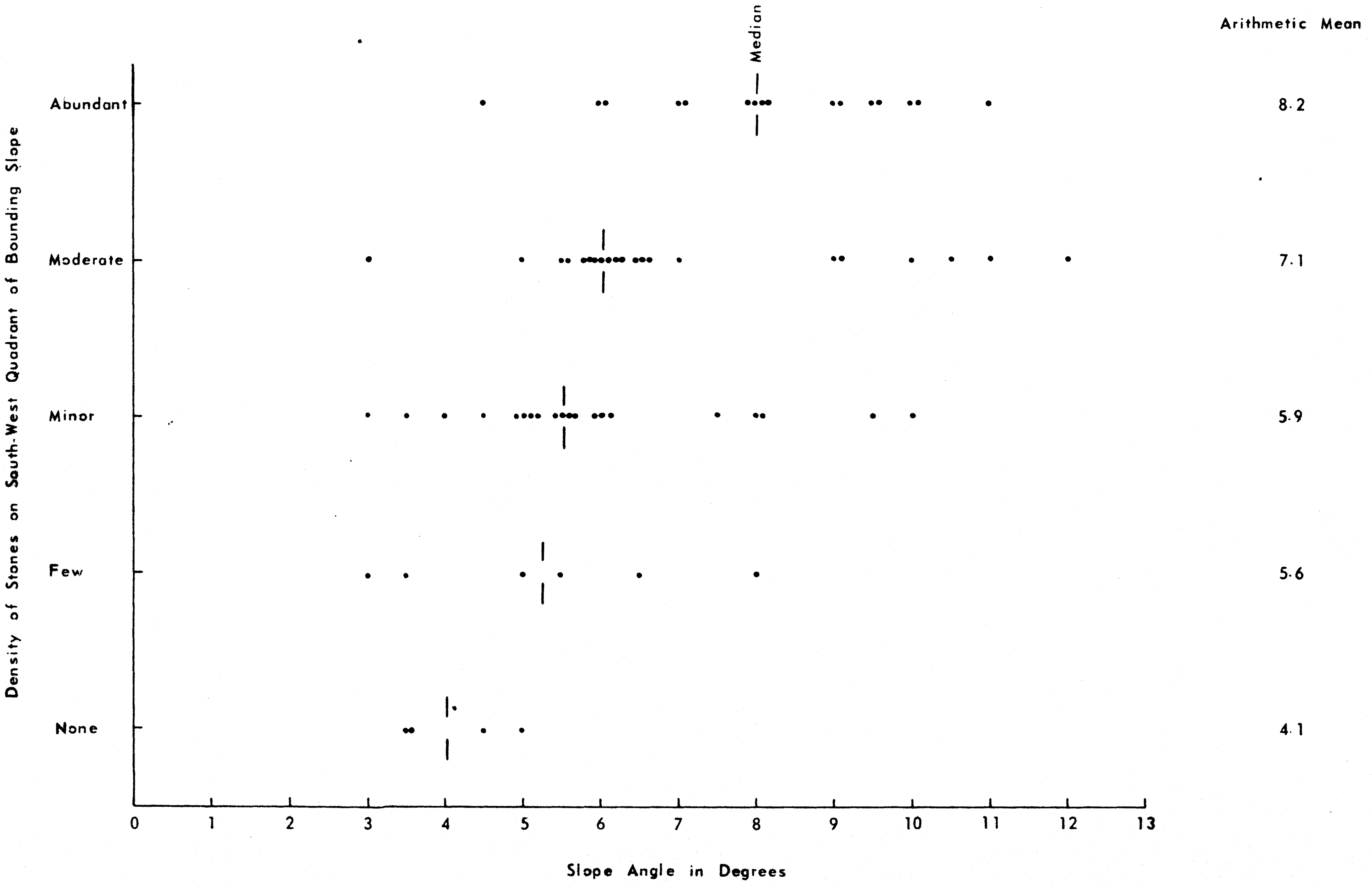

Median
Arithmetic Mean
Density of Stones on South-West Quadrant of Bounding Slope
Abundant
Moderate
Minor
Few
None
8·2
7·1
5·9
5·6
4·1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Slope Angle in Degrees

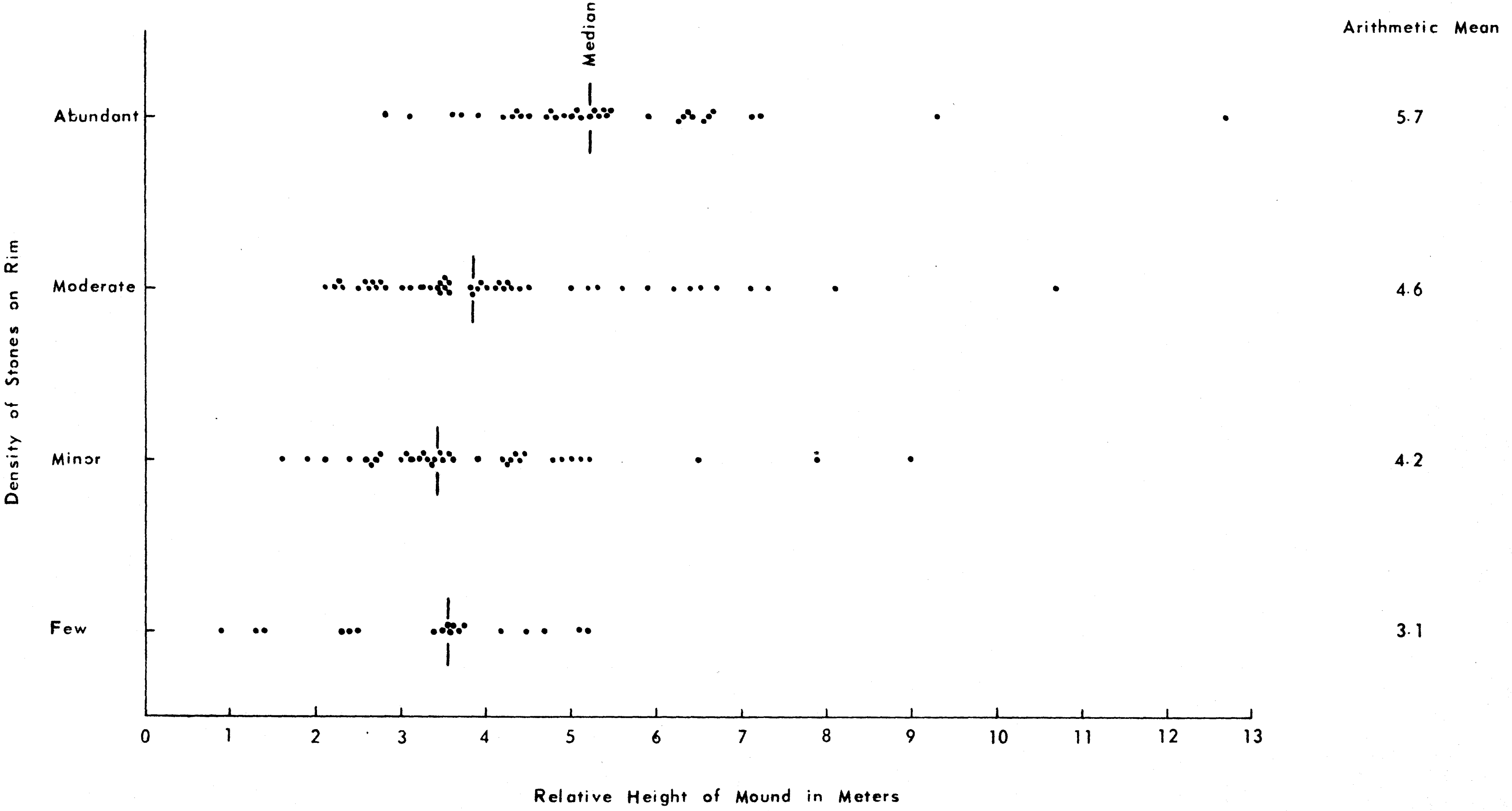
Figure 5

The abundance of stones on any given mound, estimated as that concentration which characterizes more than half of the rim of the mound, tends to increase as the relative height of the mound. This is illustrated on Figure 6 where it can be seen that the arithmetic mean of the relative heights of the mounds increases as the abundance of stones. Also both the upper and lower end values of each category systematically increase as the stone concentrations on the rims increase. The median values for the members of each category show the same general trend except for the "few" group which is slightly higher than for the "minor" group.

The surficial stones on the mounds do not show any such straightforward relationships with the absolute height of the mounds, however (Figure 7). In the Lake Pakowki area mounds at higher elevations show a slight tendency to be characterized by a lesser concentration of stones but throughout the entire region this trend does not hold.

Development and Elevation of the Mounds

The relative heights of the mounds, that is, the difference between the highest point on the rim and the adjacent intermound depression, and the maximum depths of their central depressions were determined simply by measuring the distances between the relevant points with a tape measure and the angles with an Abney level, and then making the necessary elementary trigonometric calculations. Allowing a possible half a degree of error in using the



Median
Arithmetic Mean
Abundant
Moderate
Minor
Few
5·7
4·6
4·2
3·1
Density of Stones on Rim
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Relative Height of Mound in Meters

Figure 6

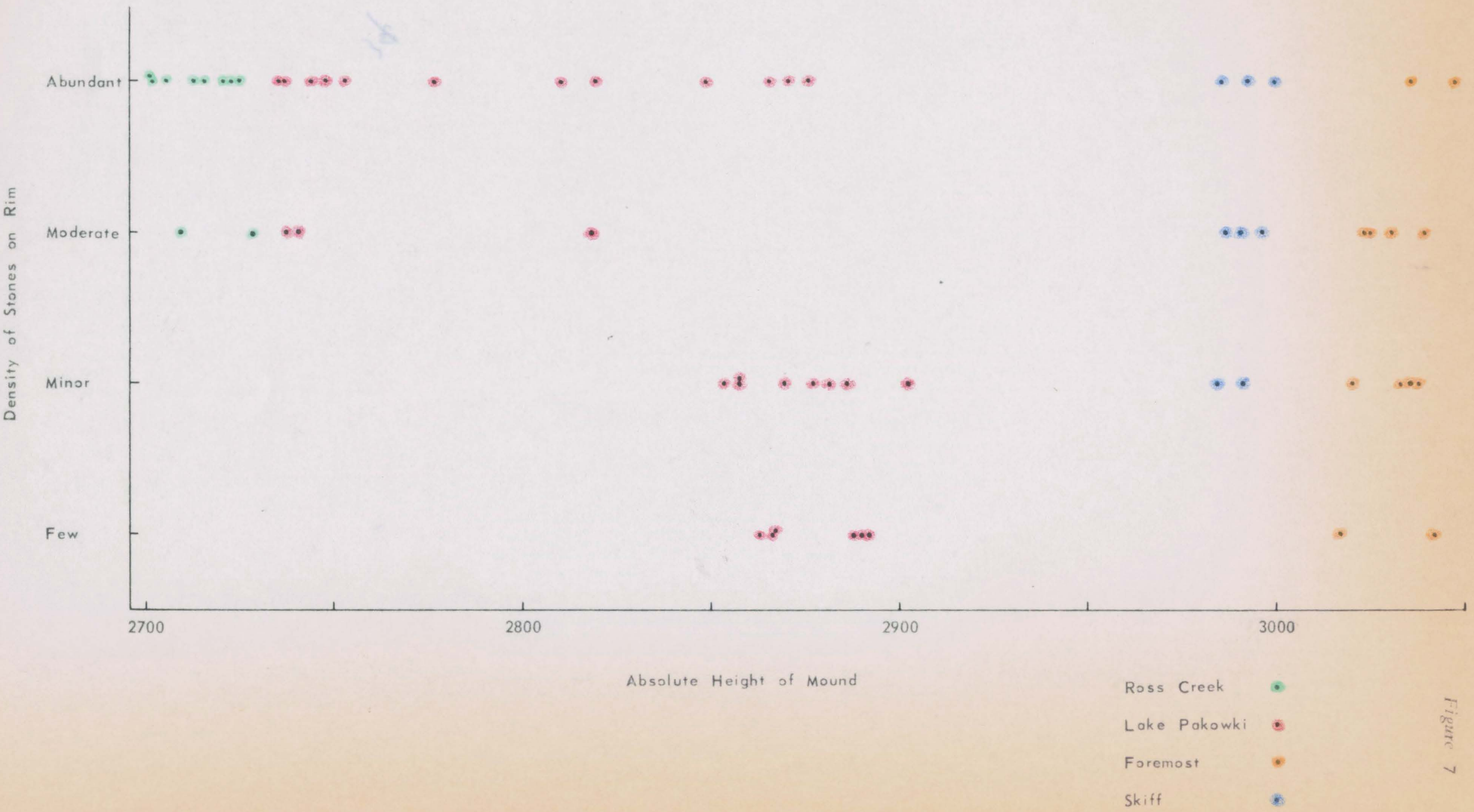

Density of Stones on Rim
Abundant
Moderate
Minor
Few
2700
2800
2900
3000
Absolute Height of Mound
Ross Creek
Lake Pakowki
Foremost
Skiff

Figure 7

Abney level, the greatest possible range of error in determining relative local relief is nearly ± 0.8 meters.

The local relief of individual mounds is plotted on Figure 8 with respect to their absolute altitude that have been estimated by aneroid barometer. Here it is evident that no relationship seems to exist between the relative and absolute heights of the mounds. The range of relative heights of the mounds is considerable on all the traverses and occurs irrespective of the general increase of altitude of the mounds from east to west.

The height of the mounds does, however, appear to vary directly as the maximum depths of their central depressions (Figure 9). An index, the depth of the central depression of the mound as a per cent of the relative height of the mound, was devised to express the characteristic morphology of the mounds. This was plotted against the absolute altitude of the mounds in the Lake Pakowki and Skiff areas on Figures 10 and 11 respectively. In both traverses, the central depression tends to more nearly reach the level of the surface adjacent to the mound as the elevation of the mound increases. At the higher elevations, however, depressions that are shallow relative to the height of the mound are also found. Therefore, the relative heights of the mounds tend to be independent of their absolute heights and the definition of the mounds in terms of the depth of their central depressions in relation to their height is

Figure 8

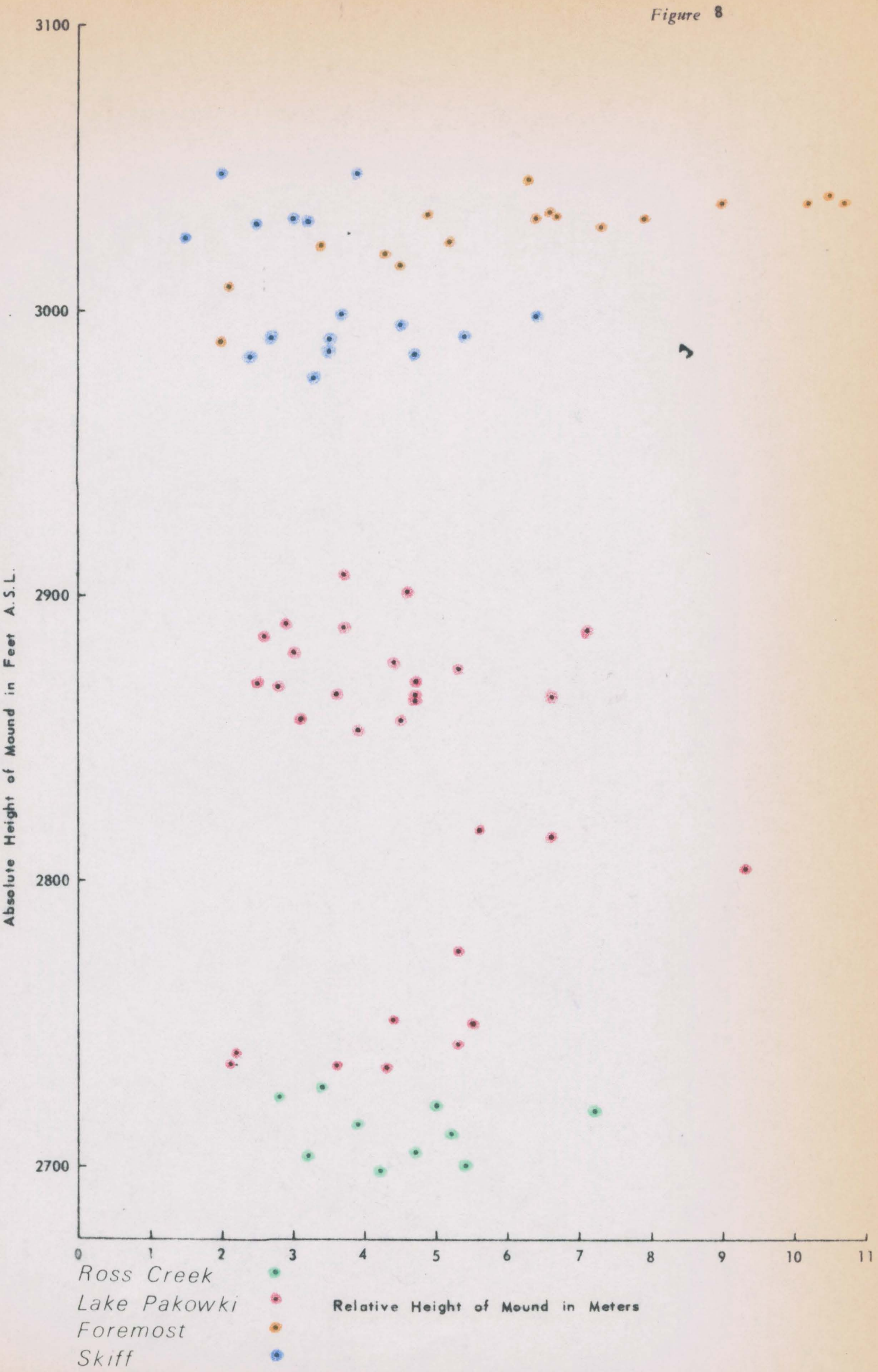

3100
3000
2900
2800
2700
Absolute Height of Mound in Feet A.S.L.
0
1
2
3
4
5
6
7
8
9
10
11
Relative Height of Mound in Meters
Ross Creek ●
Lake Pakowki ●
Foremost ●
Skiff ●

Figure 9

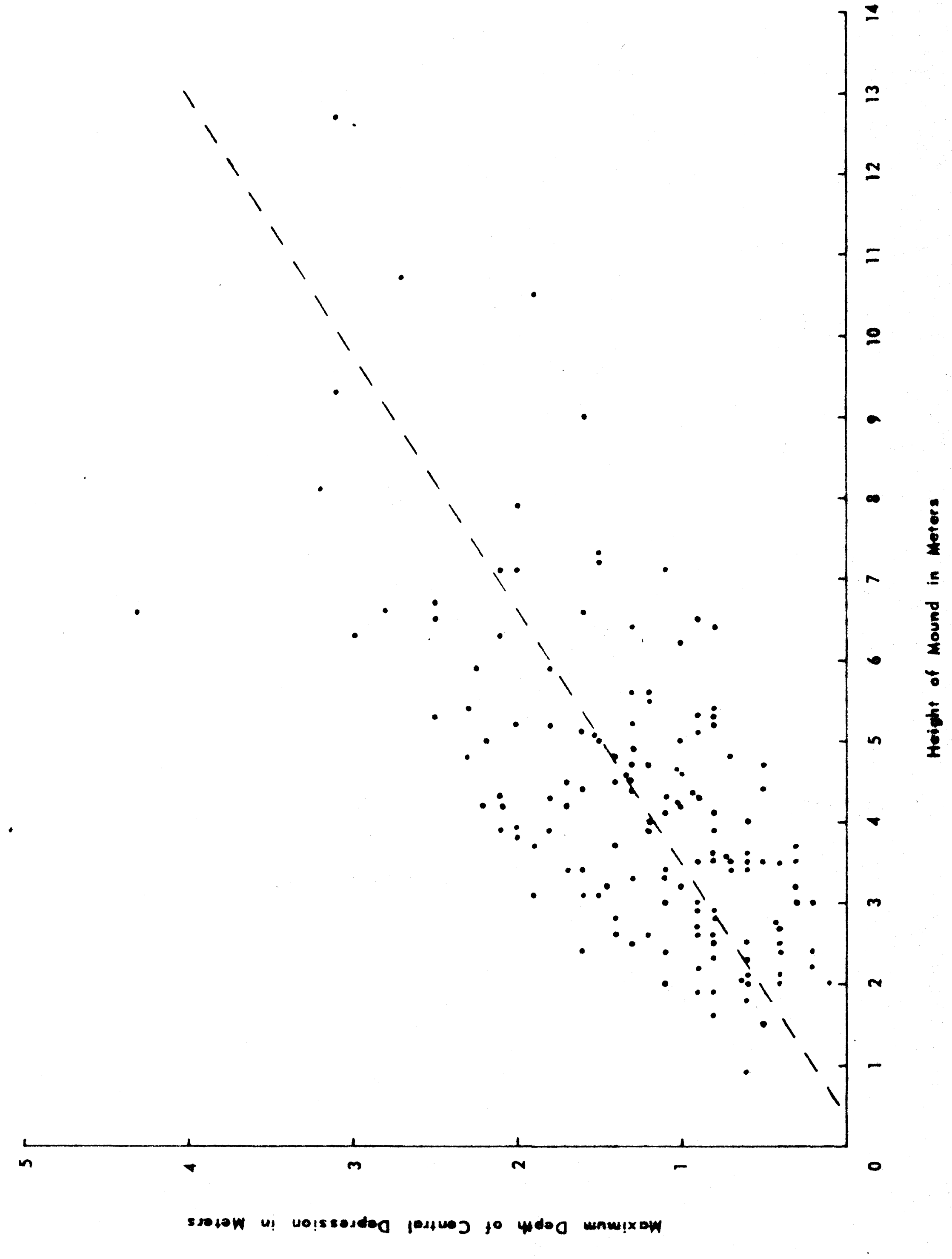
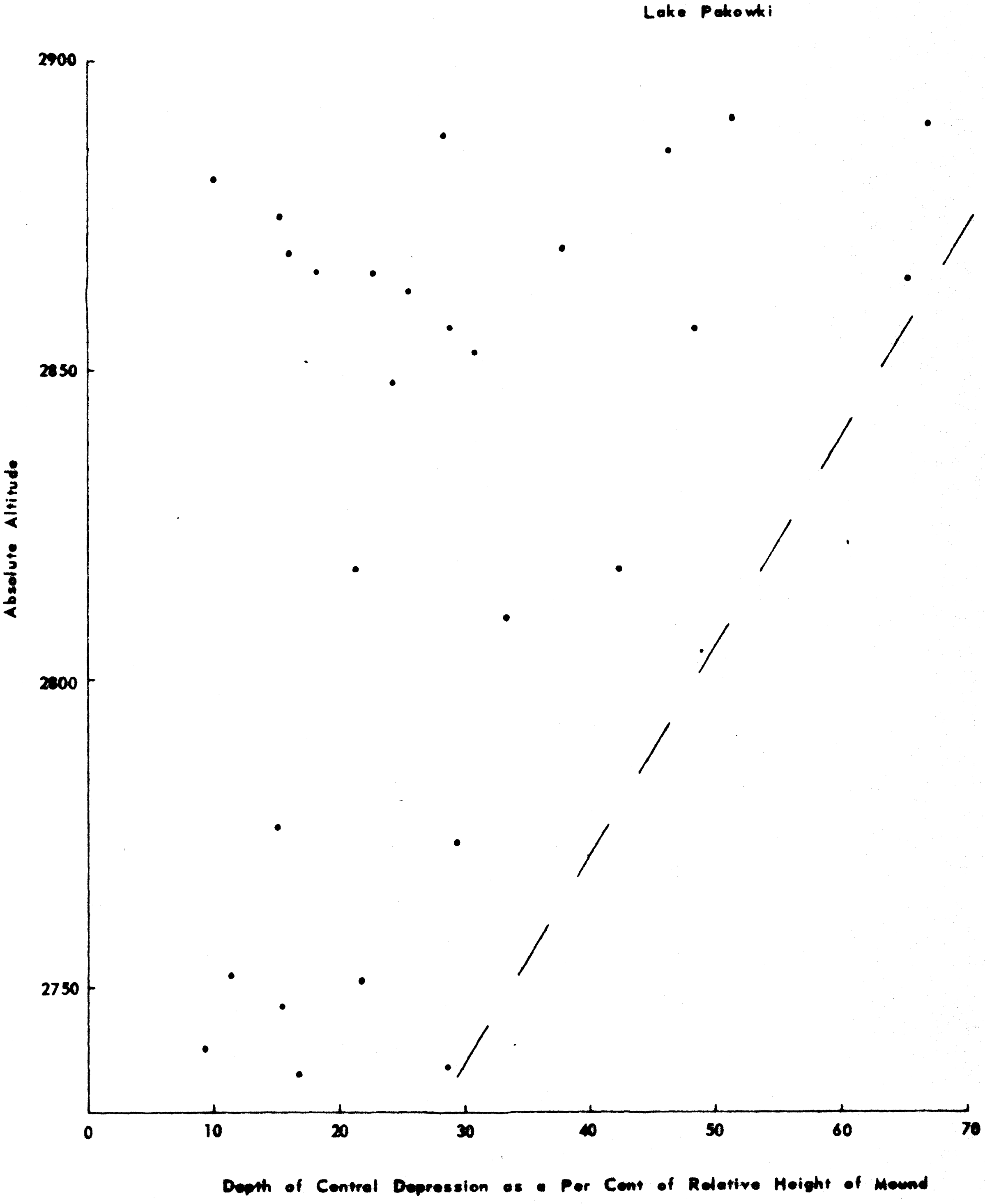
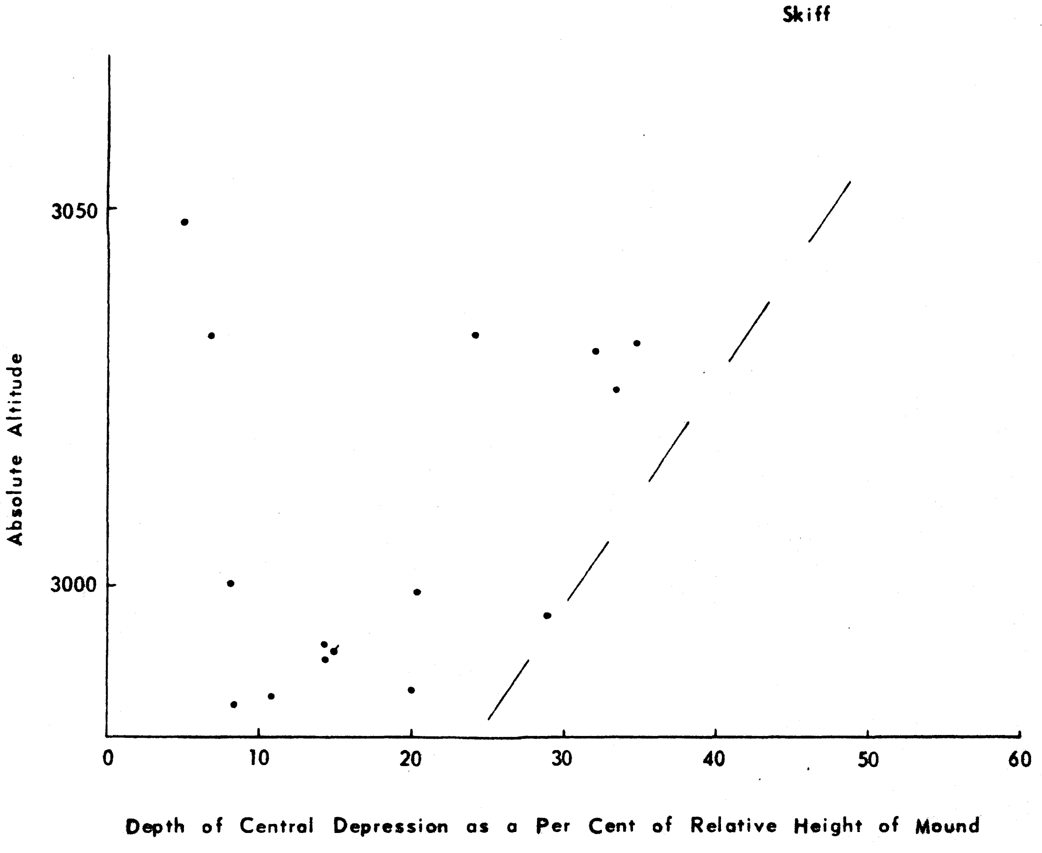

Maximum Depth of Central Depression in Meters
0
1
2
3
4
5
Height of Mound in Meters
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 10


Lake Pakowki
2900
2850
2800
2750
Absolute Altitude
0
10
20
30
40
50
60
70
Depth of Central Depression as a Per Cent of Relative Height of Mound


Skiff
3050
3000
Absolute Altitude
0
10
20
30
40
50
60
Depth of Central Depression as a Per Cent of Relative Height of Mound

more variable as the altitude increases.

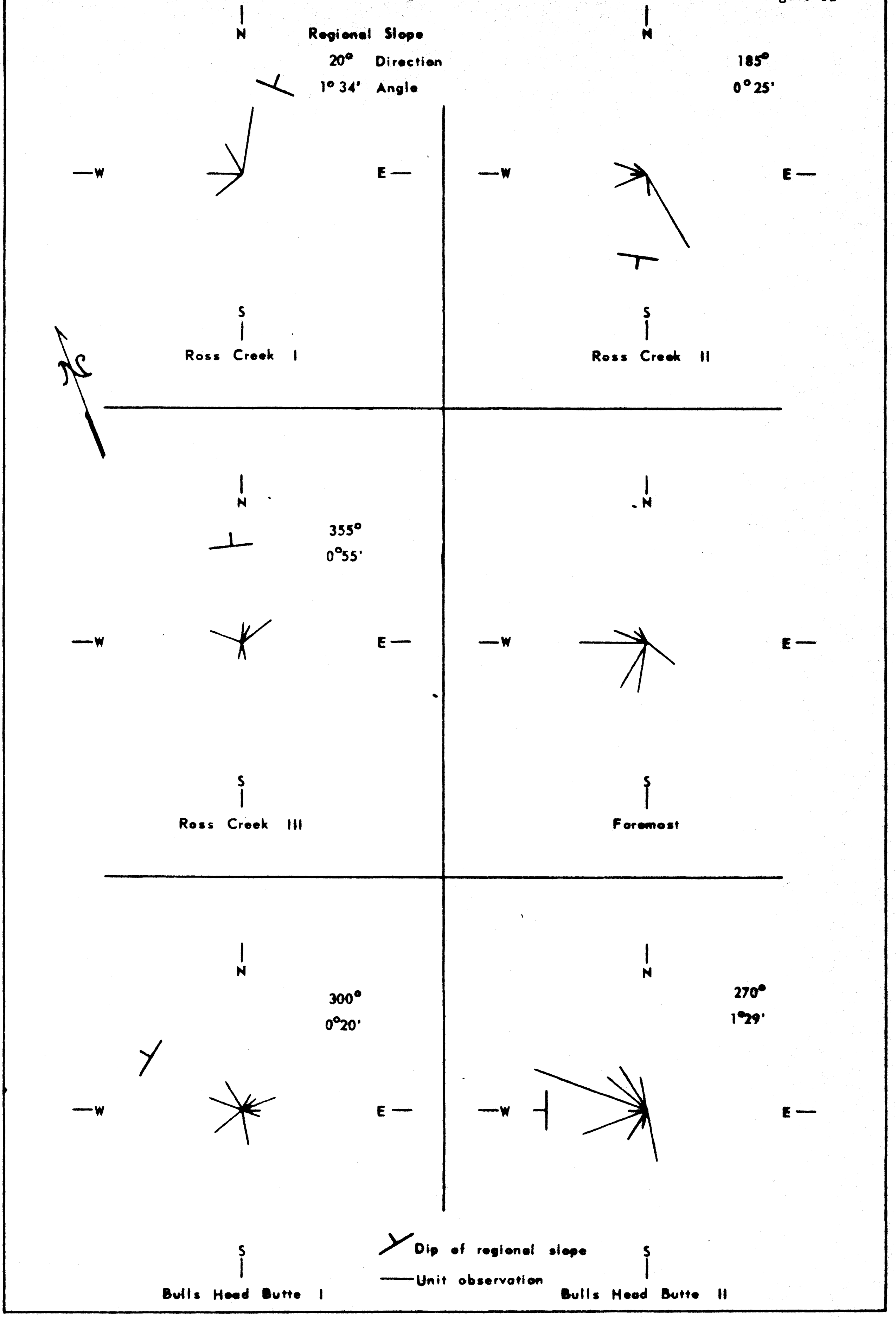
Orientation of the Breaches

On Figures 12, 13 and 14, the orientation of the major and minor breaches have been plotted with respect to traverse and the direction of the immediate regional slope on which the mounds are located.

The direction of the major breaches, that is, those notches in the rim whose base is below the floor of the central depressions and permit surficial drainage of these depressions, exhibits a relationship to the dip of the immediate regional slope. This is reflected in the diagrams I and II for the Ross Creek area where the dominant orientation of the breaches changes with the regional slope across a broad valley-like profile on which the mounds are located. A similar relationship is found in the second diagrams of both the Bulls Head Butte and Skiff Traverses, as well as in the Foremost area. The apparently anomalous situation in the first Skiff diagram probably reflects insufficient data (three mounds). Although the relationship between regional slope and orientation of major breach appears quite random in the Bulls Head Butte I and Ross Creek II diagrams, it is especially clear in the second Bulls Head Butte diagram. It is in this area that the angle of slope is greatest; however, the relationship does not necessarily seem to be influenced by the regional slope angle. In the Foremost area, where no distinct regional slope can be established since the mounds

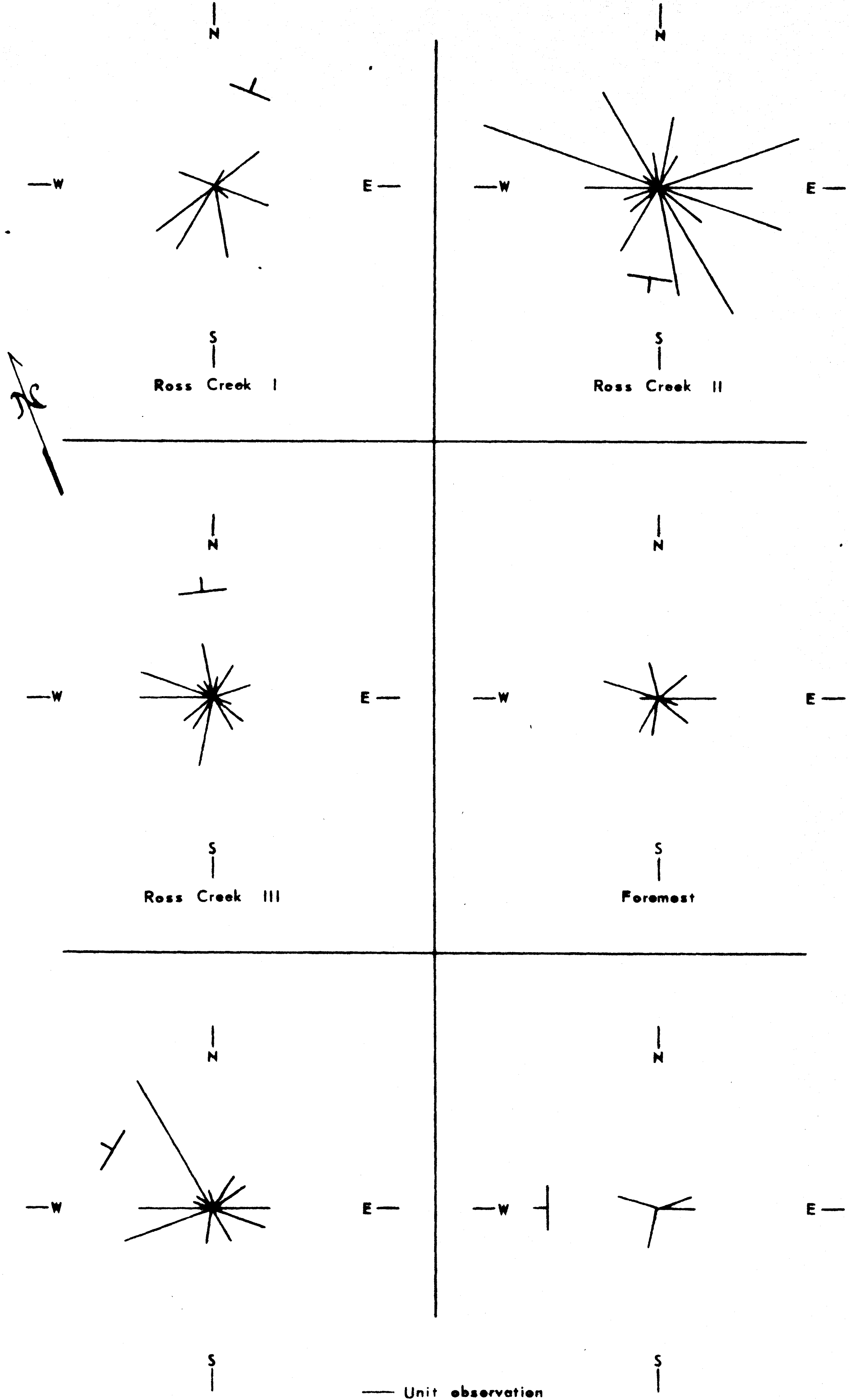
Figure 12

Orientation of Major Breaches by 20° Classes



Orientation of Minor Breaches by 20° Classes

Figure 13



Ross Creek I

Ross Creek II

Ross Creek III

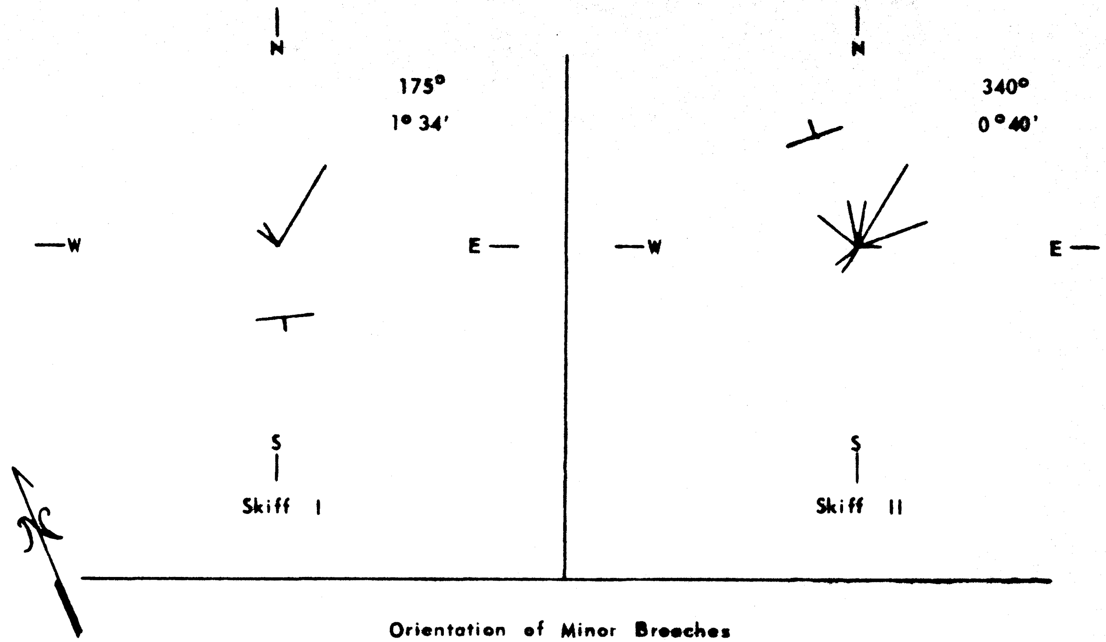
Foremost

Bulls Head Butte I

Bulls Head Butte II

Figure 14

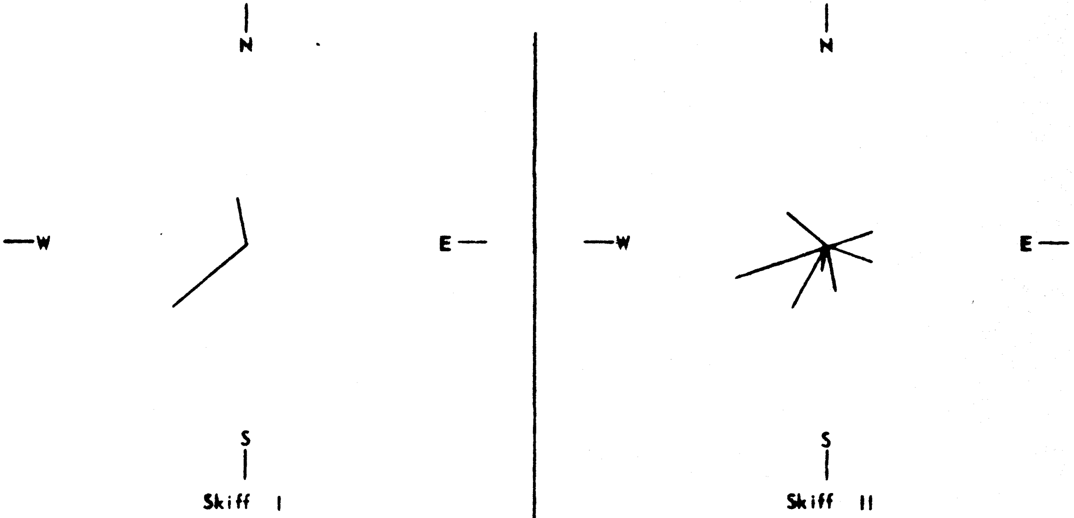
Orientation of Major Breaches



Skiff I

Skiff II

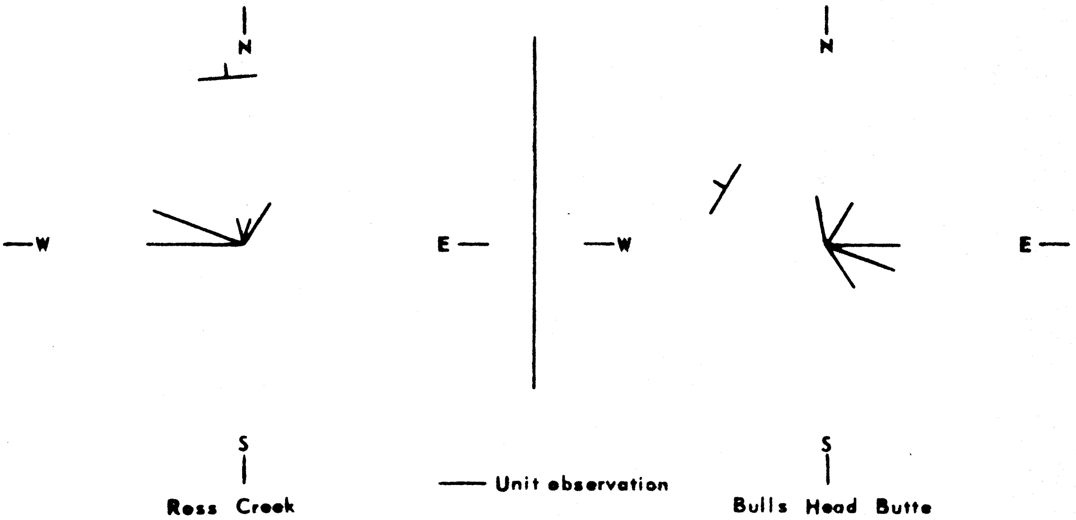
Orientation of Minor Breaches



Skiff I

Skiff II

Orientation of Lowest Minor Breach of Enclosed Central Depressions



Ross Creek

Bulls Head Butte

are situated on the top of a broad ridge, the majority of the breaches open towards the south-west.

Only one example of integrated drainage within the major belt of mounds, which was near Bulls Head Butte, was noted throughout the entire field area. However, on air photographs and even occasionally on contour maps, enclosed intermound depressions are found to be aligned in patterns that are similar to normal fluvial channels and have a gentle gradient, interrupted only by the low saddles that enclose the depressions. In the Ross Creek and Foremost areas (Figure 15) the major breaches draining the central depressions of the mounds tend to be confluent with such channels.

The orientation of the minor breaches, that is, those notches in the rim that are higher than the lowest part of the central depression , is considerably more random. Any trends reflect the proportion of mounds that have enclosed central depressions, and the general orientation of the major breaches. Where the major breaches are strongly oriented down the regional slope and the sample contains few mounds with enclosed depressions, (Ross Creek I and Foremost I, and Bulls Head Butte II and Skiff II diagrams), then the minor breaches open randomly in directions other than the major breaches and there is little overlap. On the other hand where a large percentage of the mounds have no major breach, (Ross Creek I and III, Bulls Head Butte I), then the minor

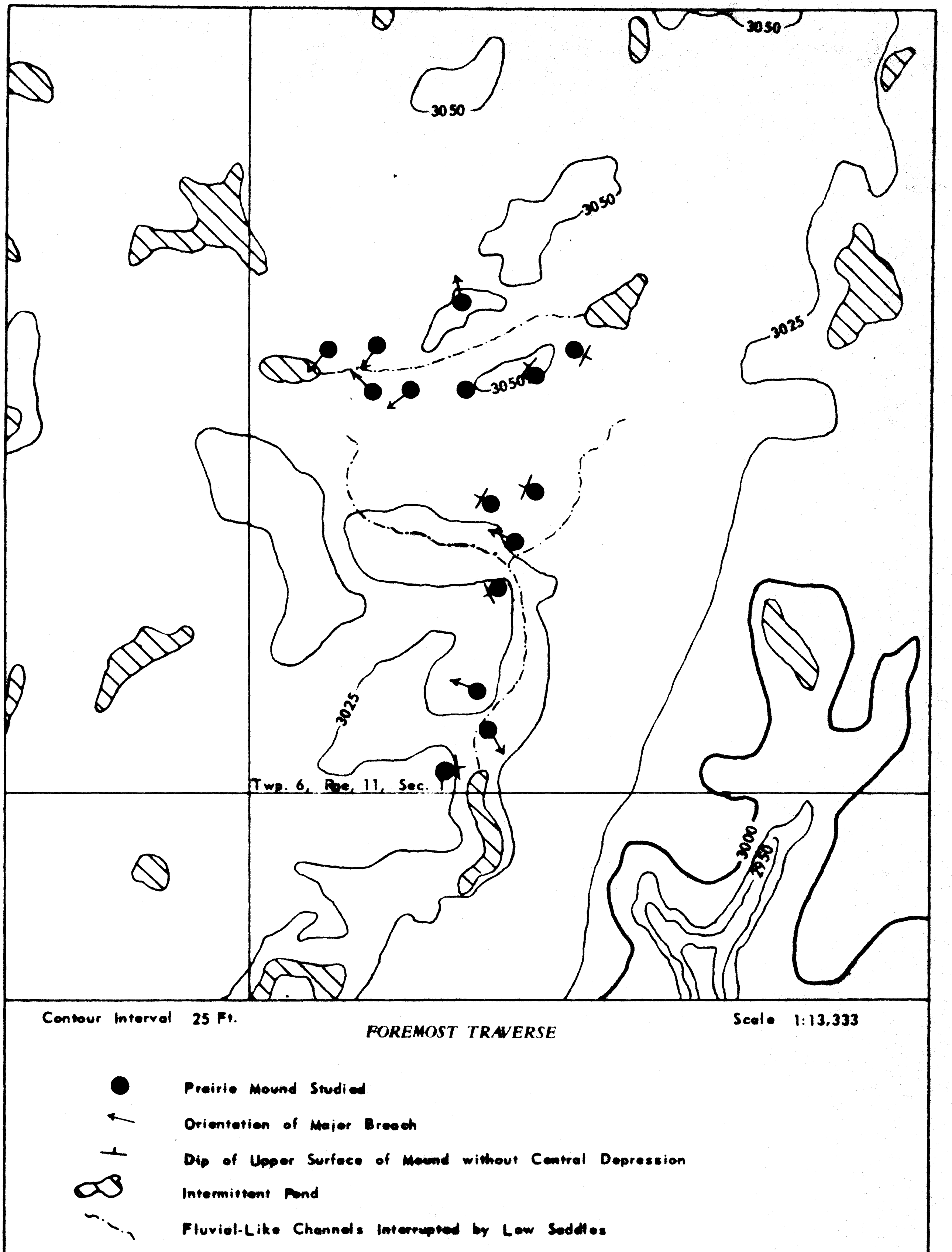


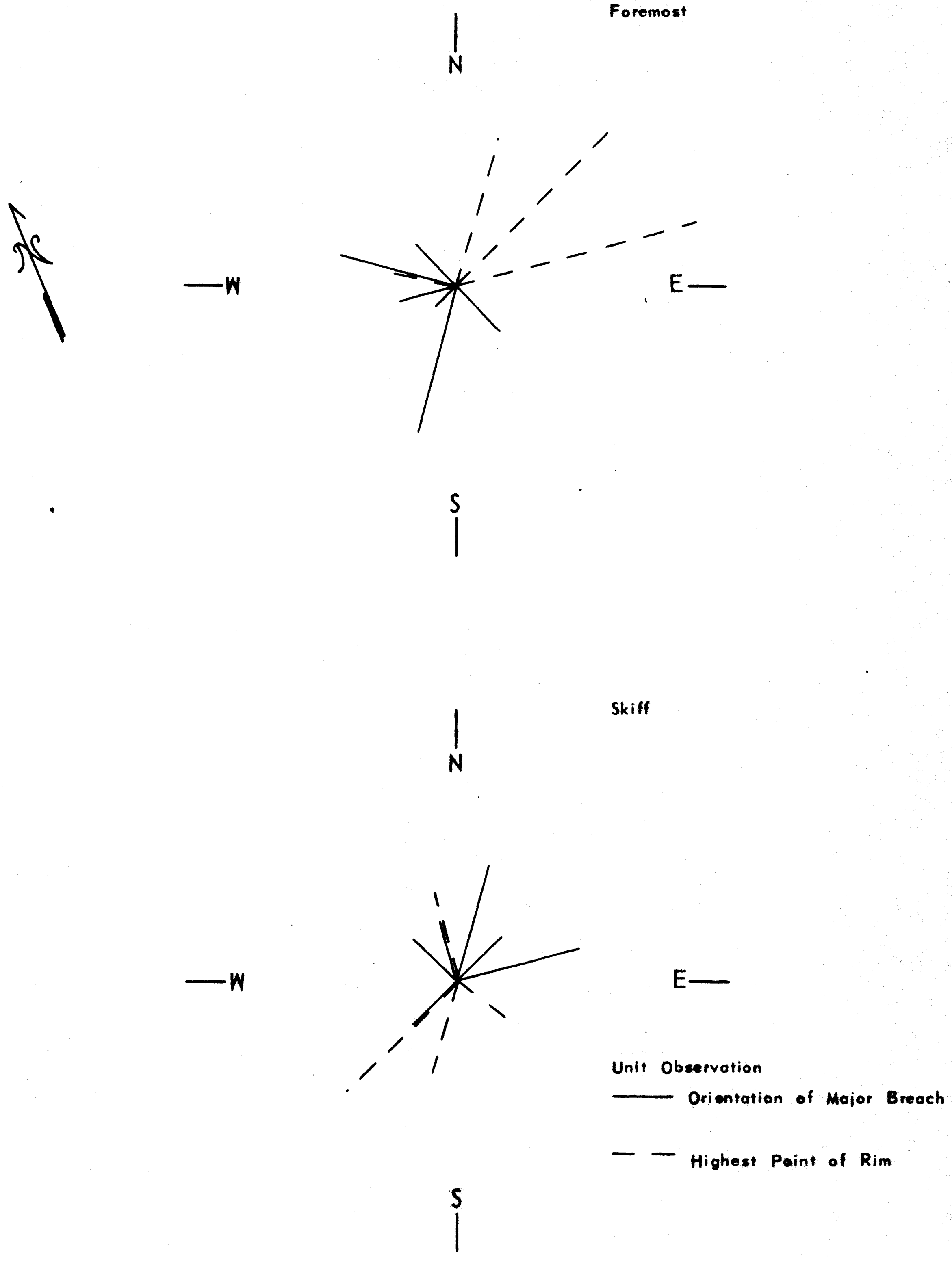
Fig. 15 Orientation of breaches of mounds in relation to their topographic site.

breaches do tend to coincide more with the major breaches. This concentration does not consist of the lowest minor breaches of the enclosed mounds in the Bulls Head Butte area, but they do contribute to it in the Ross Creek area.

Stalker (1960) observed that, in most of the plains plateaux he examined, the rim edge was equally high about each; but occasionally in the Peace River country, the southeastern sector was higher than the rest. In the Foremost-Cypress Hills area, the rims of all the mounds were broken by notches ranging in number from one to four. Moreover, the orientation of the highest segment of the rim was not constant but tended to be influenced by the location of the major breach in the rim (Figure 16). Even those features found in association with the typical prairie mound landforms which had a rounded convex upwards summit rather than a central depression usually had a distinct break in slope between the upper surface and bounding slope. The plane of this break in slope generally had a noticeable dip.

Figure 16

Frequency Distribution of Highest Point of Rim of Mound with Respect to Orientation of Major Breach in 30° Classes



CHAPTER III

INTERPRETATION OF THE OBSERVATIONS

Assessment of the geomorphological implications of the analysis of the detailed morphological characteristics of the prairie mounds can now provide the basis for evaluation of the various proposals for the formation of the mounds.

Any such task must of course be done with reference to the regional context and distribution of the mounds.

Regional Distribution

A stagnating ice front theory is not generally inconsistent with the distribution pattern of the prairie mounds. The great lateral extent of the belts of the mounds reflect similar conditions along long stretches of the decaying ice margins. The idea of a zonal arrangement of dead-ice moraine in belts parallel to the edge of the regressing ice is encountered quite often in the literature (Hoppe, 1952). Such moraine regions are asserted to represent the form of the ice margin and a marked interruption during its recessions. Varying supply of the till may have been important in accounting for striking gaps in the distribution of the moraine. Discontinuity of the belts, which occurs particularly in those belts to the north of the major belt that are composed of relatively indistinct forms of minor local relief, may be related to lack of morainic material associated with the ice, similar to breaks in terminal moraines. A varying supply of till seems to be reflected by the degree of development of the mounds. The relative height of the mounds bears no relationship to their altitude , either across or along the belt, which may reflect a variable supply of glacial debris. This inference is valid if the varying altitude of the belt has not resulted from subsequent tectonic activity in the area. The apparent clustering of data in Figure 8 probably has resulted from the sampling techniques used, that is, the selection of mounds in five local areas along a belt whose elevation changes consistently from east to west. Otherwise interruptions may be the result of subsequent fluvial and lacustrine erosion and deposition associated with proglacial lakes.

The vertical extent of the major belt in the Foremost-Cypress Hills area is quite limited along any one cross-sectional profile, being greatest in the Lake Pakowki area, (about 185 feet). Generally, the altitude of the belt increases towards the west. The highest margin of the belt near Irvine is approximately 2730 ft. A.S.L. while sixty-five miles to the west, near Skiff, it is about 3050 ft. A.S.L., that is, almost 320 ft. higher. The tendency of the belt to increase in altitude to the west may merely be a relatively local trend that has resulted from the proximity of the Cypress Hills. If it is accepted that the western portion of the plateau was not overridden by glacial ice during the Wisconsin and was a nunatak (Westgate, 1965), then on the wasting and disintegration of the ice sheet melting back at the edge of the ice would likely occur about the nunatak as well as at the southernmost margin of the ice sheet. Hence, the edge of the ice may have been reduced to a lower elevation to the north of the Hills more quickly than to the west where the ice sheet was continuous. Even with a similar or lesser rate of the horizontal retreat of the glacier margin to the north from the Cypress Hills the ice edge could still be reduced to a lower elevation faster because of the greater regional slope and lesser distance to the original position of a margin. To the south of the Hills large blocks of decaying ice probably separated quite early from the main sheet. During the advance of the ice, lobes of ice spilled over a broad bedrock ridge that joins the Cypress Hills and the Sweetgrass Hills to the WWS and through a high gap in the Hills to the east, and then spread outwards in an area of lower altitude meeting and surrounding the Cypress Hills (Westgate, 1965). In the opinion of the author later decay of the ice probably progressed more rapidly along the ridge and across the gap where tensional crevasse structures facilitated melting. More rapid melting of ice in these areas in association with a lesser thickness of ice led to an early separation of the ice to the south of the Cypress Hills and the main glacier mass. This trend of the prairie mound belt to increase in altitude to the west along with its tendency to project up into major valleys suggests that the margin of the ice sheet was controlled at various stages of wasting by the broad relief and drainage patterns of the region.

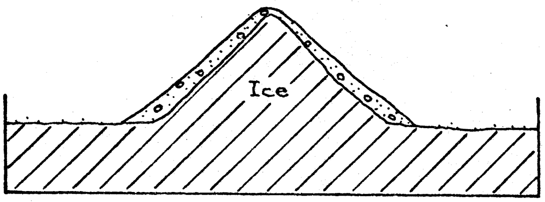
The belts, as mapped from air photographs by the author, all tend to have an east-west trend that is deflected northwards as the Rocky Mountains are approached. Relative to one another they are located more or less in a concentric pattern that coincides with the broad regional dip in slope to the north and east. That the highest and, incidentally, best-developed, prairie mound belt is located on till and sometimes is found adjacent to lacustrine deposits while the lower belts are frequently located on lacustrine deposits (Bik, 1966) is not surprising when considered in the context of the large-scale topographic surface. The highest belt on till is quite close to the drainage divide separating the tributary basins of the Missouri and Saskatchewan River systems. Therefore, during this phase of deglaciation, even if the ice mass did block drainage of melt-water to the north, only small proglacial lakes could form southwards before spilling over the drainage divide. As the margin of the glacier is displaced further north and east, the formation of extensive ice-dammed proglacial lakes becomes more likely. The different lithology of the material on which the mounds are located at the lower elevations may reflect a high degree of sorting and deposition of the glacial debris resulting from the spreading of shallow proglacial lakes over the ice front. When the lakes drained, differential melting of the buried dead ice covered by lacustrine sediments on ablation till could result in the characteristic prairie mound morphology.

The horizontal and vertical extent of the distribution of prairie mounds hence seems to be consistent with the stagnant ice front theory of Gravenor and Stalker. Their distribution is consistent with Bik's hypothesis only if the occurrence of large proglacial lakes and Recent tectonic activity are assumed.

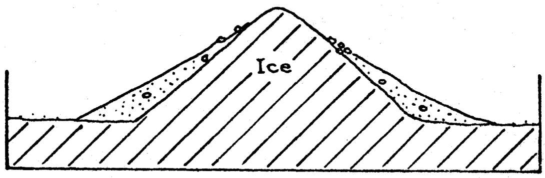
Distribution of Stones

The pattern of occurrence and relative density of stones on the mounds throughout the Foremost-Cypress Hills area appears to be strikingly consistent. The distribution of the stones is definitely not random.

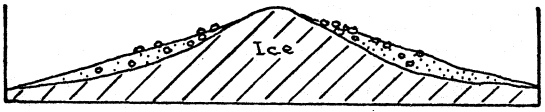
In the opinion of the author, a supraglacial origin for the mounds best accounts for the distribution of the stones on the mounds (Figure 16A). Ice pyramids (that is, ice cones covered with till) may have been initiated and formed, due differential melting owing to heterogeneous distribution of debris on the ice surface. Their destruction probably involved basal sapping of the cones due to the downward melting of immediately surrounding ice that was not insulated



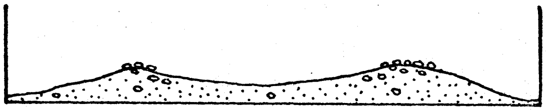
Ice pyramid



Basal sapping of ice pyramid, and slumping and mass wasting of till veneer



Translocation of fines by meltwater from exposed crest of ice pyramid, concentrating stones at highest elevation of glacial debris



Final melting of ice pyramid, creating a prairie mound with stone concentration on rim

Figure 16A. Disintegration of an ice pyramid.

by a continuous cover of debris. The glacial debris on the ice cone thus would have become unstable. Slumping and mass-wasting of the material eventually resulted in the removal of the debris cover from the top of the ice core. Thence, meltwater from the ice core was probably largely responsible for carrying the debris downslope, although solifluction processes probably also operated to some extent. Disintegration of the ice core and downslope movement of the till cover would entail a continuous crude sorting of the glacial overburden by which the stones would tend to become concentrated at the highest elevation of the accumulated debris. The actual angle of the surface of the ice cone was determined by factors such as the relative rates of erosion of the toe and of the rest of the slope. There would have been some tendency for the smaller fraction of the till to be moved downslope more readily by meltwater, leaving behind a concentration of larger fragments. Meanwhile the limiting angle of such slopes are a function of the frictional properties of the boulders (Melton, 1965). Most likely, the slope angles of the glacial debris on the ice cones were less than the limiting angles determined by the rocks. Therefore, stones concentrated at the top of the mounds would be stable, and unlikely to be redeposited on the slopes of the mound by rolling or mass wasting processes. The contention that the glacial debris of the mounds has thus undergone a rough degree of sorting during deposition is substantiated in in Figure ~~7~~ 6 where it is shown that generally as the relative height, and hence volume, of the mound increases so does the density of stones on the rim. This relationship may merely have reflected that the larger landforms have undergone greater modification since their formation but for the reasons outlined below the author does not consider that this is a primary factor. Rather it is argued that the accumulation of stones represents a fraction that has been sorted from varying quantities of till which are here assumed to be relatively homogeneous. The larger the mound the greater the number of stones presumably were incorporated in the original material. When these stones were concentrated surficially on the rim, a greater density resulted on the larger mounds, because the volume of material in the mound increases at a greater rate than the area of the rim.

Bik attempts to explain the surficial concentration on the rims of the mounds by selective erosion by subaerial processes after the formation of the mounds. On the basis of sedimentological data collected from cross-sections augered across two mounds, he interpreted colluvial deposits found on the lower slopes of the mounds and within the central depressions to have been contributed by mass wasting processes from the mound rim. From a consideration of the amount of post-glacial deposition and the geometry of the mounds, Bik estimated that the mound rims were originally up to four feet higher than at present. Observations made by the author from road cut exposures do not, however, substantiate the hypothesis that the concentrations of stones have resulted from primarily in situ removal of fines. The fraction of stones in the constituent tills is far too low for the erosion of a maximum depth of four feet of till to account for the observed surficial concentration. A trench about 1.5 meters deep and ten meters long was found through the rim of a mound to the north of Lake Pakowki. Only one large stone was exposed that is comparable to those cobbles and boulders that comprise a minor concentration on the surface of the rim to either side of the cut. If the till was fairly homogeneous when initially deposited then the erosion of only four feet of till would be insufficient to explain the accumulation of stones on the rim.

An inherent problem attendant in any such attempt to make inferences about the amount of erosion on the basis of existing lag deposits is, of course, one of dimensions. The accumulation of stones results from the erosion of a mass of material in three-dimensions. Any cross-section is only in one plane, however, and the estimation of the fraction of course material in a body of till from such evidence can be quite deceptive.

The abundance of boulders associated with some of the mounds, if also characteristic of the interior of the mounds, would probably have prevented the till from becoming plastic. This point is pertinent to Stalker's and Bik's hypotheses which both concern the upward displacement of plastic tills under differential pressure. The till of the Cypress Hills-Foremost area has a fairly low plasticity index of 5.5 to 15.5 per cent (Bik, 1967). This figure is exclusive of the extremely coarse fraction. If the boulders and cobbles did not prevent the till from becoming plastic, they surely must have inhibited displacement of the till owing to their size and density. If the till matrix was plastic, it may have flowed around the stones since the surface area of the stones is small relative to their mass and provides little frictional resistance. Decreased movement of the stones would result in a low degree of sorting of the till which then is contradictory to the observed surface concentration of stones on the highest part of the mounds.

The abundance of boulders that consistently drape down from the crest of the rim in the south-west quadrant represent a secondary accumulation due to sliding of the coarser material. This mass wasting probably occurred penecontemporaneously with the concentration of stones on the rim of the mound. This is suggested by two general tendencies.

First, rarely was the concentration of stones on the bounding slope associated with a corresponding decrease of stones on the upslope segment of the rim. This feature of the mounds can be most adequately accounted for in terms of an ice disintegration origin of the mounds. Melting of the exposed section of the ice core most likely proceeded fastest on the south-west slope of the ice pyramid owing to the reception of greater amount of insolation in this aspect. The angle of the underlying ice slope is hence reduced at a greater rate than elsewhere on the mound, and at any given time the maximum height of surficial debris is probably lower. A lateral movement of debris from adjacent sectors of the mound facilitated by freeze-thaw processes and melt-water would concentrate more till, including stones, in this quadrant. If the finer fraction of this additional material was subsequently translocated to the base of the mound and deposited out over an intermound area, then the south-western sector of the rim need not eventually be higher than the rest of the rim ridge. Stalker observed that in the Peace River country the south-eastern part of rims of morphologically similar mounds tended to be higher than the remainder of the rim. This trend may reflect other factors such as difference in exposure to winds that might have operated in conjunction with variance of insolation with azimuth to shift the area of maximum rate of melting and lateral movement of debris processes from the south-west slope to the south-east. The coincidence of highest altitude of the rims to the south-east, may, however, have resulted from the original disposition of till on the glacier's surface. The surface of the disintegrating ice probably more or less preserved the original inclination of the glacier. The transportation of the till would then have tended to become concentrated towards the distal, that is, the lowest part of the ice block. General accordance of the highest part of the rim with respect to direction may only rarely result however due to complications arising from the opposing trends of the inclination of the glacial surface and underlying topography. A study of the distribution of stones on the bounding slopes of the mounds in the Peace River area might indicate whether the highest part of the rim to the south-east is a reflection of different rates of process during the formation of the mounds or the orininal distribution of the supraglacial till.

Secondly, the densest occurrence of stones on the bounding slopes does not coincide strongly with the lowest angle of the bounding slopes (Figures 3 and 4). The differences in slope angle with azimuth are most likely an erosional feature resulting from a varying amount of insolation. Theoretically, the south-west aspect of the mound should receive the greatest amount of insolation which would here have the most marked effect. The different areas of lowest slope angle and greatest stone concentration on the bounding slopes suggests a displacement of the post-glacial zone of most intensive erosion with respect to aspect. If the high concentration of stones on the south-west quadrant came about during the formation of the mound or very shortly afterwards, the stones would negate any possible effects of greater insolation by inhibiting mass wasting processes. The angle of rest of the boulders is greater than that of the till matrix; therefore, the presence of the stones would most likely increase the stability of the slope and substantially retard mass wasting processes. Furthermore, the thermal conductivity of the stones, which are either igneous erratics or local Cretaceous sandstones, is greater than for the till matrix whose pore spaces contain air, water, and/or ice. A dense occurrence of stones has a tendency to dissipate heat received at the till surface downwards through the material rather than concentrating it near surface. Hence, diurnal temperature extremes might then be inadequate to promote solifluction or mass wasting. In summary, it seems reasonable that a higher concentration of surficial stones in the till will alter the plasticity index and thermal conductivity of the entire body of till sufficiently to offset the effects of a greater amount of insolation. This hypothesis is corroborated by Figure 5 where it can be seen that in the south-west quadrant as the surficial stone concentration increases so also does slope angle. Clearly the presence of stones has significantly influenced the angle of rest of the till slope. Hence asymmetry of the mounds' bounding slopes is not represented by a decreased slope angle facing towards the south-west as might be anticipated. Rather the greatest recline of slope angle seems to be restricted to the west and north-west where there are relatively fewer stones, and the insolation received is still somewhat greater than on the rest of the mound irrespective of the south-west quadrant.

In conclusion, the concentration of the coarser constituents of the till on the rim of the mounds thus seems most likely to have resulted from a very crude sorting of nearly the entire body of the constituent glacial material during the formation of the prairie mound rather than the post-formational erosion and sorting of the upper meter or so of the prairie mound.

Detailed till fabric analysis of the concentrations of surficial stones could prove to be very useful in a study on the origin of the prairie mounds. Hoppe (1952) based much of his reasoning on the origin of hummocky moraine regions on the results of measurements of the orientation of the coarse fraction of the deposits. While Stalker leaned heavily on Hoppe's work in formulating his hypothesis on the origin of the mounds he himself did not publish the results of any fabric analysis. Position and dip determination of the stones could give indications regarding the location from which movement of the till may have emanated, and the subsequent direction of the movement of the till. Such analysis in conjunction with the country slope angle could also be used to determine if the present position of the stones indicates primary or secondary deposition, that is, if the fabric was determined during the formation of the mounds, or reflects subsequent mass-wasting processes.

The Central Depressions

The proportion of the maximum depth of the central depression with respect to the height of the mounds does vary systematically (Figure 9). This relationship alone, however, is not very significant in any detailed genetic consideration of the mounds. Augering done in the central depression of the mounds by Bik in 1965 (Bik,1966) and the author in 1966 indicates that the depressions have been infilled subsequent to their initial formation. Hence, this aspect of the geometry of the mounds mostly reflects the stability of the material of the rim, availability of aeolian material, and dominant geomorphological slope processes since the mounds' origin.

On the other hand, distinctness of the mound, expressed as depth of the central depression as a per cent of the relative height of the mound, does seem to be related to the more general topography (Figures 10 and 11). Therefore, while the largest mounds do not tend to be restricted near the topographically upper margin of the main belt, the best developed mounds do.

At the same time indistinct prairie mounds occur across the entire belt. As well, more irregular landforms also occur throughout the area. "Twin" mounds, that is, two mounds which share an arc of their rims so that together their rims form a figure eight, are fairly common. Also in amongst clearly defined mounds are found irregular hills with several dimples on the upper surface. Mounds which do not have a clear central depression but rather a slightly convex-upwards upper surface that is joined by a rather sharp break in slope with the bounding slope, also occur in juxtaposition with the typical prairie mound form. A greater density of stones is found at the break in slope, similar to the concentration of stones on the rims of the prairie mounds. Finally the prairie mounds are found in association with hummocky knobs. The knobs are situated within tracts composed almost exclusively of prairie mounds. On the other hand occasionally prairie mound-like features are located within areas of hummocky topography. Thus, there appears to be a continuum of morphological types.

This variation of form is difficult to account for in terms of some of the hypotheses of origin suggested in the literature. Stalker's ice pressing theory is based on the assumption of fairly stringent physical conditions. On the one hand, a critical thickness of ice is required, such that the basal ice is unable to flow plastically, but the saturated till beneath is able to be extruded into basal cavities in the ice. The movement of till results from the difference in pressure exerted on the material beneath the ice and in the cavities. The direction of the flow is determined by the steepest pressure gradient, which tends to be at right angles to the tangent of the closest point at the margin of the cavity from the source of the till.

For the formation of "twin" mounds two cavities need be tangent to one another, and moreover, cannot be separated by a column of ice. Such a divide pressing on the basal till would leave a saddle between the two mounds. Under such conditions it is physically impossible for the pressure of the overlying ice to generate flow to that area where the cavities intersect, because movement of the till tends towards the centres of the two cavities, and friction causes the displaced material to heap up near the walls of the cavities. Source of the supply of material to this part of the rim is also difficult to explain, particularly when it has been observed that the highest part of the rim of such features tends to be that which is shared by the two mounds.

Stalker examined the margins of many mounds having flat tops and noticed that the rim ridges were nevertheless present but are only observed where there are cuts through the margins of the plateaux. That the rim should not rise to the level of the uppermost central sediments is inconsistent with the evidence which indicates that these sediments are later infilling of the original central depression.

Bik's contention that the mounds are essentially fossil pingoes presents fewer problems in accounting for the irregular features. The coalescence of ice lens seems to provide an adequate mechanism for the explanation of "twin" mounds and other irregular features found near the prairie mound forms. However, the same problems arise in trying to explain those mounds with flat and convex tops.

Of course, it must be kept in mind that similar morphological features may result from quite diverse geomorphological processes. There is, theoretically, no necessity to have a single hypothesis of origin for the various types of mounds. But a consideration of the spacial proximity and distribution of the features, similar order of magnitude, and similar freshness of slopes all suggest that the mounds, at least, in the belts are contemporaneous and were formed under similar conditions.

The relationship of the central depression to the rest of the mound is very pertinent to Bik's hypothesis. In the development of his thesis, the morphological similarity of the prairie mounds and features identified in Wales and Belgium (Pissart, 1963) as fossil pingoes (Plate VII) is an important piece of evidence. In the view of the present author, the degree of similarity has been exaggerated. The features in Europe are predominantly kettle-like depressions which are lower than the surrounding terrain, even with the infilling, and bounded by a relatively low, narrow, sharp ridge. These landforms are quite unlike prairie mounds which are definitely a positive element in the landscape, being a hill with a dimple in the top. The central depression is enclosed by a broad rim that is distinctly different from the ridge of the fossil pingoes. Even taking into account his introduction of plastic displacement of till in conjunction with ice

Brian Luckman

Plate VII. Fossil pingoes, as interpreted by A. Pissart (1963), near Llangurig, Wales in a glacial valley which is confluent with the Wye valley to the west and Afon Dulas valley to the east, and about twenty-two miles east of Aberystwyth.

lens formation, the morphological dissimilarity between the two types of features is great enough for one to question the validity of the genetic implications made on this basis.

Controlled disintegration of a stagnant ice front with a heterogeneous cover of debris seems to most adequately explain the origin of the mounds, since the process of ablation and deposition of englacial debris requires less strictly defined physical conditions to operate and thereby can result in a greater variation of form of deposition. Gravenor's hypothesis of ice-cored pyramids covered with glacial debris seems to be in accord with the morphological evidence presented in this paper. Melting of the ice at both the base and summit of the pyramid would result in the lowering of the entire feature, with a net outward displacement of the glacial debris. Two pyramids could very readily in their development broaden their bases such that they would join and the intervening saddle would then receive the debris from the slopes of the two adjacent mounds. This could then explain the highest segment of the rim that is shared by "twin" mounds.

Flat and even convex mounds could result, if in the final stages of the mounds' formation the ice core was extremely dirty and the englacial material was deposited in situ, an essentially ice matrix melted away and comparatively little loss of mass resulted within the mound. The stone concentration at the convex break in slope would still be present because the rim of the mound is composed of the crudely sorted material accumulated from higher in the original ice block. No observations of the material within such mounds were made but the results of such a study could prove quite fruitful.

Any model of disintegration that is proposed to explain the unique shape of the mounds must entail some qualifications. That ice core pyramids on a scale comparable to the prairie mounds can form is indicated by observations made by Russell in 1893 on the Malaspina Glacier. For the rather regular morphology of the ice pyramids to be inherited by the ultimate depositional form of the supraglacial and englacial till the ice surrounding the pyramid must melt at the same rate or faster than the ice core. Otherwise the system would break down, and need to be repeated to form the prairie mounds. More possibly, very little ice underlay the ice pyramids during their formation and the debris from their slopes was deposited directly on their destruction. The occurrence of the most distinct mound forms at higher elevations could reflect the existence of either locally less debris in the ice core or a tendency to lessened infilling. The disintegration of the mounds into irregular hummocky terrain, especially towards the topographically lower margin of the major belt could reflect thicker ice conditions, a logical enough assumption, that inhibit the regular deposition of the debris.

On the basis of the evidence available, both the regular and irregular aspects of the morphology of the mounds can be best explained in terms of controlled ice disintegration.

The Breaches

The existence of breaches in the rims of the mounds is a characteristic of the mounds that can be readily accounted for in terms of the major theories of their origin. Stalker makes no mention of the notches in the rim at all. However, in the context of his ice-pressing theory, the breaches could result from a variable distribution of plastic basal till resulting in a varying amount of material available to be extruded into the glacial cavities. Bik's hypothesis could also account for the irregularities of the rim. Modern pingoes in the MacKenzie delta area exhibit a rupture of the overlying sediments resulting from the internal pressures of the subjacent forming ice lens, such that the material is interrupted by irregular V-shaped notches that expose the ice core. Subsequent melting of the ice will probably result in a rim ridge of uneven height. Gravenor's heterogeneous distribution of englacial and supraglacial till could also adequately explain the breaches in the rims of the prairie mounds.

While the presence of the breaches in the rims of the mounds can be readily explained, the more specific characteristics of the breaches warrant further consideration. On virtually all of the mounds fewer surficial stones are to be found across the breaches than elsewhere on the rims. This paucity of stones even frequently extends down the adjacent bounding slopes. This characteristic indicates that the breaches are probably not of glacio-fluvial origin. Hoppe noted that notches in the rim ridges he studied were associated with small boulder deltas. The absence of stones with respect to the breaches of the prairie mounds suggests that the breaches have not resulted primarily from erosion by meltwater, but rather from a heterogeneous distribution of debris.

Although the occurrence of the breaches seems to be associated with this heterogeneous distribution, the orientation of the breaches does not appear to be entirely random. Those breaches that drain the central depression open out in a direction that is loosely controlled by the slope of the immediate terrain. Even more specifically, the orientation of the breaches frequently seems to be integrated with fluvial-like channels that are interrupted by low saddles (Figure 16). The belt studied within the Foremost-Cypress Hills area was crossed by only one integrated stream channel, which was below Bulls Head Butte. Elsewhere, however, the configuration of contour lines and alignment of intermound depressions often suggest the presence of channels with undulating long profiles. Surficial drainage of meltwater, the probable mechanism for the erosion of these channels, is not compatible with either an ice-pressing or periglacial mode of formation of the adjacent mounds. However, it is quite likely that supraglacial streams would be closely associated with ice pyramids. Ablation of the underlying ice would then cause the channels left by these streams to have irregular long profiles.

Outwash deposits might then be expected to be associated with the mounds. Near Lake Pakowki, exposures in a gravel pit directly abutting the southern margin of the major belt investigated, revealed fairly well sorted gravel, nearly all less than 10 cm. in diameter, with a coarse sand matrix. The nature of the material, bedding structures, and the orientation of the stones indicate that the deposit is glacial outwash that has been laid down by water flowing from the north, that is, from the area of prairie mound topography. The area of sand dunes immediately to the south most probably represents the sand fraction of the outwash which was deposited in the shallows of a proglacial lake that occupied the present Lake Pakowki basin. The sand has subsequently been reworked by aeolian processes to increase the degree of sorting and create the present topography. The belt of mounds sometimes parallels coulees, such as Etzikom Coulee extending westwards from the north-west arm of Lake Pakowki and the Gros Ventre tributary of the Ross Creek, which very likely carried meltwater run-off.

In summary, four characteristics of the prairie mounds, all of which occur throughout the Foremost-Cypress Hills area, indicate that prairie mounds are most likely a product of differential ablation along the margin of a dead-ice mass which controlled the deposition of residual supraglacial and englacial debris. First, the distribution of fields of prairie mounds in belts which conform roughly to the contours of the broad relief and drainage patterns of southern Alberta is reminiscent of the zonal arrangement of dead-ice topography in belts parallel to the edge of the regressing ice encountered in other areas. Secondly, the occurrence and nature of irregular landforms and the range of morphological expression of the prairie mound form within fields of prairie mounds is consistent with the mechanism of formation and its less stringent physical requirements for operation involved in the controlled deposition of till by wasting stagnating ice. Thirdly, the ubiquitous concentrations of stones on the rims of the prairie mounds which cannot be explained as solely in situ lag deposits also point towards an interpretation of ablation material that has undergone very crude sorting during deposition. Finally, the presence of fluvial-like channels with undulating long profiles within the prairie mound topography, and the sometimes apparent integration of those breaches that drain the central depressions of the prairie mounds, is in accordance with the discharge of meltwater that accompanies the development of ice pyramids and the deposition of prairie mounds.

CHAPTER IV

ORIGIN OF THE MOUNDS

Gravenor (1955) gave an account of how the differential melting of a stagnant dirty ice mass could produce the prairie mounds (Figure 16B). In this chapter a modified and more explicit account of the differential melting theory is presented.

Although Gravenor based his hypothesis substantially on the observations and ideas of Russell (1893) on the margins of the Malaspina Glacier in Alaska, he made little reference to the earlier writer. The author here considers that a review of Russell's work, in particular, with respect to the implications that it may have for an analysis of the prairie mound form in southern Alberta, is most appropriate at this time.

Russell was intrigued by the abundant lakelets that occurred on the stagnant border of the Malaspina Glacier. He recorded that the lakes were usually rudely circular and less than one hundred feet in diameter, although larger ones were not uncommon, several being observed that were one hundred fifty to two hundred yards in diameter. Moreover, the lakes were enclosed by crater-like walls which had angles of 40° to 50° and frequently were from fifty to one

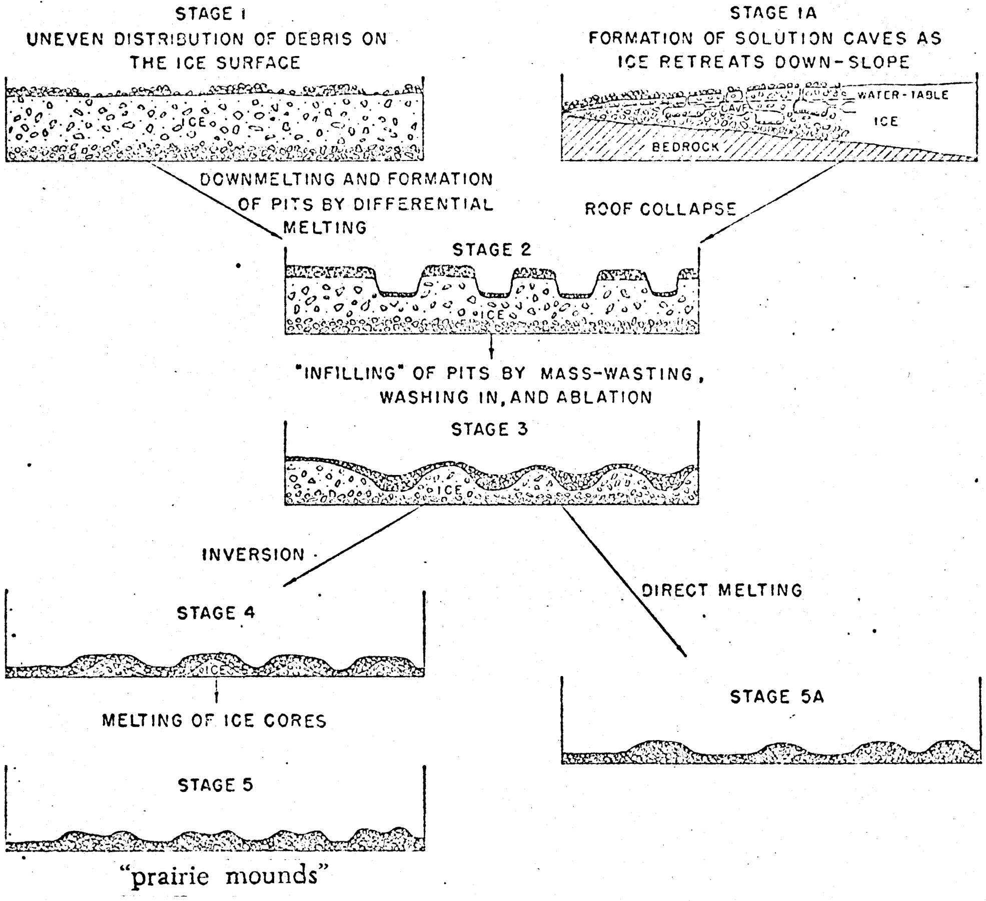


Fig. 16B Formation of hummocky disintegration moraine. (from Gravenor, 1955).

hundred feet high. These walls were formed from the sheet of debris covering the glacier and seldom were of uniform height, often rising into pinnacles and occasionally broken by low saddles through which in some instances the lakes overflowed.

For the formation of these "thermokarstic" lakelets, the first requisite is that the wasting ice mass be stagnant. If the ice were active new crevasses might be opened that would permit the lake water to escape. Also any flow of ice would distort or destroy the circular form of the melted depression. Secondly, a variable distribution of superglacial debris in association with crevasse structures that are zones of weakness in dense and impermeable ice, and that facilitate melting are necessary. Thirdly, essential for their formation is relatively rapid melting of the upper surface of the ice by direct insolation, rain or high air temperatures.

In the opinion of the writer, it seems entirely plausible that the above set of conditions could have existed along the margins of the last retreating glacier across the Great Plains for long distances. In fact, Clayton (1964) concluded that glacial karst, that is decayed glacial ice, although rare today, was widespread on stagnant glaciers in areas such as the northern Great Plains in late Wisconsin time. His suggestion corroborates the present hypothesis in that it is based on the interpretation of dead-ice moraines and associated landforms other than prairie mounds which are found throughout the region (Gravenor and Kupsch, 1959).

In association with the lakelets of the Malaspina Glacier were found debris pyramids, almost conical hills that were ice cores veneered with a coat of debris. The pyramids frequently rose to a height of sixty or eighty feet. Although Russell made no attempt to estimate the density of these features or describe the texture of the glacier surface, he did state that they were the most characteristic features of the outer border of the glacier, and that the number of both lakelets and pyramids must have been many thousand.

The ice pyramids are interpreted by Russell as an inversion of the lakelet form resulting from the processes of mass wasting and differential ablation. The waters of the lakelets were always turbid due to the glacial debris carried into them by solifluction and small avalanches, and by the small rills that flowed from the surrounding walls. Material accumulates in the base of the karst-like depressions, either by deposition or residual concentration. As long as it remains permeable and permits the circulation of relatively warm water, (which is an extension of the convection system developed in the lake due to temperature differences), the depressions are also being enlarged laterally as the sides are melted back, and even undercut.

The explanation proposed by Russell for the formation of lakelets on stagnant ice can be applied to the Great Plains and extended. Because the tills in Alberta have a high clay content which in turn contains a high fraction of hygroscopic minerals such as montmorillinite (Bik, 1966) a relatively thin accumulation of debris would effectively insulate the ice at the base of the depression by restricting movement of water to the sediment-ice interface. The active surface of heat transfer then becomes the lowest depth within the debris to which water does circulate. Movement of heat towards the ice surface, generally downwards, is then largely by conduction. Since saturated till has a low conductivity, a relatively thin overburden protects the ice beneath from further melting. At this point, most of the melting resulting from the transfer of heat from the water of the ice is concentrated on the sides of the depression. Progressive undercutting of the walls leads to avalanching and it is not inconceivable that the net concentration of glacial debris could be less in the center of the lake as avalanching accounted for the displacement of a greater per centage of the debris, especially the coarser fraction, and fluvial transport resulted in less. The degree of sorting will vary as the rate of melting, being greatest when rapid ablation not only causes meltwater movement of debris to predominate over mass wasting, in particular avalanching, but also inhibits residual accumulation of debris in situ. In considering the general glacial surface during this phase of its deterioration, it is apparent that the formation and development of the depression results in a general displacement and concentration of supraglacial and englacial debris towards the centers of the depression.

As the till is eroded from those areas between the depressions, melting tends to be restricted to these higher areas, owing to the fact that material deposited in the depressions effectively insulates the underlying ice, and protects it from further melting. Ostrem (1959) noted that the melting of a glacier surface was retarded when the ablation cover was greater than 0.5 cm. thick. From experiments conducted in the Tarfala valley, he determined that the relationship between the rate of ablation in centimeters of ice per day and the thickness of the moraine layer was asymptotic; therefore, the thickness of cover which would permanently preserve ice from all melting was difficult to determine. However, the important point here, in the view of the author, is that the rate of melting is substantially reduced beneath a debris cover, owing to the relatively low conductivity of the material. Further, the ablation period is most likely shorter here since the amplitude of both the annual and diurnal temperature range decreases as the waves penetrate from the active surface, until they are no longer discernible. The influence of the debris cover has its greatest effect only after the walls surrounding the depressions have been sufficiently lowered so that the depressions can be drained by the low saddles or notches in the walls. When the interstitial spaces within the morainic material become filled with air rather than water, the conductivity of the till is considerably decreased and it then becomes an even more effective insulating layer.

According to Russell and Gravenor, continued differential melting of the glacier's surface ultimately results in an inversion of topography and the formation of "ice pyramids", providing that a considerable depth of ice exists beneath the former depressions. As the level of the ice surrounding the depressions continues to fall and eventually is lowered even below the ice protected by debris, material then begins to slide down the minor cliffs that lead up to the debris covered areas. Extra material accumulating at the foot of the cliffs retards melting there, and the angle of the immediately subjacent ice slope is gradually reduced until it can once more hold its cover of insulating debris.

These ideas can be furthered in the present thesis. The angle of the surface of the ice core does not continue to decrease since the basal height of the ice pyramid becomes greater as a result of the level of the surrounding ice continuing to fall. The recline of the slope that is also being eroded downwards at the base results in an increase in the diameter of the area covered by glacial debris, and moreover, a net displacement of the debris outwards from the previous focus of concentration of the material. The size of pyramids observed by Russell, and the above hypothesized increase in their diameter during their development seem adequate to account for the size of prairie mounds, which generally have a diameter of about one hundred meters. Gradually the sides encroach on the original area covered by debris so that the ideal end form is a cone-shaped hill which has an ice-core. Ice-cored moraines analogous to Russell's "ice pyramids" then occupy the sites of the former depressions.

As material is gradually removed from the top of the ice pyramid by mass wasting processes, it becomes insufficient to protect the ice beneath it. Here melting proceeds more rapidly than on the lower slopes. Gravenor states that melting of the ice core will result in a central depression but the author considers that this explanation is inadequate. If the ice beneath the initial lakelets is thin, mounds without a central depression will form as a result of direct melting. If the base of the ice pyramid is underlain by little ice, then the final stages of ablation will result in the deposition of the till as it was concentrated on the basal slopes of the nearly conical-shaped ice pyramids, that is, approximating the shape of a doughnut. Breaches in the form may well reflect irregularities in the height of the wall of debris originally surrounding the lakelet, and may have been further accentuated by the erosion by meltwater from the ice core. If, on the other hand, there remains a considerable thickness of ice beneath the decaying ice pyramid, further differential melting may lead to the formation of an even larger mound or concentric rim ridges of till, but will more likely just result in the destruction of the form. The writer considers the depth of the decaying ice mass to be critical in the formation of prairie mounds. If the thickness of the ice is outside rather narrow limits, then the ultimate depositional forms of the till will not reflect the symmetrical morphology of the ice pyramids, but rather will lie in irregular topographic forms.

In the opinion of the author, ice pyramids are closely related in origin to the smaller dirt cones of the northern margins of Vatnajökull, Iceland which were described by Lewis (1940) and Swithinbank (1950). Lewis, in fact, recorded dirt cones near the end of Eyjabbajökull which rose to over forty feet above the surface of the glacier, and had debris consisting of ordinary morainic material varying from large boulders down to the finest clays. He also noted that the frequency of the cones varied as the abundance of the superficial material. Meanwhile Swithinbank observed that they were most abundant where there were the most crevasses, that is, near the ice margins and near nunataks. Where the cones are most numerous, the majority occur along crevasse lines and are usually aligned in subparallel series, broken at intervals by transverse lines, the pattern obviously conforming to crevasse systems and the largest cones being formed at the intersection of two or more such systems.

Both Lewis and Swithinbank attribute the initiation and development of these features to the uneven distribution of morainic debris on the surface of the glacier, and to conditions of stagnant ice and relatively rapid ablation. A primary phase of thermokarstic water-filled depressions is not referred to, but Swithinbank does envisage an initial accumulation of debris by meltwater in crevasses and hollows. Lewis merely implies a random heterogeneous distribution on the glacier surface. Otherwise the formation of Russell's "ice pyramids" subsequent to the draining of the lakelets is very similar to that of the dirt cones. Hence, it may be inferred that the occurrence of ice pyramids, like dirt cones, may be controlled by the development of crevasse patterns in the ice and the abundance of glacial debris. This relationship could explain the alignment of prairie mounds in fields noted by Stalker.

A major difference between the formation of dirt cones and ice pyramids is time, which perhaps is just an aspect of their varying dimensions. The regime of the building and destruction of dirt cones tends to be annual, while the ice pyramids require several seasons to develop and decay.

Post-Glacial Modification of the Mounds

In western Canada, the generally received interpretation is that the surface has been spread with several Pleistocene drift sheets and fluvial deposits, and subsequently very little modified. For example, Lemke (1965) in his summary of the Quaternary geology of the northern Great Plains region concludes that the topography in the area covered by the Wisconsin glacial advances has been little modified since the last deglaciation. Recently, however, this general opinion has been challenged by some well-founded criticism. Crickmay (1966), for instance, described an exposure to the south of Calgary which he interprets as exhibiting extensive erosion by fluvial and mass wasting processes during the Holocene. Morphological observations collected from the prairie mounds support the contention that the northern Great Plains terrain has been modified since the last deglaciation, and furthermore, suggest that the modification probably took place under periglacial conditions.

Lemke notes that the periglacial features are nearly all confined to the drift sheet of the "first advance" which he broadly correlates with the early Wisconsin stadial of the Great Lakes basin. Westgate and Bayrock (1964) describe involutions and fossil ice wedges in Saskatchewan sands and gravels near Edmonton which they attribute to frost action in a periglacial environment. Because some of the structures are truncated, and undistrubed tills which have been dated as older than 31,000 B.P. are superimposed on the sands and gravels, they logically conclude that the periglacial conditions associated with the formation of the involutions and wedges existed in central Alberta prior to the classical

Wisconsin advance. Jungerius (1966), however, records a layer of poor sorting and with many pebbles in a vertical position in a profile near the northern edge of the Cypress Hills plateau. He argues that it denotes solifluction under periglacial conditions. Stratigraphic relationships seem to indicate that the solifluction was promoted during the late Wisconsin. It is the opinion of this author that the extreme climatic conditions implied by evidence of periglacial processes are highly unlikely to be merely local in extent; therefore Jungerius' periglacial phase may possible coincide with that established by Black (1957) during the Cary substage in Wisconsin, or that established by Horberg (1951) after the Mankato substage (Elson, 1957) in North Dakota.

Analysis and interpretation of the slope angle data from the prairie mounds tends to substantiate the contention that periglacial conditions did exist beyond the borders of the continental ice sheet during the late Wisconsin.

Various theories have been proposed to account for asymmetry of slope angles with respect to azimuth (Gregory and Brown, 1966). Most authors who have considered this problem have concluded that differences in slope angle with azimuth are an erosional feature resulting from varying degrees of exposure, particularly under periglacial conditions. Logically, morphological units orientated in one particular direction should suffer a greater degree of weathering, erosion and mass movement. The intensity of the periglacial processes is thought to vary on opposite slopes, the principal reasons offered being differences in the amount of insolation received, differences in the depth and persistence of the permafrost, and differences in exposure to winds.

In the Foremost-Cypress Hills area it is most likely that the decrease in the slope angle between the south-west and north-west observed on the prairie mounds (Table 3) has been the result of more intensive solifluction of material downslope due to the predominantly westerly winds and variation of ground temperature with slope direction. The surface temperature depends on conditions of the ground surface, particularly moisture content and composition, as well as insolation. Throughout the early day much insolation is used in evaporation, causing the soil to dry out. By early afternoon when the south-west quadrant receives the maximum insolation, the surface has dried out considerably; therefore, the maximum surface temperature tends to be on the south-west facing slope. Hence, in this quadrant a greater amount of radiant energy is available to be converted to latent heat of fusion necessary for the melting of interstitial ice within the till material. Saturation of the till will then facilitate the progressive downslope movement of the material by viscous flowage. Moreover, the greater daily temperature extremes to the south-west might intensify solifluction by increasing frost heaving which depends on the frequent occurrence of freeze-thaw cycles. The occurrence of lowest bounding slope angles with a west to north-west direction reflects the influence of an original distribution of surficial stones on the south-west quadrant which alters the plasticity and thermal conductivity of the till to prevent increased solifluction on this aspect. The greatest recline of slope angle on those mounds that do have stones on the south-west bounding slope is displaced to the west and north-west where there are less stones and the insolation received is still somewhat greater than on the rest of the mound.

In south-eastern Alberta a humid frost climate extending beyond the margins of the retreating ice sheet can thus be inferred. Solifluction deposits occur on slopes as gentle as 2°, and in a location which extends back into the glaciated region, as in the Appalachian area (Flint, 1957), can occur as a result of only seasonal freezing to a depth of a few meters at most, followed by spring thawing accompanied by abundant water in the mantle. Therefore, intensive periglacial conditions in which the ground was frozen continuously and/or perennially during post-glacial times need never have existed in order to explain the lessened slope angles facing towards the west. Permafrost conditions persisting from the preceding glacial period, may be considered unlikely in view of Williams' (1967) hypothesis that basal till beneath a temperate continental glacier remains largely unfrozen.

Differential erosion on the western slopes by solifluction could be accentuated by prevailing westerly winds that support a perennial snow cover on the east-facing, lee slopes while leading to the more frequent melting of snow on west-facing slopes and so to more active solifluction processes on the windward slopes. On the other hand, if the greater amount of snow on the lee side did melt in any one year, this side might be expected to undergo more solifluction. If, however, the westerlies covered the west-facing slopes, annual melting would intensify mass wasting here. The effects of prevailing winds are difficult to determine due to the possible variation of climatic conditions and the accumulation patterns of snow.

The intensity and duration, and even the existence of a true periglacial realm in the Great Plains during the late Wisconsin seems to be still open to question. Well-developed periglacial structures that have been described in the literature (Schafer, 1949; Westgate and Bayrock, 1964) originated in the early Wisconsin. In the Foremost-Cypress Hills area, sections in numerous gravel pits were examined and only on the summit surface of the western extent of the Cypress Hills was there any indication of a significant disturbance of the original attitude of the pebbles by frost action. This height of land is generally believed to have been a nunatak throughout the Pleistocene, so the vertical position of high numbers of pebbles to a depth of about two meters which may reflect periglacial conditions cannot be even relatively dated. The general absence of well-developed periglacial structures elsewhere suggests that if permafrost conditions did exist during the late Wisconsin in southern Alberta, they were neither very continuous nor intense.

The inside slopes as well as the bounding slopes even more clearly exhibit modification since the original deposition of the mounds (Bik, 1966). Field inspection of samples from the centers of mounds selected along the five traverses and taken during the summer of 1966, indicate that the central depressions have generally undergone considerable infilling. Laboratory analysis has yet to be done so an interpretation of the sequence of sediments will not be included at this time.

CHAPTER V

CONCLUSIONS

Analysis and interpretation of morphological observations systematically collected from a sample of prairie mounds in the Foremost-Cypress Hills area of Alberta substantiates Gravenor's hypothesis of the origin of the mounds. The formation of the mounds by differential ablation along the margin of a dead ice mass which controlled the deposition of residual supraglacial and englacial debris is corroborated in the present paper by four pieces of evidence. First, the distribution of fields of prairie mounds in belts which conform roughly to the contours of the broad relief and drainage patterns of southern Alberta is reminiscent of the zonal arrangement of dead-ice topography in belts parallel to the edge of the regressing ice encountered in other regions. Secondly, the occurrence and nature of irregular landforms and the range of morphological expression of the prairie mound form within fields of prairie mounds is consistent with this mechanism of formation and its less stringent physical requirements for operation involved in the controlled deposition of till by wasting stagnant ice. Thirdly, the ubiquitous concentrations of stones on the rims of the prairie mounds, which cannot be explained solely as in situ lag deposits, also point towards an interpretation of ablation material that has undergone very crude sorting during deposition. Finally, the presence of fluvial-like channels with undulating long profiles within the prairie mound topography, and the sometimes apparent integration of those breaches that drain the central depressions of the prairie mounds, is in accordance with the discharge of meltwater that accompanies the development of ice pyramids and the deposition of prairie mounds.

On the basis of the morphological evidence presented and further consideration of the differential ablation model, several modifications of Gravenor's hypothesis, particularly with respect to those landforms studied in south-eastern Alberta, are now proposed.

i) Prairie mounds are closely related genetically to dirt cones, but the process of the building and destruction of dirt cones tends to be annual, while ice pyramids require several seasons to develop and decay.

ii) The formation of prairie mounds is probably controlled by crevasse patterns in the stagnant ice mass, and the abundance of supraglacial and englacial debris.

iii) The thickness of the wasting ice mass when the lakelets develop and formation of the mounds is initiated is critical for the development of the relatively symmetrical prairie mound form. Beyond a limited range of thickness of ice, the deposition of residual glacial debris results in irregular hummocky topography.

iv) Prairie mounds and the adjacent inter-mound depressions can be considered to be the result of the initial accumulation of debris in "thermokarstic" lakelets, and then the systematic outward displacement from these loci of concentration during the inversion of the ice surface topography and the ensuing destruction of the ice pyramids.

v) The mounds have been considerably modified since their formation and the end of the last deglaciation by the mass wasting of their bounding slopes, probably under periglacial conditions, and the infilling of their central depressions.

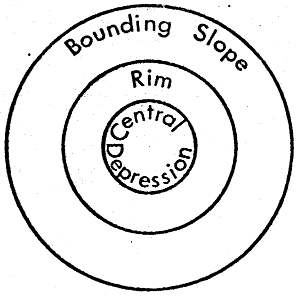
The above inferences should be regarded as tentative rather than conclusive because of the limitations imposed by the approach taken to the problem. Any attempt to make inferences about the formation of a landform from an analysis of its morphology, with little reference to present day processes or detailed study of its materials, can at best be provisional. It is essential to bear in mind the axiom that landforms of different origin may have a considerable morphological similarity.

On the basis of this study, the writer feels that further investigation of the problem might best be directed along the following lines. Firstly, trenching by a back-hoe of two or three mounds sampled randomly could facilitate the sampling and field study of the compositional materials, and furthermore permit examination of the structure and stratification of the deposits. If "collapse" structures typical of ice-contact deposits were found adjacent to the infilling materials of the central depressions, the differential ablation hypothesis would be more strongly substantiated. However, if stratified tills parallel to the bounding slopes were discovered, then the "fossil pingo" hypothesis should be evaluated again. Secondly, inadequate reference has been made in the study to the relationship of the prairie mounds to the adjacent terrain. Interpretation of the origin of a landform necessarily bears implications concerning the chronological sequence and processes of formation of adjacent complexes of landforms and vice versa. For an intensive local investigation of this type, the Lake Pakowki area seems to be a fruitful area because of the areal relationship of the belt of prairie mounds with such features as abandoned meltwater channels, outwash deposits, and sand dunes. Finally, fabric and compaction analysis of the constituent tills could prove quite useful. Fabric analysis could reveal significant implications regarding the location from which movement of the till may have emanated and the subsequent direction of the movement of the till. Such data would be very pertinent to an evaluation of Stalker's ice-pressing hypothesis. It could also provide further evidence applicable to the question of whether the present location of the surficial stones on the mounds are the result of primary or secondary deposition. Measurements of the degree of compaction of the tills comprising the mounds might prove significant. Ablation till would logically undergo a lesser degree of compaction in its deposition than would glacial debris that had been mounded by pressures exerted subglacially or periglacially.

APPENDIX 1

DISTRIBUTION OF SURFICIAL STONES ON PRAIRIE MOUNDS

Key



A stylized prairie mound

○ Stone Ring

Density of Stone Concentration:

□ None

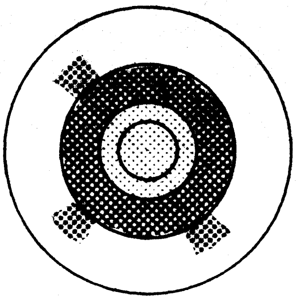
░ Few (1 or less stones per sq. m.)

░ Minor (2 or 3 stones per sq. m.)

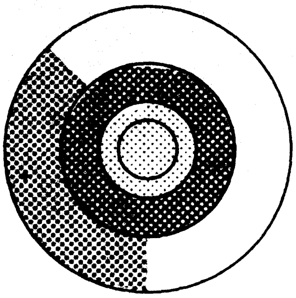
▒ Moderate (4 to 7 stones per sq. m.)

▓ Abundant (more than 7 stones per sq. m.)

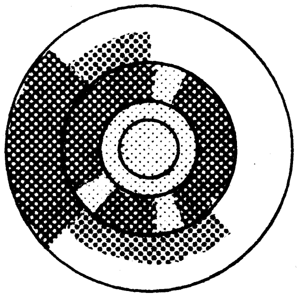
■ Very Abundant (almost a solid stone pavement)



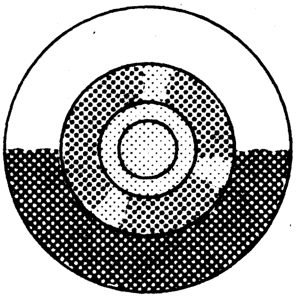
Twp. 11, Rge. 3, Sec. 16



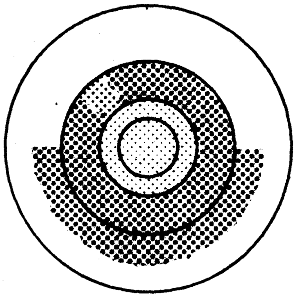
Twp. 11, Rge. 3, Sec. 16



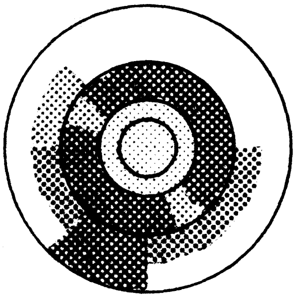
Twp. 11, Rge. 3, Sec. 16



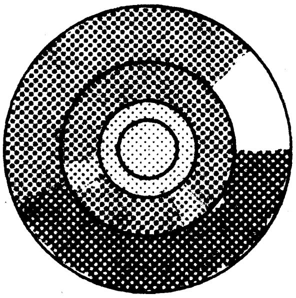
Twp. 11, Rge. 3, Sec. 16



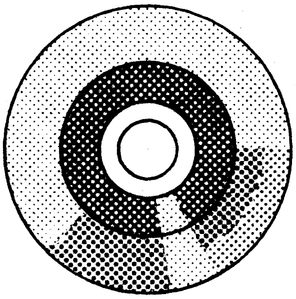
Twp. 11, Rge. 3, Sec. 16



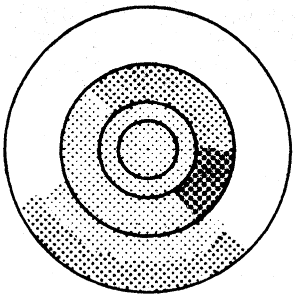
Twp. 11, Rge. 3, Sec. 16



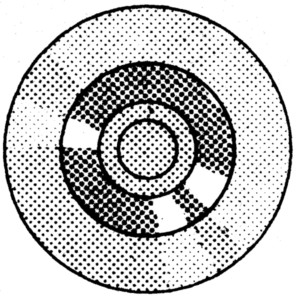
Twp. 11, Rge. 3, Sec. 16



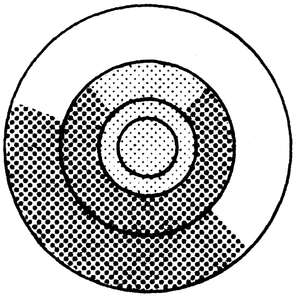
Twp. 11, Rge. 3, Sec. 16



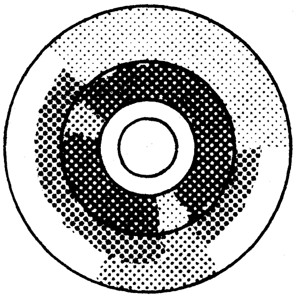
Twp. 11, Rge. 3, Sec. 16



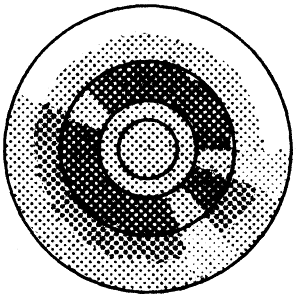
Twp. 11, Rge. 3, Sec. 16



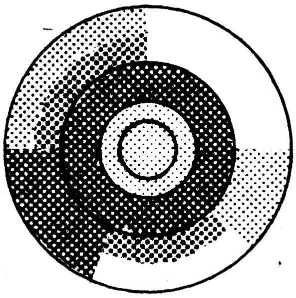
Twp. 11, Rge. 3, Sec. 16



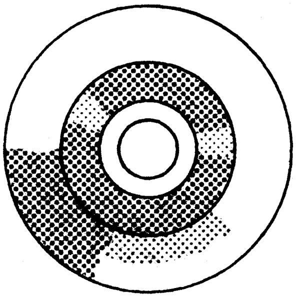
Twp. 11, Rge. 3, Sec. 16



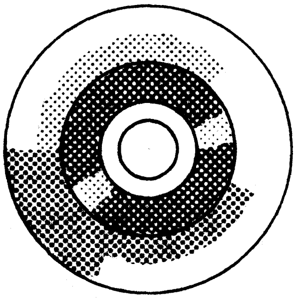
Twp. 11, Rge. 3, Sec. 16



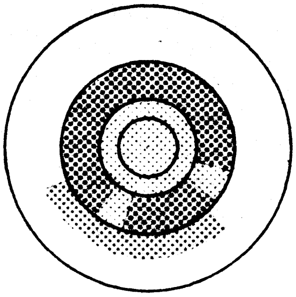
Twp. 11, Rge. 3, Sec. 16



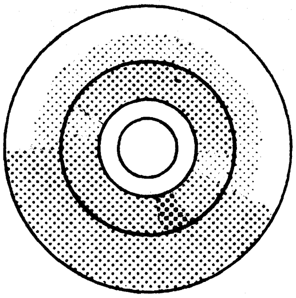
Twp. 11, Rge. 3, Sec. 16



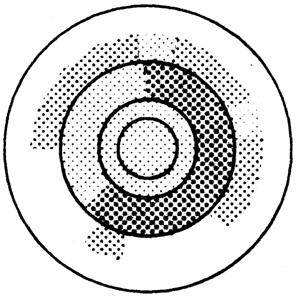
Twp. 11, Rge. 3, Sec. 16



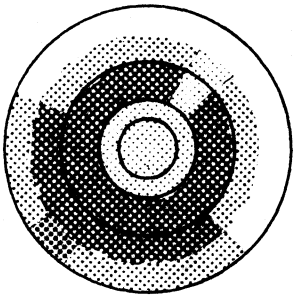
Twp. 11, Rge. 3, Sec. 16



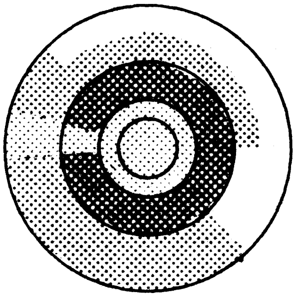
Twp. 11, Rge. 3, Sec. 16



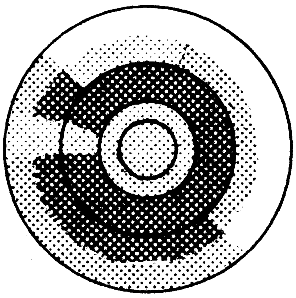
Twp. 11, Rge. 3, Sec. 21



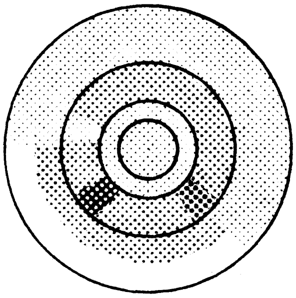
Twp. 11, Rge. 3, Sec. 16



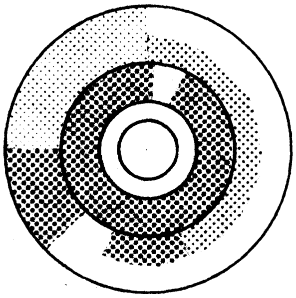
Twp. 11, Rge. 3, Sec. 16



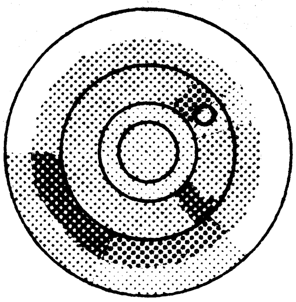
Twp. 11, Rge. 3, Sec. 16



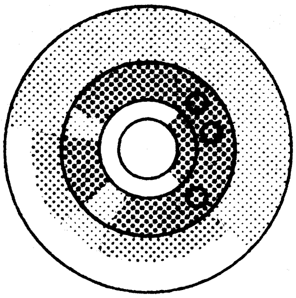
Twp. 11, Rge. 3, Sec. 21



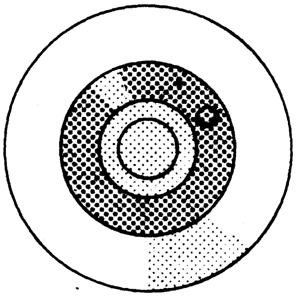
Twp. 11, Rge. 3, Sec. 21



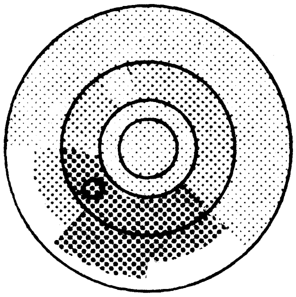
Twp 11, Rge. 3, Sec. 21



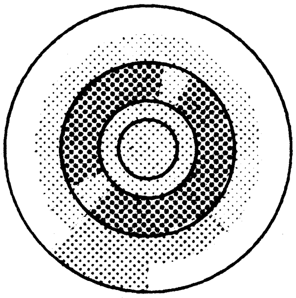
Twp. 11, Rge. 3, Sec. 21



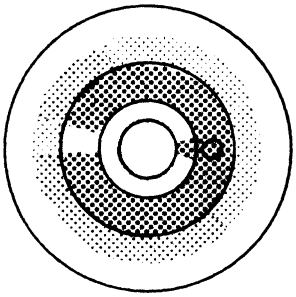
Twp. 11, Rge. 3, Sec. 21



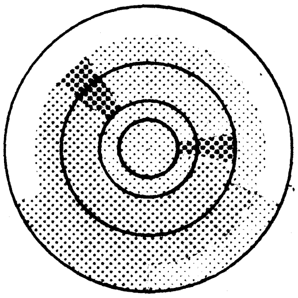
Twp. 11, Rge. 3, Sec. 16



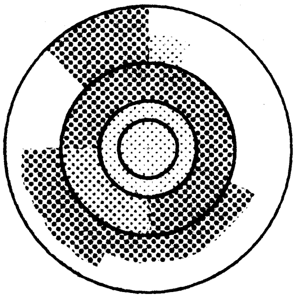
Twp. 11, Rge. 3, Sec. 21



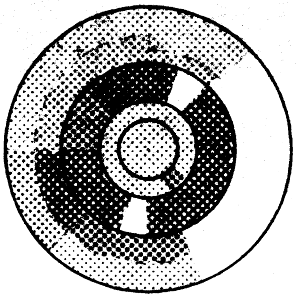
Twp. 11, Rge. 3, Sec. 21



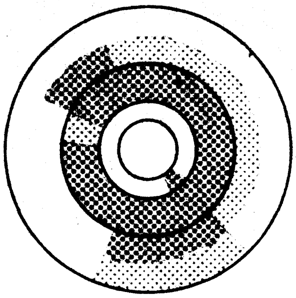
Twp. 11, Rge. 3, Sec. 21



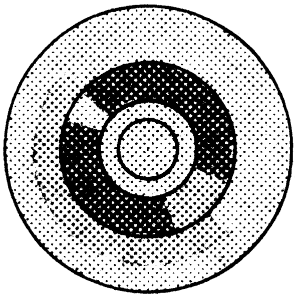
Twp. 11, Rge. 3, Sec. 21



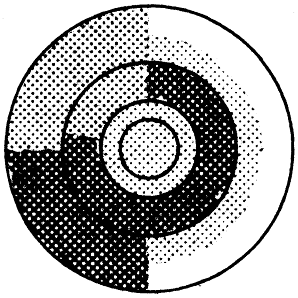
Twp. 11, Rge. 3, Sec. 21



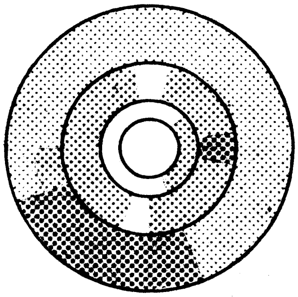
Twp. 11, Rge. 3, Sec. 21



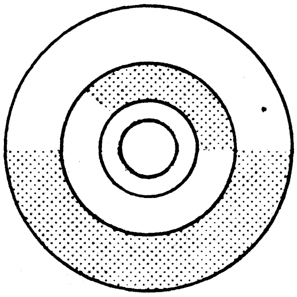
Twp. 11, Rge. 3, Sec. 21



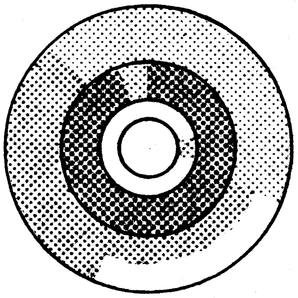
Twp. 11, Rge. 3, Sec. 27



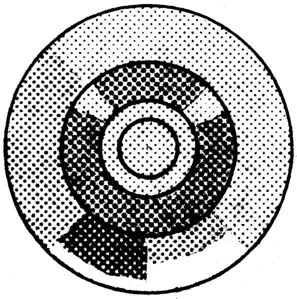
Twp. 11, Rge. 3, Sec. 28



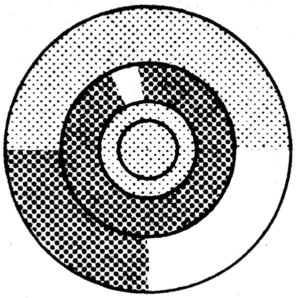
Twp. 11, Rge. 3, Sec. 28



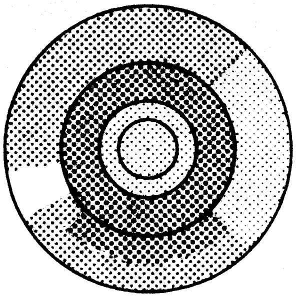
Twp. 11, Rge. 3, Sec. 21



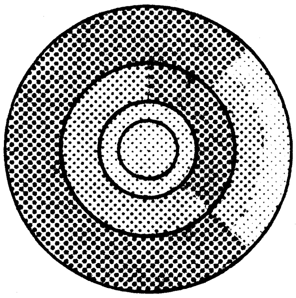
Twp. 11, Rge. 3, Sec. 21



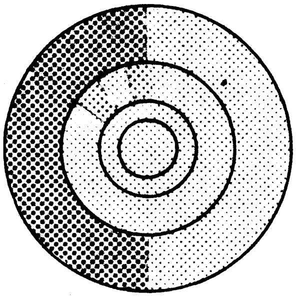
Twp. 8, Rge. 7, Sec. 8, Lsd. 3



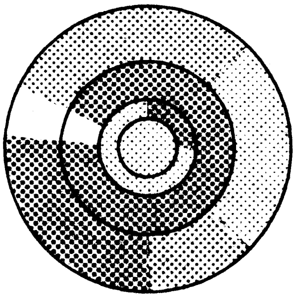
Twp. 8, Rge. 7, Sec. 8, Lsd. 14



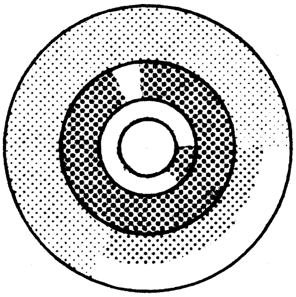
Twp. 8, Rge. 7, Sec. 8, Lsd. 14



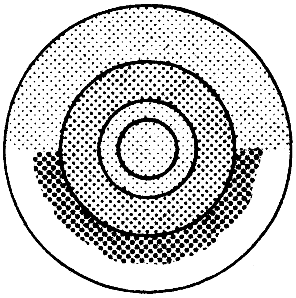
Twp. 8, Rge. 7, Sec. 8, Lsd. 15



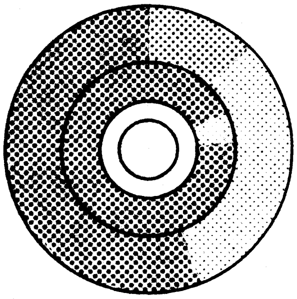
Twp. 8, Rge. 7, Sec. 8, Lsd. 10



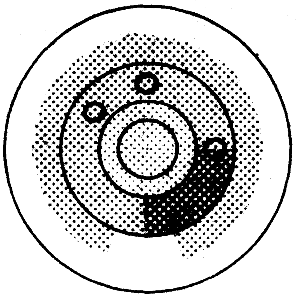
Twp. 8, Rge. 8, Sec. 12, Lsd. 13



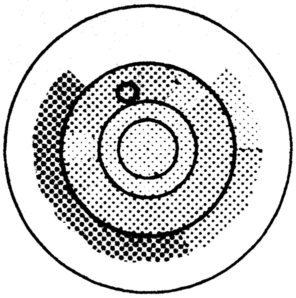
Twp. 8, Rge. 8, Sec. 13, Lsd. 4



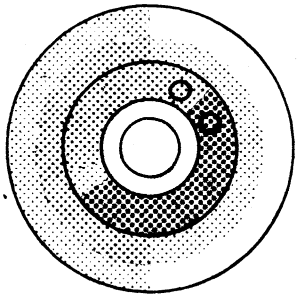
Twp. 8, Rge. 8, Sec. 11, Lsd. 16



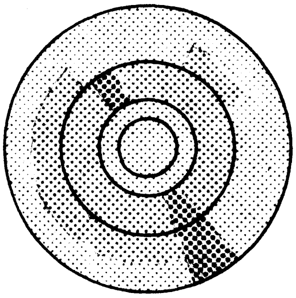
Twp. 8, Rge. 8, Sec. 11, Lsd. 16



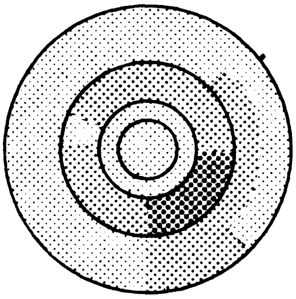
Twp. 8, Rge. 8, Sec. 11, Lsd. 16



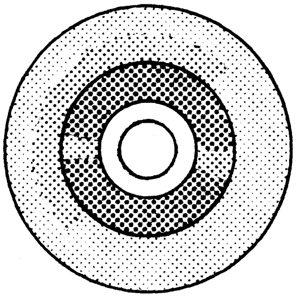
Twp. 8, Rge. 8, Sec. 11, Lsd. 15



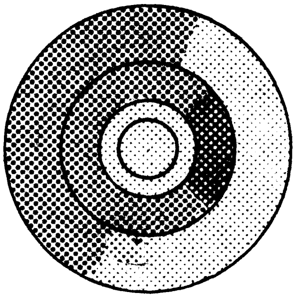
Twp. 8, Rge. 8, Sec. 11, Lsd. 14



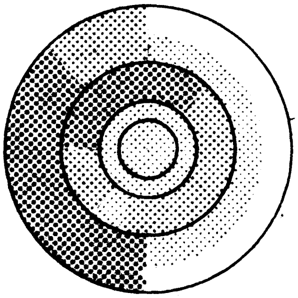
Twp. 8, Rge. 8, Sec. 11, Lsd. 14



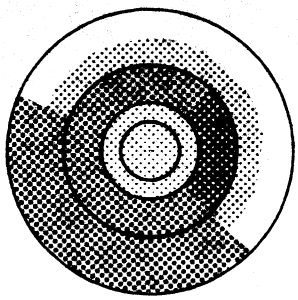
Twp. 8, Rge. 8, Sec. 11, Lsd. 14



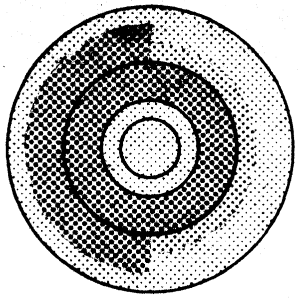
Twp. 8, Rge. 8, Sec. 11, Lsd. 13



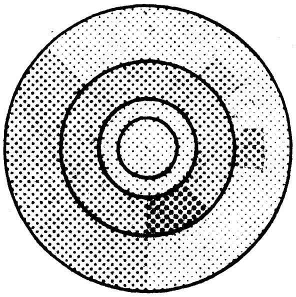
Twp. 8, Rge. 8, Sec. 11, Lsd. 12



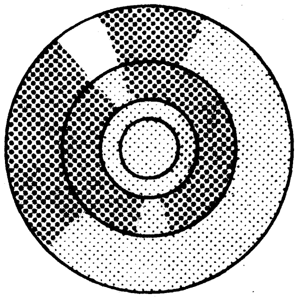
Twp. 8, Rge. 8, Sec. 10, Lsd. 9



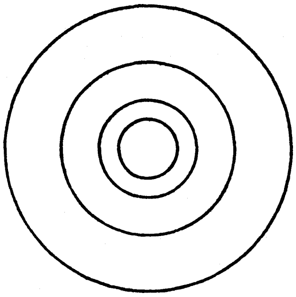
Twp. 8, Rge. 8, Sec. 15, Lsd. 12

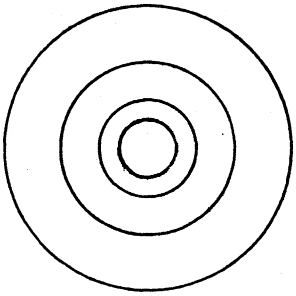


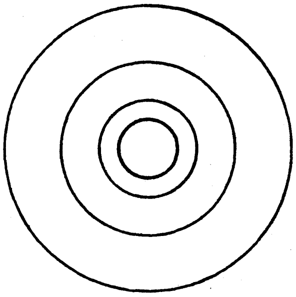
Twp. 8, Rge. 8, Sec. 10, Lsd. 9

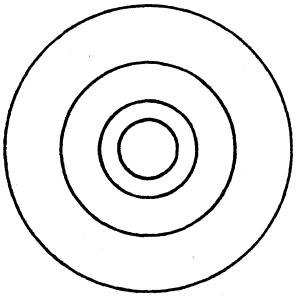


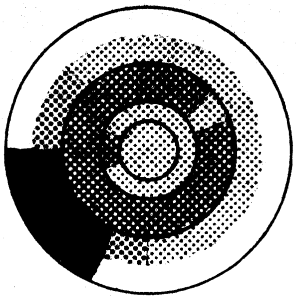
Twp. 6, Rge. 15, Sec. 13, Lsd. 19



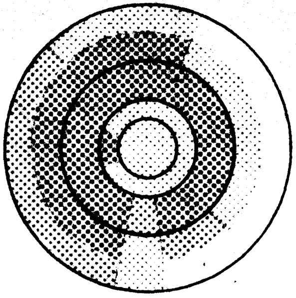




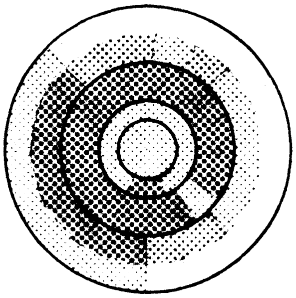




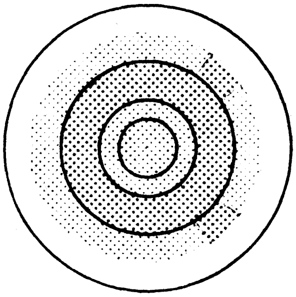
Twp. 6, Rge. 7, Sec. 5



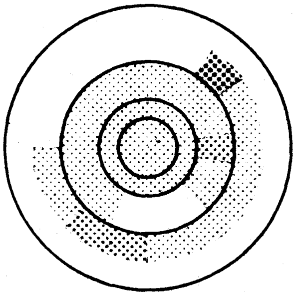
Twp. 6, Rge. 7, Sec. 5



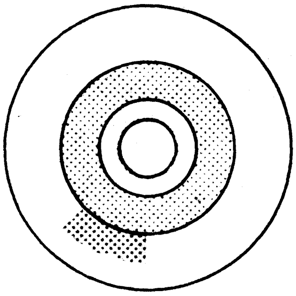
Twp. 6, Rge. 7, Sec. 5



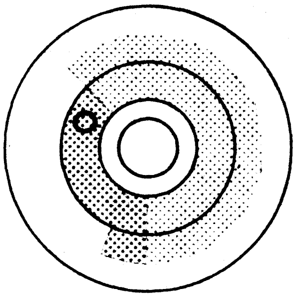
Twp. 6, Rge. 7, Sec. 9



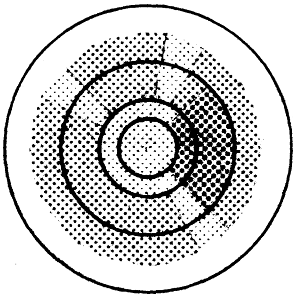
Twp. 6, Rge. 7, Sec. 9



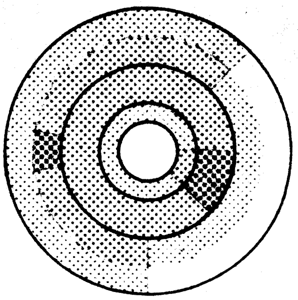
Twp. 6, Rge. 7, Sec. 9



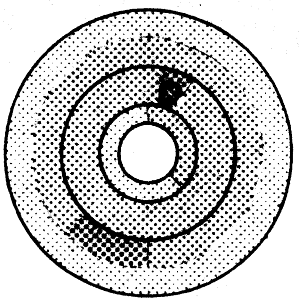
Twp. 6, Rge. 7, Sec. 9



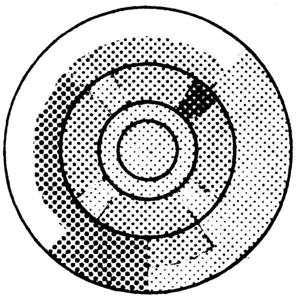
Twp. 6, Rge. 7, Sec. 9



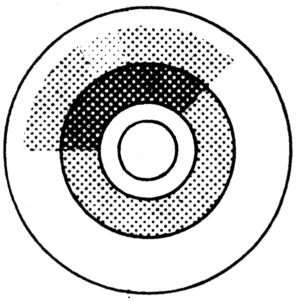
Twp. 6, Rge. 7, Sec. 9



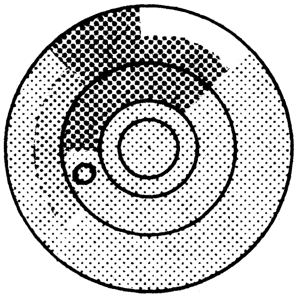
Twp. 5, Rge. 7, Sec. 34



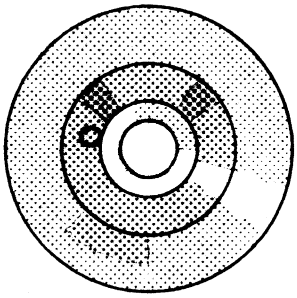
Twp. 5, Rge. 7, Sec. 34



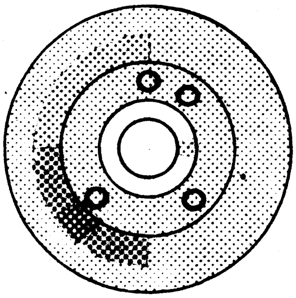
Twp. 5, Rge. 7, Sec. 34



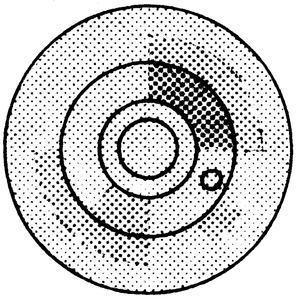
Twp. 5, Rge. 7, Sec. 34



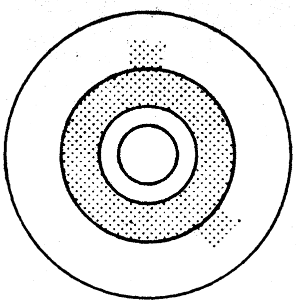
Twp. 5, Rge. 7, Sec. 34



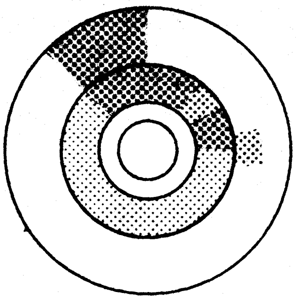
Twp. 5, Rge. 7, Sec. 34



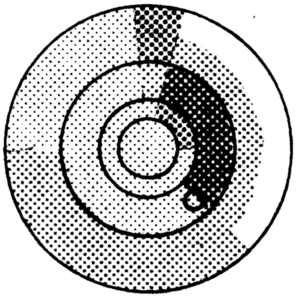
Twp. 5, Rge. 7, Sec. 34



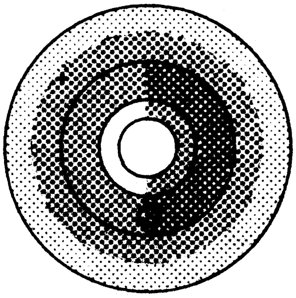
Twp. 5, Rge. 7, Sec. 28



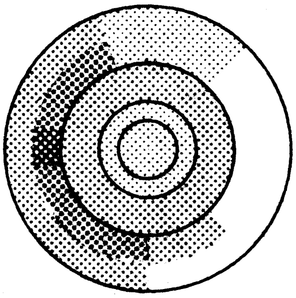
Twp. 5, Rge. 7, Sec. 28



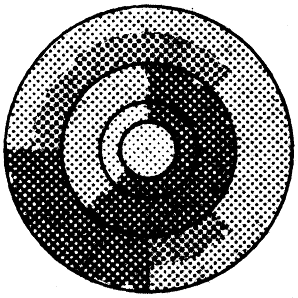
Twp. 5, Rge. 7, Sec. 33



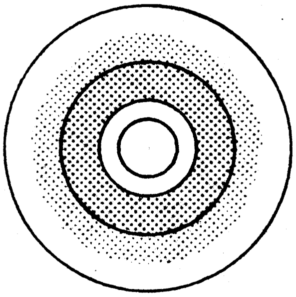
Twp. 6, Rge. 7, Sec. 3, Lsd. 3



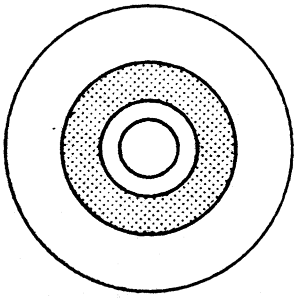
Twp. 6, Rge. 7, Sec. 3, Lsd. 3



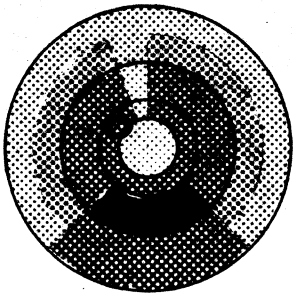
Twp. 6, Rge. 7, Sec. 3, Lsd. 5



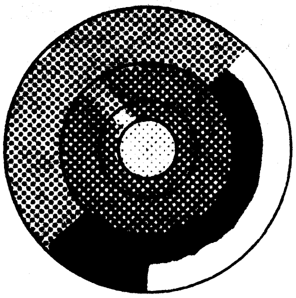
Twp. 6, Rge. 7, Sec. 4, Lsd. 9



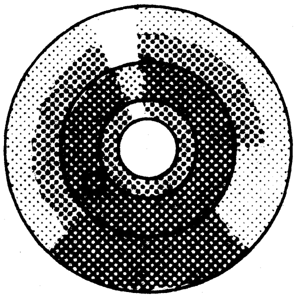
Twp. 6, Rge. 7, Sec. 4, Lsd. 15



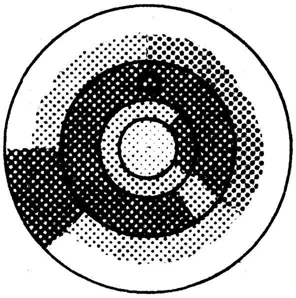
Twp. 6, Rge. 7, Sec. 19, Lsd. 12



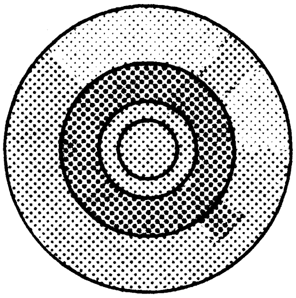
Twp. 6, Rge. 7, Sec. 19, Lsd. 5



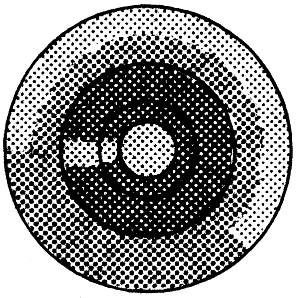
Twp. 6, Rge. 7, Sec. 19, Lsd. 3



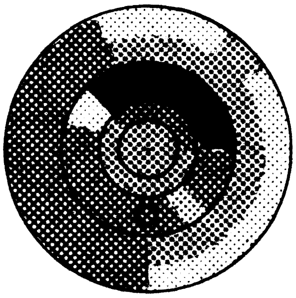
Twp. 6, Rge. 7, Sec. 19, Lsd. 1



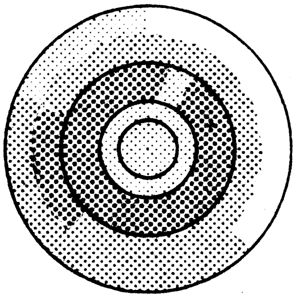
Twp. 6, Rge. 7, Sec. 19, Lsd. 10



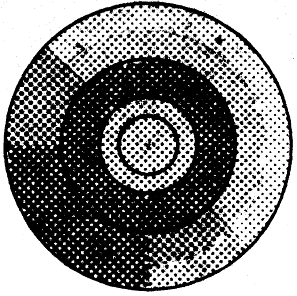
Twp. 7, Rge. 8, Sec. 11, Lsd. 2



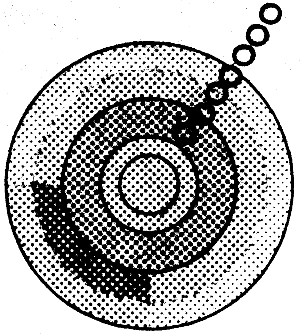
Twp. 7, Rge. 8, Sec. 11, Lsd. 7



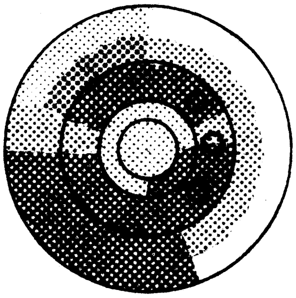
Twp. 7, Rge. 8, Sec. 11, Lsd. 14



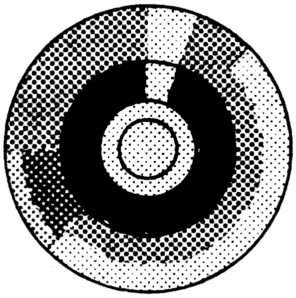
Twp. 7, Rge. 8, Sec. 11, Lsd. 14



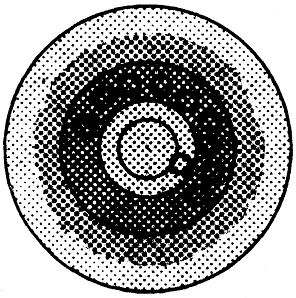
Twp. 7, Rge. 8, Sec. 11, Lsd. 8



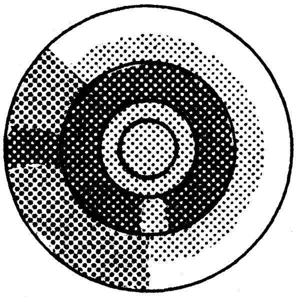
Twp. 7, Rge. 8, Sec. 11, Lsd. 13



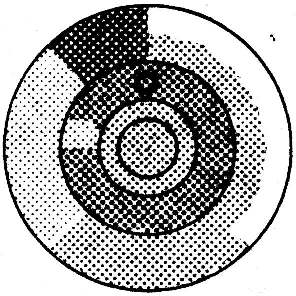
Twp. 7, Rge. 8, Sec. 10, Lsd. 14



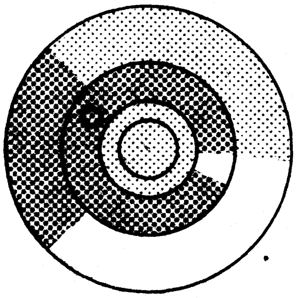
Twp. 7, Rge. 8, Sec. 10, Lsd. 14



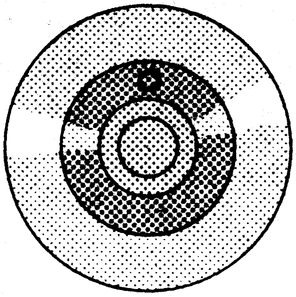
Twp. 7, Rge. 8, Sec. 10, Lsd. 11



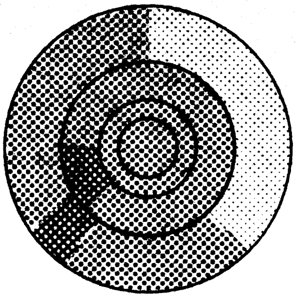
Twp. 7, Rge. 8, Sec. 10, Lsd. 13



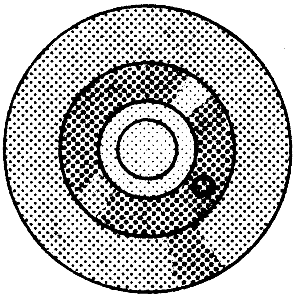
Twp. 7, Rge. 8, Sec. 10, Lsd. 12



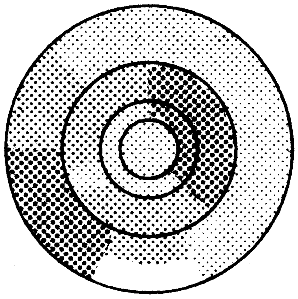
Twp. 7, Rge. 8, Sec. 11, Lsd. 6



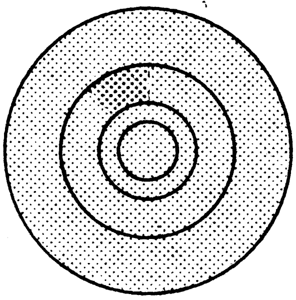
Twp. 7, Rge. 8, Sec. 16, Lsd. 16



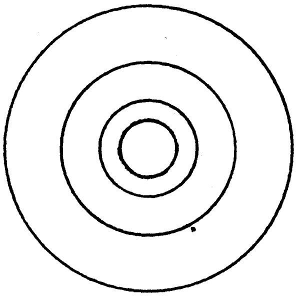
Twp. 7, Rge. 8, Sec. 22, Lsd. 4

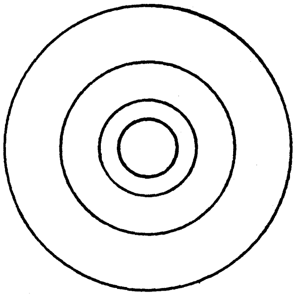


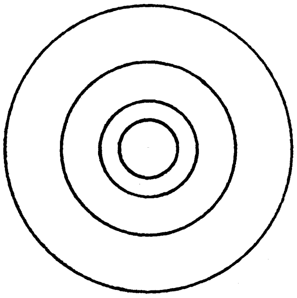
Twp. 7, Rge. 8, Sec. 22, Lsd. 10

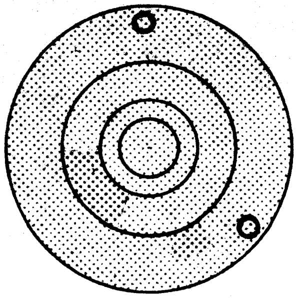


Twp. 7, Rge. 8, Sec. 21, Lsd. 14

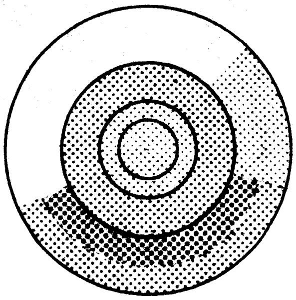




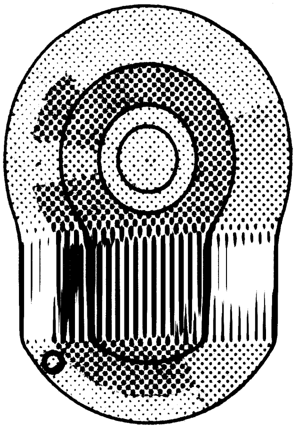




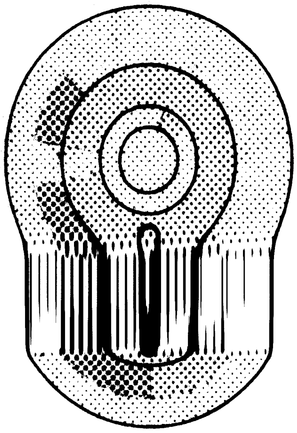
Twp. 6, Rge. 11, Sec. 1



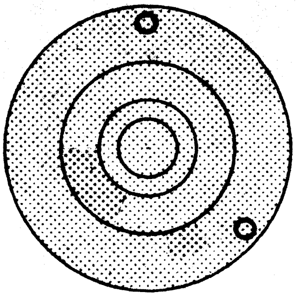
Twp. 6, Rge. 11, Sec. 1



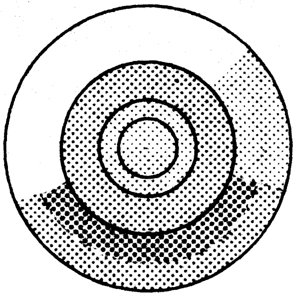
Twp. 6, Rge. 11, Sec. 1



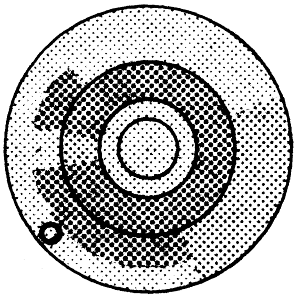
Twp. 6, Rge. 11, Sec. 1



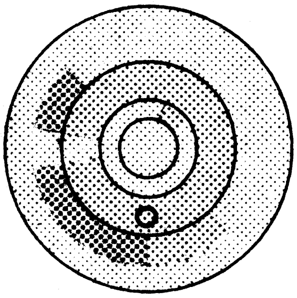
Twp. 6, Rge. 11, Sec. 1



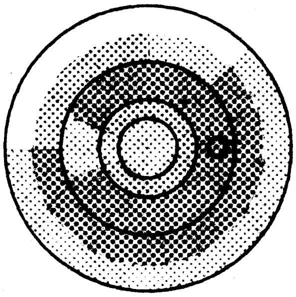
Twp. 6, Rge. 11, Sec. 1



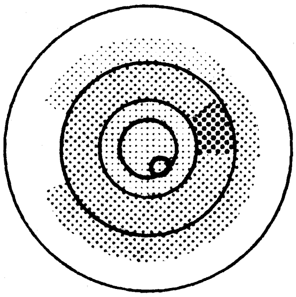
Twp. 6, Rge. 11, Sec. 1



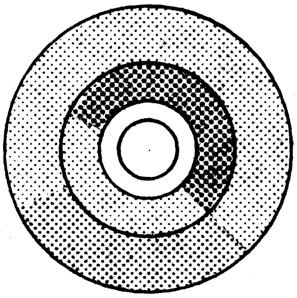
Twp. 6, Rge. 11, Sec. 1



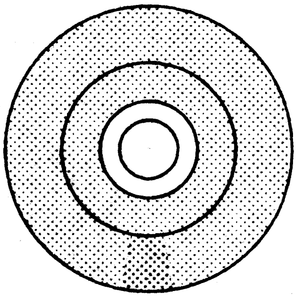
Twp. 6, Rge. 11, Sec. 1



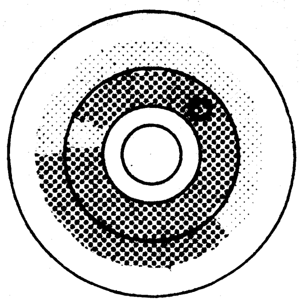
Twp. 6, Rge. 11, Sec. 1



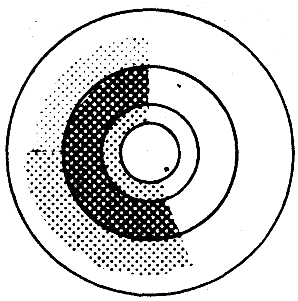
Twp. 6, Rge. 11, Sec. 1



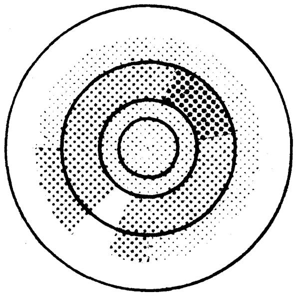
Twp. 6, Rge. 11, Sec. 1



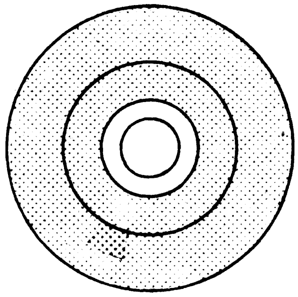
Twp. 6, Rge. 11, Sec. 1



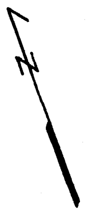
Twp. 6, Rge. 11, Sec. 1

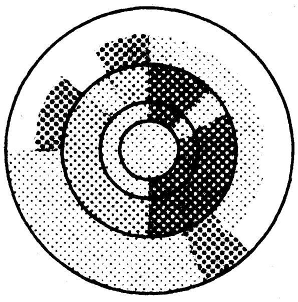


Twp. 6, Rge. 11, Sec. 1, Lsd. 12

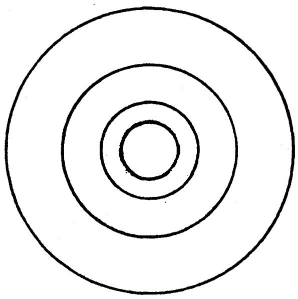


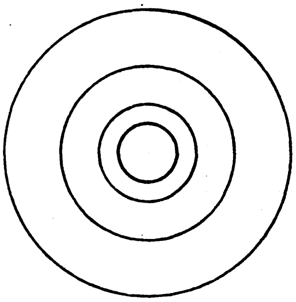
Twp. 6, Rge. 11, Sec. 1, Lsd. 12

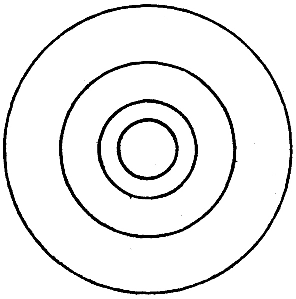


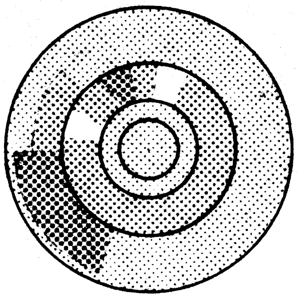


Twp. 6, Rge. 11, Sec. 1, Lsd. 11

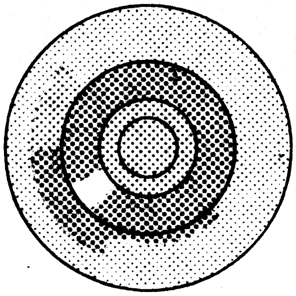




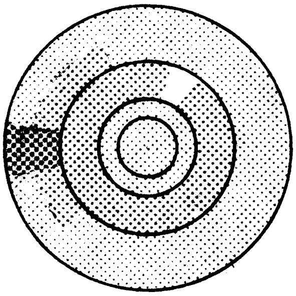




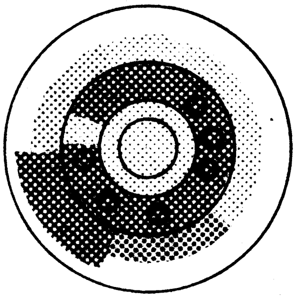
Twp. 5, Rge. 14, Sec. 16, Lsd. 12



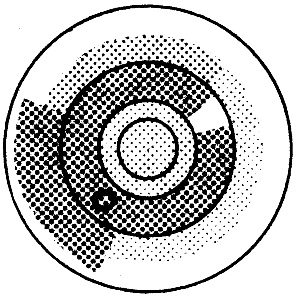
Twp. 5, Rge. 14, Sec. 16, Lsd. 12



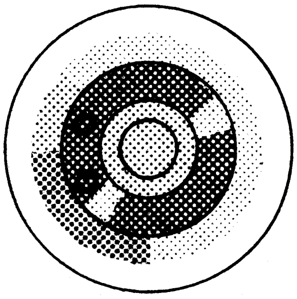
Twp. 5, Rge. 14, Sec. 16, Lsd. 11



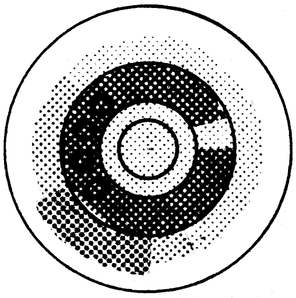
Twp. 5, Rge. 14, Sec. 16, Lsd. 12



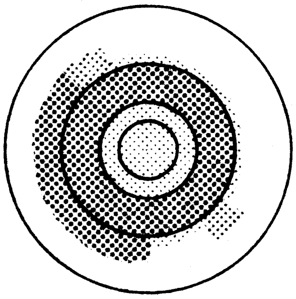
Twp. 5, Rge. 14, Sec. 16



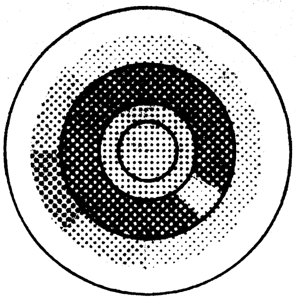
Twp. 5, Rge. 14, Sec. 16



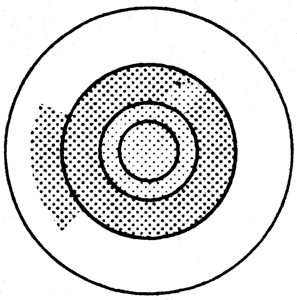
Twp. 5, Rge. 14, Sec. 16



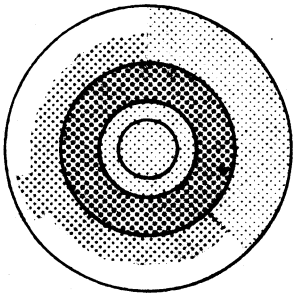
Twp. 5, Rge. 14, Sec. 16



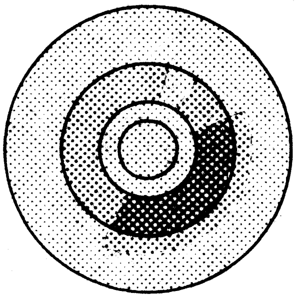
Twp. 5, Rge. 14, Sec. 16, Lsd. 3



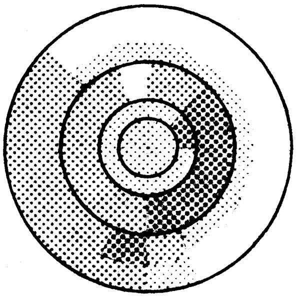
Twp. 5, Rge. 14, Sec. 16, Lsd. 3



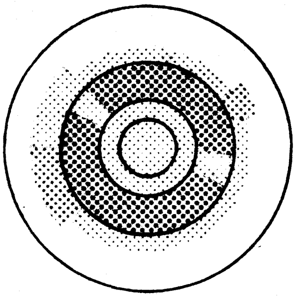
Twp. 5, Rge. 14, Sec. 16, Lsd. 2



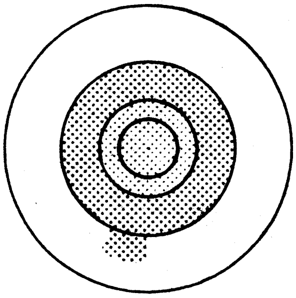
Twp. 5, Rge. 14, Sec. 16, Lsd. 7



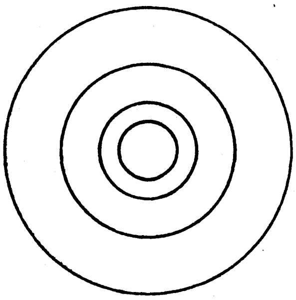
Twp. 5, Rge. 14, Sec. 16, Lsd. 1

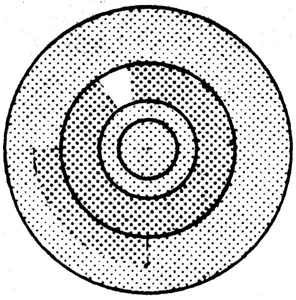


Twp. 5, Rge. 14, Sec. 16, Lsd. 8

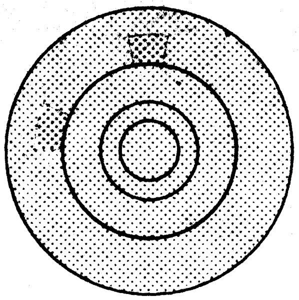


Twp. 5, Rge. 14, Sec. 16, Lsd. 8

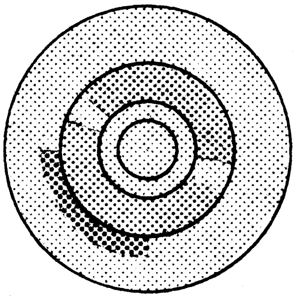




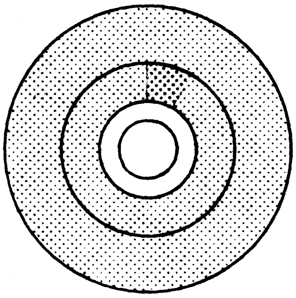
Twp. 6, Rge. 15, Sec. 13, Lsd. 15



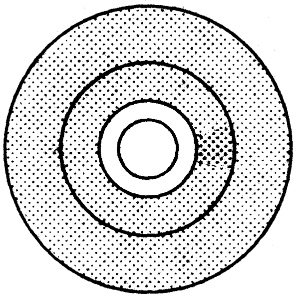
Twp. 6, Rge. 15, Sec. 13, Lsd. 15



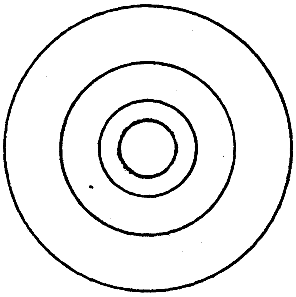
Twp. 6, Rge. 15, Sec. 13, Lsd. 11

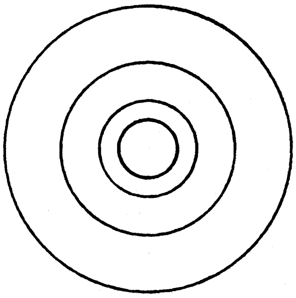


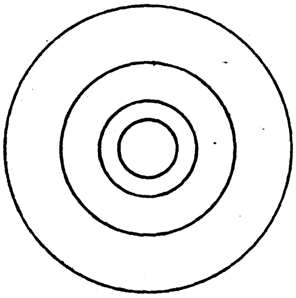
Twp. 6, Rge. 15, Sec. 13, Lsd. 10



Twp. 6, Rge. 15, Sec. 13, Lsd. 12







APPENDIX 2

STONE RINGS IN SOUTHERN ALBERTA

In the Foremost-Cypress Hills area of south-eastern Alberta circular patterns of stones were found in association with prairie mounds (Plate VIII). The stone rings vary from three to eight meters in diameter and consist of small boulders from 15 to 40 cm. in diameter. As well as being fairly uniform in size the boulders are invariably sub-angular to sub-rounded, showing no evidence of frost shattering, and are partially imbedded in the sod, exposed surfaces being encrusted with lichens.

A survey of the literature indicates that stone rings are predominantly a northern Great Plains characteristic, with its locus centered in the upper regions of the Missouri River system. Occurrences of the rings have been reported between the continental divide in western Montana and the mouth of the Cheyenne River in South Dakota, and as far south as Nebraska and to the north into Alberta. They are sometimes found near the divide itself but are rare to the west, the only ones known to date being around Flathead Lake, Montana (White, 1959).

The stone rings seem to find their most plausible

Plate VIII. A compact single-coursed stone ring about 8 meters in diameter, located in the central depression of a prairie mound.
SW.$\frac{1}{4}$, Sec. 1, Twp. 6, Rge. 11, W.4.

explanation in the culture of the prehistoric occupants of the area. While archaeologists seem to have no doubts about the cultural affinities of these rings their explicit function has been a subject of considerable confusion and uncertainty. Substantial evidence has been rallied by Kehoe (1960) to support the hypothesis that the rings are true occupation sites in that they were used by an indigenous population of presumably nomadic hunters to secure the edges of their shelters, either conical skin lodges of the tipi type or crude hogans covered with grass mats. As well as being used as weights to prevent the lodge from being overturned by strong winds, the rocks were used to keep it warm by fixing the cover close to the ground. Others, however, contest this idea and maintain that the rings served some obscure esoteric role. Mulloy (1952), in fact, bombastically refers to them as "manifestations of unknown relationships". They may have been used for ceremonial or religious purposes, or even for games.

To date any interpretation of the rings has been based on a review of artifacts, early historical documents and ethnological data. It is the thesis of this paper that intensive excavation and study of the geographic setting of stone rings may provide further evidence that will bear on the interpretation of the rings. Careful excavation, which has not been pursued due to the lack of encouraging surface finds, may produce culturally diagnostic artifacts such as projectile points that may vary with the different types of rings found in the area. The stone rings may thus be established as secondary indications of the cultural affiliations of their occupants.

Shelter and subsistence were the most vital aspects of the life of prehistoric people. Although the way in which these needs were satisfied may have depended to some extent on the type of society, the availability of raw materials and the habitat were the most significant factors. If the rings are to be related to satisfying a need of shelter, a consideration of the geographical-ecological context of these sites could be invaluable. The geographic setting of surface sites can in part be successfully studied in terms of the associated geomorphology. When the typical geomorphic situation of a certain type of occupation site is understood, regional landforms can be evaluated as to their possible role in the pattern of prehistoric settlement. Therefore, their setting in relation to regional landforms can be particularly interesting. The study of archaeological sites and their setting can be a dual process in which, first, the geographical context of the site aids the student in interpreting the function and nature of the site, and second, the type of occupation site enables him to evaluate the role of various geographical settings in the pattern of the occupancy.

Analysis of stone rings in the Foremost-Cypress Hills area, and a comparison of the observations with those made by Kehoe (1960) in north-central Montana, which is generally believed to have been similarly long settled by the Blackfoot Indians, form the basis of the theme of the paper.

Local relief and the abundance of surficial stones have inhibited cultivation of the prairie mound type of topography in southern Alberta. Since much of it has never been broken by the plough and remains relatively unaffected by farming, many of the archaeological aspects of the Great Plains are still preserved. In this respect, this landscape is comparable to Kehoe's research area, which is the Blackfoot Indian Reservation in north-central Montana immediately east of the Rocky Mountains. A total of seventy-four stone rings were recorded in the vicinity of prairie mounds. A consideration of the material found at these sites and detailed examination of their immediate environment could lead to a better understanding of the significance of the rings and of the nature of the prehistoric occupance of this type of landscape.

In the Foremost-Cypress Hills area, the rings are most often circular, but two oval, one semi-circular, and three modified circular patterns were also noted. Kehoe, however, did not find any eccentric forms. In south-eastern Alberta, gaps in the stone rings were noted at 32 per cent of the sites studied, whereas in Kehoe's area only 13 per cent of the sites included rings that were broken (Table 5). The gaps exhibit a markedly preferred orientation, facing predominantly east in both areas (Figure 17). Kehoe and others have tended to attribute this characteristic to rather elusive esoteric purposes, noting that it is reminiscent of the historic tribes' tradition of placing a doorway towards the rising sun. If one accepts the interpretation of these gaps as doorways, however, it seems entirely plausible that the occupants were merely adapting to the climate by placing their doorways in the side of their lodges to the lee of the incessant prairie winds that prevail from the south-west. Rock concentrations in the centers of the rings, that are possibly firehearths, occurred in 16 per cent of the sites in Montana, and in a comparable 19 per cent in Alberta.

The quantity of rock material in the stone rings reported by Kehoe always seemed to be in proportion to that needed in weighting down a lodge cover. In Alberta both double-coursed and single-coursed rings were found, the former being composed of two rows of tightly spaced stones, the latter a single row of sometimes quite widely spaced stones (Figure 18). Size of the stones seems to be fairly constant for both types. This difference in the rings may represent shifts in cultural and economic patterns. Kehoe suggests that before the acquisition of steel axes and hatchets, the Indians could not easily cut and sharpen wooden pegs to fasten down their lodges but instead tended to use rocks as weights. During the proto-historic period which began with the introduction of the horse and steel cutting tools, pegs that would not come out in the wind become more commonplace. At first

TABLE 5

Relative Occurrence of Characteristics and Patterns of Stone Rings

	Montana (1960)		Alberta (1966)			
			I*		II*	
Door-gaps Sites studied	$\frac{11}{85}$	13%	$\frac{10}{31}$	32%	-	-[1]
Rock concentration in center Sites studied	$\frac{23}{144}$	16%	$\frac{7}{37}$	19%	$\frac{8}{42}$	19%
Single isolated ring Number of sites	$\frac{63}{137}$	46%	$\frac{24}{37}$	65%	$\frac{28}{42}$	67%
Sites of 3 or less rings Number of sites	$\frac{92}{137}$	67%	$\frac{32}{37}$	86%	$\frac{39}{42}$	93%
Single isolated ring Total number of rings	$\frac{63}{750}$	8%	$\frac{24}{74}$	32%	$\frac{28}{74}$	38%

1. Those sites that include single-coursed "loose" rings are not considered due to the difficulty of recognizing possible door-gaps.

* I Each cluster of rings is treated as one site.

*II Clusters of rings with two or three rings (Figure 18) are treated as two or three sites respectively.

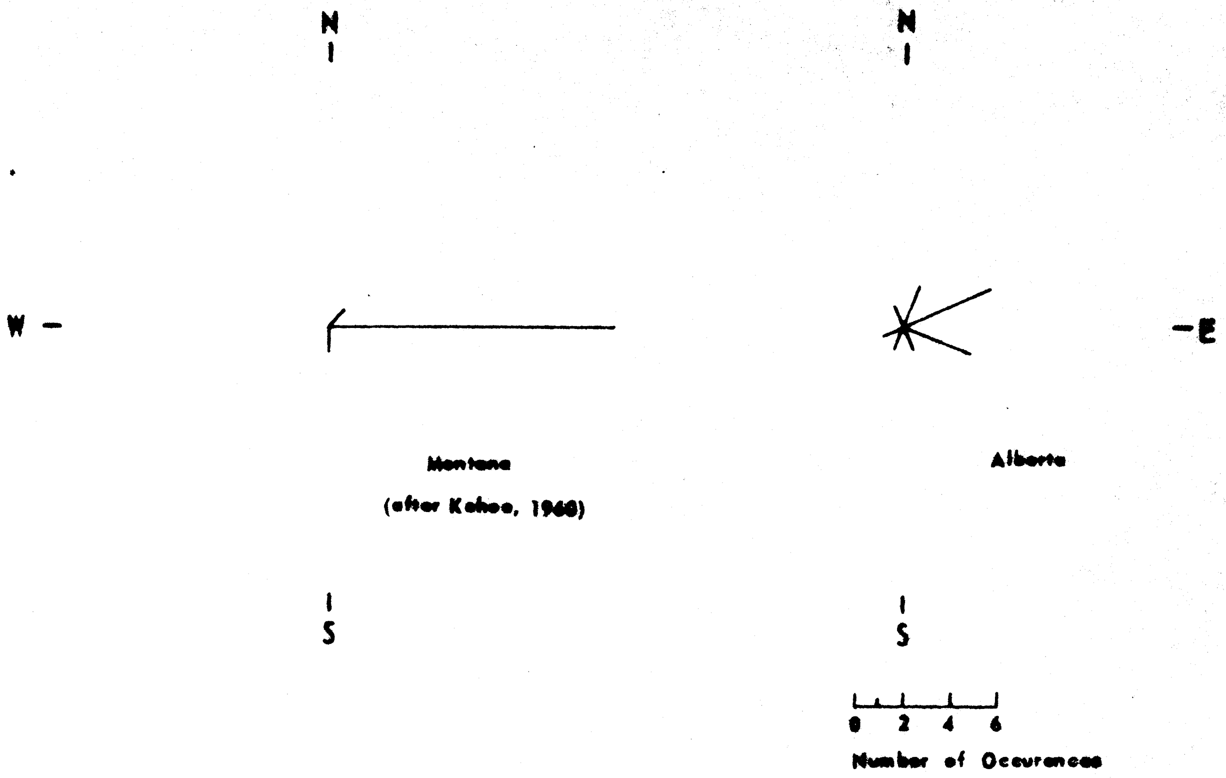
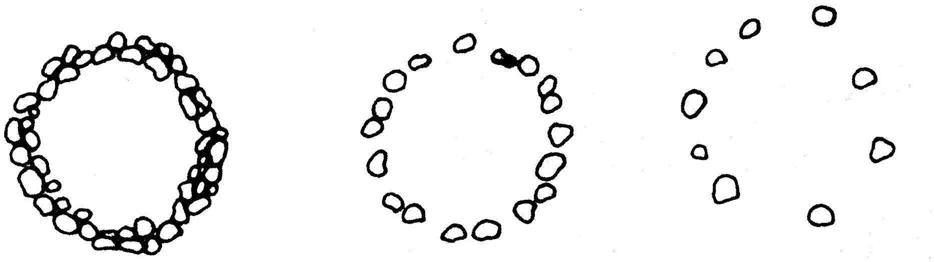


Figure 17 ORIENTATION OF OPENINGS IN THE STONE RINGS



Compact Double-Coursed Compact Single-Coursed Loose Single-Coursed

Figure 18 STONE RING FORMS

these were used either solely or in conjunction with stones. Later in historic times stones continued to be used with hide covers, especially for ceremonial lodges of sacred persons and burial lodges; however, they were not used with canvas lodges since taut canvas does not stretch in the wind and stones tend to roll off. It is possible then that most of the double-coursed rings are prehistoric, while the single-coursed rings were used in conjunction with pegs to hold down the last widely-used hide lodge covers, mainly during the proto-historic period.

There may be a relationship between the numbers and arrangement of rings that are to be found at any site (Table 6) and the topographic setting, if indeed these sites are true camp-plans. Frequently the sites include both "compact" double and single-coursed rings and "loose" single-coursed rings. If differences are indicative of changes in cultural and economic patterns, then the present existing camp-plans are the result of more than one occupation, the "loose" rings being more recent than the "compact". For this reason the quantity of rock material in the stone rings has been taken into account in determining total number of sites and in describing camp-plans. Where both types occur together, two sites are recorded and separate camp-plans are described for each type. This seems justifiable particularly if, as Kehoe claimed, old rings were not re-occupied out of respect for the deceased "owners". A comparison of camp-plans in the

TABLE 6

Frequency of Occurrence of Camp-Plans

Plan	I* Number of Sites	Number of Rings	II* Number of Sites	Number of Rings
Single isolated ring	24	24	28	28
Two rings	5	10	7	14
Three-ring triangle	2	6	3	9
Single Row	2	10	2	9
Semi-circle	3	20	1	10
Circle	1	4	1	4
Total	37	74	42	74

*I Each cluster of rings is treated as one site.

II Clusters of rings with two or three rings (Figure 18) are treated as two or three sites respectively.

Montana and Alberta areas reveals significant differences. Of the total number of sites, single isolated rings contribute 67 percent in the Alberta area, as compared to 46 percent in Montana. Analagous differences also exist when camp-plans having three or fewer rings are considered, 67 per cent being included in Montana to 93 per cent in Alberta. Furthermore, single isolated rings comprised only 8 per cent of the total in Montana as compared to 38 per cent in Alberta. Clearly, then, the sites in Montana suggest generally much larger encampments than in Alberta.

The size of the stone rings may reflect economic and cultural changes. Kehoe stated that their size, although somewhat variable, is circumscribed within narrow limits, rangging from 7.5 to 29 feet in diameter. Mulloy (1952), however, noted circles varying from 5 to 40 feet in diameter, and observed that occasionally larger are found. In Alberta rings from approximately 3 to 10 meters in diameter were recorded, figures that correspond very well to Kehoe's. Kehoe maintained that transportation had a direct bearing on the size of the rings. Tipis were not as large before the horse was acquired since they had to be carried on a travois pulled by dogs. Hypothesized changes in size of the lodges during protohistoric and historic times seemed to be corroborated by the fact that he often noted that stone rings of large diameter seemed to contain fewer rocks. Insufficient observations were made in Alberta in order to comment on his thesis.

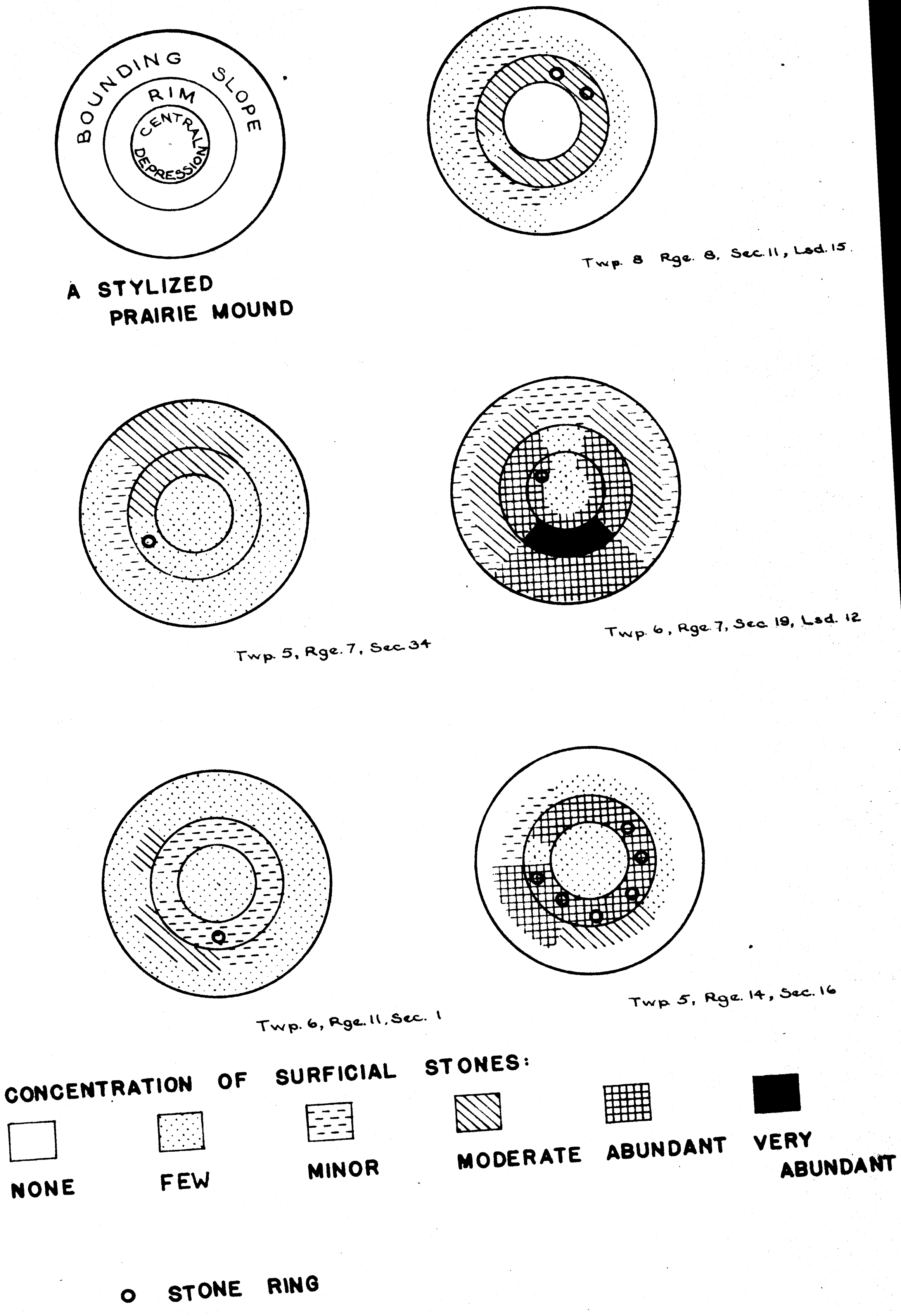
The stone rings found near prairie mounds were most frequently located on the "rims" of the mounds, and then usually on the highest segment. Of the total studied, sixty-seven were located on rim sites, whereas only three were situated in "central depressions", and four in intermound sites. Meanwhile it was also noted that for any one mound the greatest concentration of surficial stones was generally on the rim of the mound. Hence, locally the sites of the rings corresponded to the areas of greatest stone concentration. Throughout the Foremost-Cypress Hills area, however, this seemingly positive relationship is actually only apparent since the occurrence of stone rings is not determined by the density of stone cover (Figure 19).

Mounds that are sites of stone rings are often adjacent to enclosed depressions that still are wet far into the summer dry period. Kehoe likewise found the rings to be frequently situated in the open, either on high places or hills, and near water.

In many respects the stone rings observed in southern Alberta are similar to those studied by Kehoe in Montana. Kehoe's thesis that the stone rings are true occupation sites is very convincing, particularly since he includes eyewitness accounts and explanations. It is here suggested that the differences that do exist between the two areas reflect cultural and economic differences in the type of the occupance, The most notable difference is in the number of stone rings

Figure 19

SITES OF STONE RINGS



A STYLIZED PRAIRIE MOUND

Twp. 8 Rge. 8, Sec. 11, Lsd. 15

Twp. 5, Rge. 7, Sec. 34

Twp. 6, Rge. 7, Sec. 19, Lsd. 12

Twp. 6, Rge. 11, Sec. 1

Twp. 5, Rge. 14, Sec. 16

comprising the camp-plans, which has been emphasized only slightly by taking into account the various types of rings observed in Alberta. In Montana some sites include so many rings that they could mark the settings of entire tribal gatherings convened for the intensive hunting of buffalo and ceremonial observances during the summer. The locations for such sites were favoured because they are near "sweet" running water. In contrast, the stagnant ponds found in the prairie mound landscape of Alberta probably attracted only small migrating groups following the buffalo watering at these ponds. Such differences as the more frequent occurrence of doorgaps in Alberta might indicate a variant lodge type preferred by a greater number of the population in this area. If this type of shelter was innovated quite late, the relative occurrence of this characteristic might even reflect the later settlement of the Great Plains by Europeans in Canada than in the United States. A more detailed analysis of the quantity of rocks in the stone rings of both areas could possibly demonstrate cultural and economic changes in the way of life of the Great Plains brought about by first, cultural diffusion from, and then direct contact with, the European.

The northern Great Plains contains much evidence of a long occupancy by man, beginning with an early post-glacial population, but the short-grass and sagebrush plains is still very imperfectly known (Wedel, 1961). The rings cannot as yet be related to specific cultures but the study of the morphology and setting of the stone rings may possibly lead to the cultural and chronological definition of these sites. The building of such a historical framework will be very difficult and tenuous. Because the sites are invariably superficial, relative dating by principles of geological superposition is not feasible. Furthermore, recent geomorphological processes in the region are inadequately known to make any valid inferences. Kehoe noted that a correlation existed between the size of a ring and the depth to which its stones are imbedded in the ground. However, the depth of burial of the rocks is a poor criterion for chronological classification or dating, for conditions such as erosion, deposition, and frost action would affect each site differently. Also care must be taken to distinguish between variance in the rings and especially their "camp-plans" that can be attributed to seasonal subsistence cycles, and variance that reflects real cultural change. Associated cultural-diagnostic materials, that is, those artificants which exhibit technological changes whose sequence can be correlated with successive time periods, in particular projectile points, are extremely rare. None were found near the stone rings observed in the Foremost-Cypress Hills area, but excavations were not made. If the rings themselves are ever to have any cultural-diagnostic value, it is possible only by careful excavation and by detailed studies of the distribution of various types and geographic settings of the rings. Excavation is essential in order to find artifacts necessary in determining the cultures to which the stone rings belong, and hence, the relative date at which they were occupied. Distribution maps can sometimes be used quite effectively to argue questions on cultural history. For example, distributions of diagnostic characteristics which coincide or strongly overlap suggest that the cultures are successive.

Archaeology is concerned with the excavation of man's material culture and the systematic study of this material in reconstructing the past. Its subject matter has primarily consisted of the material remains of past human life and activities. A cursory survey of some stone rings in the northern Great Plains region indicates that the morphology of the rings varies in the same local area and the proportion of any type of ring varies from place to place throughout a region believed to have been occupied at least in the late prehistoric by the same cultural group, that is , the Blackfoot Indians. A more comprehensive study of the material remains of the stone ring sites by way of systematic excavation, along with a consideration of their geographical-ecological context could very well be invaluable in assessing the significance of the Great Plains' stone rings and their variations.

REFERENCES

Hoffman, J.J. "Comments on the Use and Distribution of Tipi Rings in Montana, North Dakota, South Dakota, and Wyoming", Anthropology and Sociology Papers of Montana State University, No. 14 (1953), 16 pp.

Kehoe, T. F. "Stone Tipi Rings in North-Central Montana and the Adjacent Portion of Alberta, Canada: Their Historical, Ethnological, and Archeological Aspects", Bulletin of the Bureau of American Ethnology, 173 (1960), 417-473.

Mulloy, Wm. "The Northern Plains", in J. B. Griffin, ed., Archaeology of Eastern United States. Chicago: University of Chicago Press, (1952), 124-138.

Stephenson, R. L. "Quaternary Human Occupation of the Plains", in H. E. Wright, Jr. and D. G. Frey, Ed., The Quaternary of the United States. New Jersey: Princeton University Press, (1965), 685-696.

Wedel, W.R. Prehistoric Man on the Great Plains. Norman: Univ. of Oklahoma Press, (1961).

White, T. "Tipi Rings in the Flathead Lake Area, Western Montana", Anthropology and Sociology Papers of Montana State University, No. 19 (1959), 8 pp.

BIBLIOGRAPHY

Bik, M.J.J. "Morphoclimatic and Morphotectonic Observations in Southern Alberta, Parts 1 and 2", *Geog. Bull.*, (in press).

Bik, M.J.J. "On the Periglacial Origin of Prairie Mounds", In: *Glacial Geology of the Missouri Coteau.* Editors: L. Clayton and T. F. Freers. North Dakota Geological Survey, Miscellaneous Series 30, 1967, 83-94.

Black, R.F. "Pleistocene Climatic Change Recorded by Ice-Wedge Polygon Casts of Cary Age at River Falls, Wisconsin", *Bull. Geol. Soc. Am.*, 68 (1957), 1888-1889.

Boulton, G.S. "The Development of a Complex Supraglacial Moraine at The Margin of Sørbreen, Ny Friesland, Vestspitsbergen", *Jour. Glac.*, 6 (1967), 717-735.

Christiansen, E. A. "Geology and Groundwater Resources of the Kindersley Area, Saskatchewan", Sask. Research Council, Geol. Div. Rept. 7, 1965.

Clayton, L. "Karst Topography on Stagnant Glaciers", *Jour. Glac.*, 5 (1964), 107-112.

Crickmay, C. H. "Profound Erosion of a Pleistocene Deposit", *Bull. Can. Pet. Soc.*, 14 (1966), 134-144.

Elson, J. A. "Lake Agassiz and the Mankato-Valders Problem", *Science*, 126 (1957), 999-1002.

Flint, R. F. *Glacial and Pleistocene Geology.* New York: John Wiley and Sons, Inc., 1957.

Gravenor, C.P. "The Origin and Significance of Prairie Mounds", *Am. Jour. Sci.*, 253 (1955), 475-481.

Gravenor, C.P. and W. O. Kupsch. "Ice-Disintegration Features in Western Canada", *Jour. Geol.* 67 (1959), 48-64.

Gregory, K.J. and E. H.Brown, "Data Processing and the Study of Landform", *Zeit. für Geomorphologie*, 3 (1966), 237-263.

Hoppe, G. "Hummocky Moraine Regions", *Geog. Annaler*, 34 (1952), 1-71.

Horberg, L. "Intersecting Minor Ridges and Periglacial Features in the Lake Agassiz Basin, North Dakota", *Jour. Geol.* 59 (1951), 1-18.

Jungerius, P.D. "Age and Origin of the Cypress Hills Plateau Surface in Alberta", *Geog. Bull.*, 8 (1966) 307-318.

Lemke, R.W. et al. "Quaternary Geology of Northern Great Plains", In: *The Quaternary of the United States*, Editors: H.E. Wright, Jr., and D .G. Grey (1965), 15-27.

Lewis , W. V. "Dirt Cones on the Northern Margins of Vatnajökull, Iceland", *Jour. Geomorphology*,3 (1940), 16-26.

Mathews, W.H. "Quaternary Stratigraphy and Geomorphology of the Fort St. John Area, Northeastern British Columbia", Victoria, B.C.: Dept. Mines and Pet. Res., Miscellaneous Report, (1963).

Melton, M.A. "Debris-covered Hillslopes of the Southern Arizona Desert - Consideration of their Stability and Sediment Contribution", *J. of Geol.*, 73 (1965), 715-729.

Müller, F. "Observations on Pingos", *Meddelser om Grønland*, 153(3), 1959, 127p.

Ostrem, G. "Ice Melting Under a Thin Layer of Moraine, and the Existence of Ice Cores in Moraine Ridges", *Geog. Annaler*, 41 (1959), 228-230.

Pissart, A. "Les Traces de "Pingoes" du Pays de Galles (Grande-Bretagne) et du Plateau des Hautes Fagnes (Belgique)", *Zeitschr. Geom.*, 7 (1963), 147-165.

Russell, I.C. "Malaspina Glacier", *Jour. Geol*. 1 (1893), 219-245.

Schafer, J. P. "Some Periglacial Features in Central Montana", *Jour. Geol.*, 57 (1949), 154-174.

Stalker, A.M. "Ice-pressed Drift Forms and Associated Deposits in Alberta". *Geol. Sur. Canada:* Bulletin 57, (1960).

Swithinbank, C. "The Origin of Dirt Cones on Glaciers", *Jour. Glac.*, 1 (1950), 461-465.

Westgate, J. A. "Surficial Geology of the Cypress Hills Area, Alberta", *Research Council of Alberta*, Preliminary Report 65-2, (1965).

Westgate, J.A. and L. A. Bayrock,"Periglacial Structures in the Saskatchewan Gravels and Sands of Central Alberta, Canada", *Jour. Geol.*, 72 (1964), 641-648.

Williams, P.J. *Properties and Behaviour of Freezing Soils*. Oslo: Norwegian Geotechnical Institute, Publication Nr. 72. 1967.