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Possible Subglacial Origin for "Minor Moraine" Topography

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Abstract. Surface expression of the Cary Age Drift (Des Moines lobe of Iowa) exhibits a pattern of intersecting linear ridges and depressions, known as swell-swale or "minor moraine" topography. Linear ridges, as mapped from air photos, are aligned either parallel or approximately transverse (45° to 90°) to associated end morainal systems.

Both parallel and transverse ridges appear genetically related, range in height from 5-20 feet and are composed predominantly of till. Ridge intersections produce "T", "offset" "step" and "box" patterns. The irregular shape and high dip of crossbedding of small sand bodies and the dip of small faults and joints suggest a controlled ice disintegration origin. Alignment of till fabric with glacier flow is indicative of a lodgment till or ground moraine.

The current hypothesis that the "minor moraines" represent "annual" recessional moraines does not explain the lack of outwash, the origin of transverse ridges, till fabric, the number of moraines and their geographic distribution.

Alternate hypotheses for the observed pattern are: 1) crevasse fill 2) ice marginal thrust 3) basal crevasse "squeeze" and 5) boundary wave phenomenon.

THE PROBLEM

The topography of the Des Moines Lobe in Iowa is the product of Late-Wisconsin, Cary glaciation. The upland topography throughout much of the lobe presents a complex pattern of intersecting ridges, closed circular depressions, open linear depressions and short, sinuous, glacial meltwater channels. The relatively young age of the Cary Lobe, (13,000-14,000 Y.B.P., Ruhe and Scholtes 1959) suggests that the present topography is essentially an unmodified, glacial depositional landscape.

The first quantitative investigation of the surficial topography of the Des Moines lobe was undertaken by Gwynne (1941, 1942a and 1942b). Gwynne noted that the "pattern of ground moraine (was) formed of narrow, alternating, discontinuous light and dark streaks or patches which gave a banded effect" to aerial photographs and photo mosaics. The topography producing this banded photographic effect consists of a series of parallel swells and intervening swales. A series of linear elements perpendicular to the swells was not recognized by Gwynne.

Similar glacial topographies dominated by linear elements have been observed in North Dakota and Minnesota (Gwynne 1951), Western Canada (Gravenor and Kupsch 1959), Alberta (Stalker 1960), Baffin Islands (Andrews 1963) and east of the Hudson Bay, Quebec (Prest 1968). Glacial topographies dominated by linear

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elements of the type found throughout the Des Moines Lobe have been variously named by these authors swell-swale topography, minor moraine topography, cross-valley moraines and De Geer moraines.

Various hypotheses have been advanced to explain the formation of glacial topographic lineaments. These hypotheses can be generally classified as 1) crevasse fill origin, 2) thrust plane origin, 3) basal crevasse fill origin, 4) basal boundary wave phenomenon, 5) annual recessional moraine origin.

Methods

Aerial photographs and compiled photomosaics taken in 1939, 1952, 1955 and 1967 were utilized in studying the glacial landform patterns of the Des Moines lobe in Iowa. For a detailed investigation, an area in northwest Story County was selected for study (figure 1). A photomosaic study of the entire Des Moines Lobe in

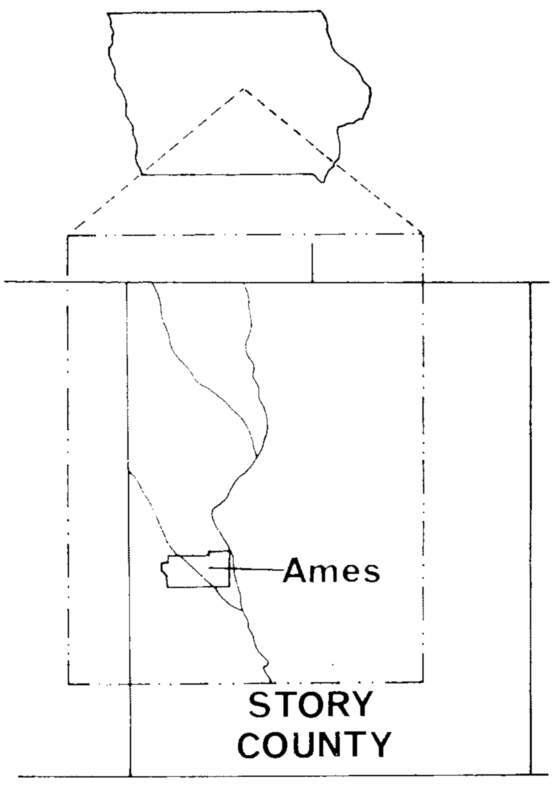

Figure 1—Location of study area in northwest portion of Story County.

Iowa indicated that the study area exhibited all the glacial landforms characteristic of the Des Moines Lobe.

The lithology and stratigraphy of selected glacial landforms were determined by outcrop description and auger hole information gathered by the authors during the summer of 1968 and financed by the Iowa State University Small Grants Committee. This information was supplemented by Iowa Highway Commission soil survey profiles of Interstate 35 and relocated Highway 30 in Story County.

The method of till fabric analysis used in this study is essentially that described by Harrison (1957a). The procedure involved includes 1) collecting in the field an oriented block of till, 2) reorientation of the till block on a two stage contact goniometer, 3) measurement of long axis ('a' axis) and intermediate axis ('b' axis) where possible, of particles longer than 4mm, and 4) presentation of the data by standard statistical and petrographic techniques. Till fabric sites were chosen where 1) the topographic expression of the glacial features was well defined and could be located on aerial photographs and 2) where landforms were large enough to produce multiple sample sites. The number and distribution of sample sites was limited to artificial outcrops (quarries and road cuts) in the study area.

Results

The physiography of the study area may be divided into two parts, 1) flat to gently rolling uplands and 2) youthful river cut valleys 50-75 feet below the the upland. The uplands regions can be classified into two distinct geomorphic types based on the topographic relief and on the tone and texture of aerial photographs. These two geomorphic types are end members in a continuium from a nearly level, featureless topography to a distinctly lineated topography. These end members are designated as non-lineated and lineated topography.

Non-lineated Topography

Areas classed as nonlineated are characterized by 1) a low surface slope and subsequently poor drainage, 2) a lack of relief, 3) poorly defined linear elements and 4) dark tones and a smooth, even texture on aerial photographs. These areas have been previously mapped as ground moraines (Ruhe 1969).

The Story City flats, covering an area of approximately 20 square miles in the north central part of the study area (figure 1) is typical of a non-lineated geomorphic region. Photographically, the area can be isolated by its darker tones and lightly mottled, random texture (Plate 1). The mottled texture results from soil and moisture variations resulting from the gentle, 2-5 feet of relief. Intersecting linear elements appear randomly distributed throughout the area and do not dominate the topography. Two sets of orthogonal ridges can be isolated and are oriented NE-SW and NW-SE (Plate I, A and B respectively).

Plate I—Aerial photograph of nonlineated upland surface. A and B indicate the two linear trends which appear randomly within the area, but do not dominate the topographic pattern.

Lineated Topography

Within the area defined as having a lineated topography, four distinct glacial features can be identified. These are 1) parallel ridges, 2) transverse ridges, 3) glacial drainageways, and 4) kame like deposits. All linear elements are classified as either parallel or transverse according to their relationship to associated morainal systems. Lineated areas have been previously mapped as end morainal areas (Ruhe 1969).

Description of parallel ridges. Predominant among the glacial elements within the study area is the NE-SW trending series of ridges and intervening depressions (Plate II, A). Gwynne (1941) named the parallel ridges minor moraines because of their approximate parallel relationship to the margin of the Des Moines lobe and described the succession of ridges and depressions as swell-swale topography. The non-genetic term "parallel ridges" is prefered and will be used in this report.

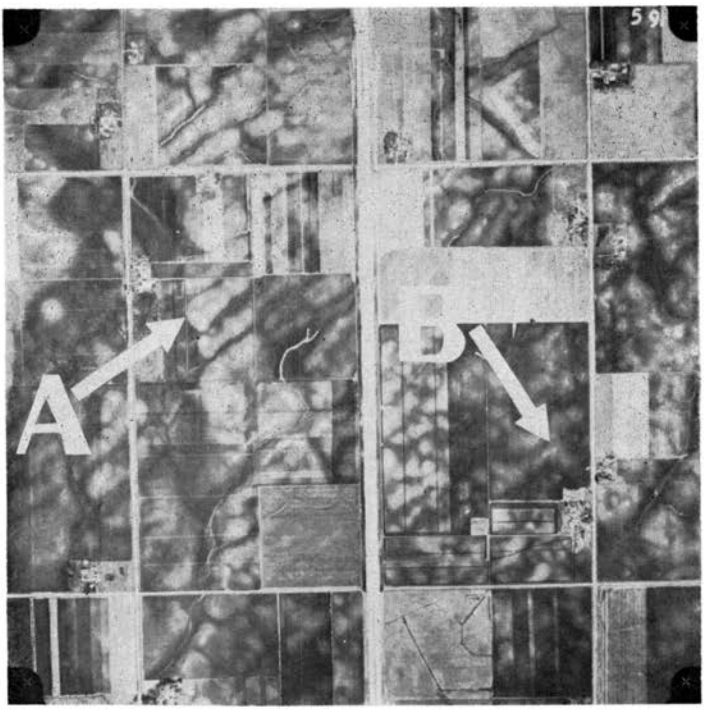

Plate II—Aerial photograph of a lineated glacial topography. Parallel and transverse ridges are located by A and B respectively. In the western half of the photo can be seen a glacial drainageway trending nearly north-south.

Parallel ridges range from 5-40 feet in height. The average spacing of successive parallel ridges is 350 feet (15/mile) with a variability from 100 to 600 feet.

The parallel ridges locally exhibit a scalloped pattern in which they curve up ice and approach a transverse trend (figure 2). Scalloped patterns occur within the study area, along Squaw Creek, Skunk River (below Ames), Indian Creek, and East of Randall.

Results of the drilling program (Table 1) and outcrop observations indicate that parallel landforms consist predominantly of sandy clay till. Less than 2% of the total footage drilled in these

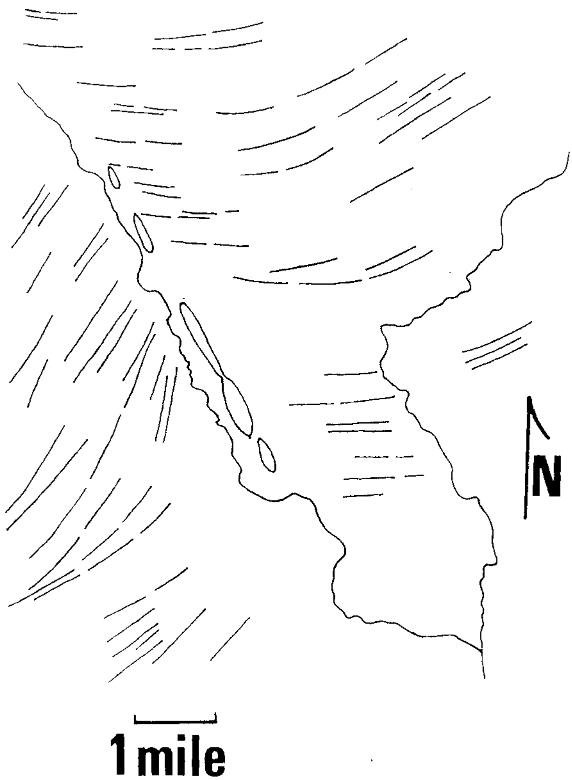

Figure 2—Scalloped patterns along Squaw Creek west of Ames.

features consists of sand or gravels. The lack of sand and gravel bodies is also confirmed by Iowa Highway Commission soil survey profiles for Interstate 35 and new Highway 30.

It is important to note that where sand and gravel bodies are found, they appear lenticular to irregular in shape. Locally the sands will have cross bedding or graded bedding, and where cross-bedding is evident, the beds will usually dip at extreme angles, 40-60° and be considerably distorted. Highway Commission borings indicate that where larger sand bodies are found they generally dip away from the crest of the feature whether parallel or transverse.

Description of transverse ridges. Transverse ridges are composed predominantly of till (Table 1) and are identical to parallel ridges in form and composition but differ in orientation (B in Plate 2). These features are less prominent than parallel trends and were not recognized by Gwynne in his description of the Des

Table 1

Results of Drilling Program

Type of Feature	Parallel Trends	Transverse Trends	Kame-like Features	Drainageways
No. of holes	32	4	13	15
Thick. Wisc. Till	759 feet[1]	123 feet	108 feet	211 feet
Thick. Wisc. sand and gravel	13	7	149	111
Others*	—	—	24L	51A
Thick. Kan. Drift	92	11	—	40
Total footage	864	141	281	414

1 Numbers indicate total thickness of material for all auger holes in each class of glacial feature.

* L-Loess
A-Alluvium

Moines lobe.

The transverse features are distributed randomly throughout the upland and are oriented from 45° to 90° to the parallel ridges. Regionally they appear to parallel hypothetical glacial flow lines as inferred from morainal trends and striae.

Glacial drainage channels. Glacial drainage channels appear on aerial photos as short, sinuous depressions, a fraction of a mile to several miles in length (see western half of Plate 2). Fifteen auger holes were drilled in these features, representing ten distinct drainage channels (Table 1). Their composition of graded sands and gravels, averaging about seven feet thick, suggests deposition from flowing water. The upper 3-5 foot of clay or silt represents post-glacial deposition of material eroded from the adjoining uplands.

Four characteristics of these features are apparent: 1) many channels are integrated with the present drainage systems, 2) when integrated with the present drainage systems they are distinct and easily recognized only at the source but downstream become indistinguishable from the modern floodplain, 3) in all cases the glacial drainage channels within the study area had an apparent southeast flow direction, approximately parallel to the transverse trends and the modern drainage, 4) drainage ways are associated with the axis of most scalloped regions.

Kame-like deposits. Kames or kame like deposits occur as conical hills to elongate ridges of high relief (50-75 feet). These features are composed almost entirely of sands and fine gravels, which show stratification where exposed in outcrops. Kame-like deposits are found associated with scalloped patterns, where they are clustered along and parallel to the axis of the scallops and flanked by glacial drainage ways.

Intersection patterns. The pattern produced by the intersection of parallel and transverse ridges is highly varied and complex, but generally falls within one of five classes. Combinations of intersections of all the class types produce the complex landform patterns are shown diagramatically in figure 3 and include: A) offset, B) "T",C) box, D) cross intersections and F) a nonintersection where either a parallel or transverse ridge is discontinuous at an apparent intersection. A sixth pattern could be considered the scalloped pattern discribed previously where the parallel ridges curved into a transverse trend (figure 2).

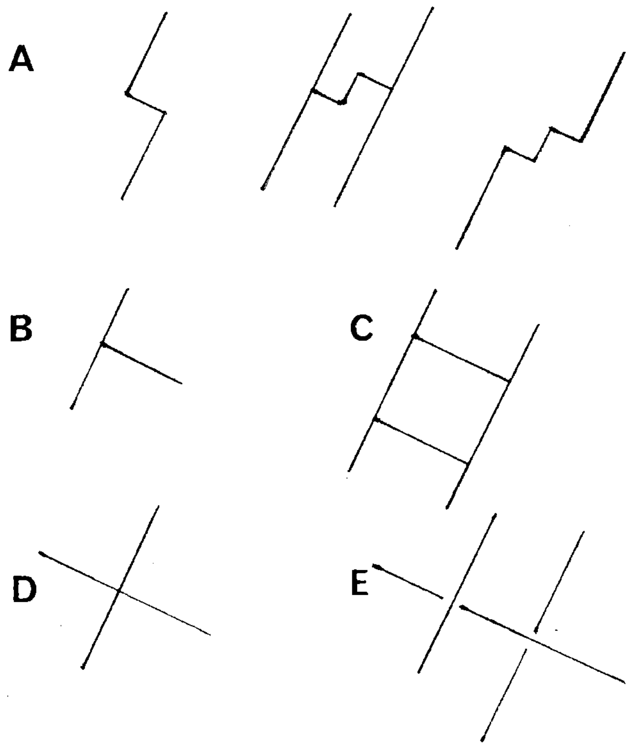

Figure 3—Patterns produced by the intersection of parallel and transverse ridges. A, off set intersections; B, "T" intersection; C, box intersection with central undrained depression; D, cross intersection; E, nonintersection pattern.

Fabric Studies

Two sites were selected for detailed fabric studies of parallel

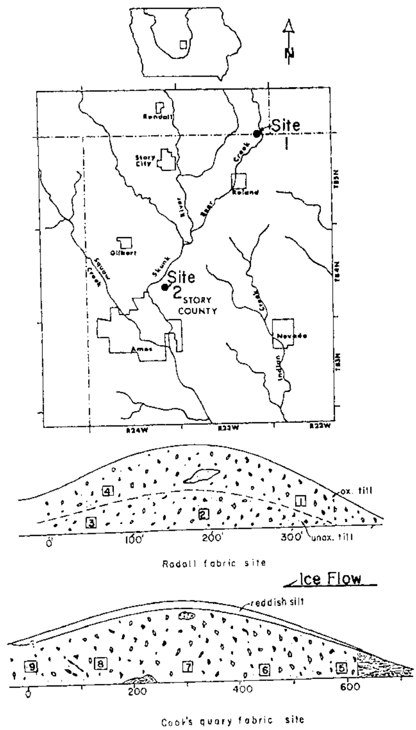

Figure 4—Location and cross-sections for fabric sample sites.

ridges (Figure 4). Site 1 is located 3¾ miles west of Garden City on County Road C. The axis of the parallel ridge trends N 30° E. Striae on a bedrock surface, previously unreported, in a quarry 2¼ miles south west of the fabric site trend S 35° E.

Sample Site 2 is located at Cook's Quarry 1¼ miles northeast of Ames (Figure 4). The south face of the quarry cuts through a parallel ridge which trends N 40° E. Bedrock striae in the immediate area (Gwynne 1950) trend S 42° E.

Nine fabric samples were taken from the two parallel ridges (4 from Site 1 and 5 from Site 2). The location and orientation of each sample is shown in Table 2. For Site 1 (Figure 5) samples 1 and 4 represent approximately the same elevation (10 feet below the crest) on the proximal and distal slopes respectively. Samples 2 and 3 were taken along the base (18 feet below the crest) at the center and distal portion of the ridge. At the Cook's Quarry outcrop all five samples were taken along the base of the cut (5 through 9 from proximal to distal portion respectively).

Examination of the fabric diagrams indicate that some vertical

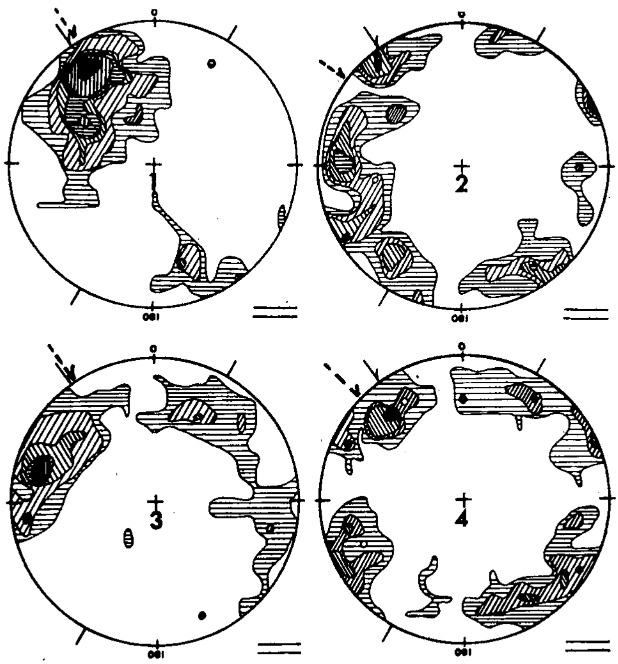

Figure 5—Fabric diagrams for site 1, 3¾ miles west of Garden City. Striae trend shown with an arrow in fourth quadrant. Ridge axis is shown by the two marks outside the first and third quadrants. Dashed arrow indicates mean fabric azimuth. Zero degree (top) is north.

and lateral variations occur within a single outcrop and between outcrops. For site 2 the striae trend and short axis of the parallel ridge agree within 3°. For site 1 the striae trend and ridge short axis differ by only 10°. Sample 6 appears anomalous since its fabric axis is 90° to all other fabric axis. This sample probably was not reoriented properly due to fracturing during recovery and transport to the laboratory. Sample 8 appears to have a random fabric even though the fabric axis agrees with other samples.

The characteristics of the fabric diagrams, excluding samples 6 and 8, are listed below and in table 2.

1. Fabric axes approximate glacial striae trends. Minimum divergence is 1°, maximum divergence is 35°.
2. All of the diagrams have their strongest concentration in the fourth quadrant, 270-360°, indicating a preferential imbrication up glacier of the elongate clasts.
3. Low plunge angle of 'a' axes for majority of pebbles samples.
4. A secondary concentration in the second quadrant, 90-180°,

which is diametrically opposed to the fourth quadrant concentration.

5. Minor cross-fabric at 90° to major fabric axis.

Discussion

The characteristic fabric of the two ridges sampled is indicative of a lodgement till or ground morainal deposit (Holmes 1941, Krumbein 1939, Harrison 1957b). Harrison suggests that the fabric-pattern maxima "define vanished slip planes" produced by internal deformation of the moving glacier and that the till was transported over "upstream-inclined thrust surfaces."

The "parallel, discontinuous, sandy-silty till ridges (washboard moraines)" of low relief and spaced 300-500 feet apart, forming a

Table 2. Compiled fabric data for sites 1 and 2. Column 1, sample number; 2, mean fabric azimuth; 3, striae trend; 4, trend of ridge long axis; 5, deviation of fabric from striae trend; 6, deviation of fabric from ridge long axis; 7, devation of fabric from ridge short axis. For fabric site 2, sample 6 was excluded for determination of average values.

1	2	3	4	5	6	7
Fabric Site 1						
1	323°	325°	30°	-2°	67°	23°
2	300	325	30	-25	90	0
3	326	325	30	1	65	26
4	*317*	*325*	*30*	*-8*	*73*	*17*
average	316			9	74	16
Fabric Site 2						
5	312	318	45	-6	93	3
6	29	318	45	71	16	16
7	335	318	45	17	70	20
8	283	318	45	-35	122	32
9	*289*	*318*	*45*	*-29*	*117*	*26*
average	305			22	100	20

lobate pattern near Cartwright, Manitoba have a petrofabric characteristic of lodgement till (Elson, 1957). The preferred fabric orientation of these ridges conformed to the regional striae trends.

Several hypothesis have been advocated to account for the formation of glacial topographic lineaments. These may now be critically evaluated in light of this study.

Hypothesis 1: Minor Moraine Origin

First proposed by Gwynne (1941), this hypothesis states that swell-swale patterns are in essence minor end moraines of a receeding glacier, possibly representing an annual fluctuation of the margin of the ice sheet. Ruhe (1969) has accepted the minor moraine hypothesis and has mapped large areas of the Des Moines Lobe as end moraine using swell-swale topography as his criteria.

Gwynne's hypothesis advocates the classical concept of advance and retreat of a continental glacier. Recent studies of ice-masses and glaciers indicate that deglaciation is a result of ice stagnation and downwasting rather than backwasting (Flint 1957, Goldthwait 1961, Hartshorn 1961, Clayton and Freers 1967). Where a stagnating glacier becomes covered with 1-2 feet of superglacial debris the processes of ice wasting become substantially slower (Sharp 1949). Where found in central North Americal the 350-foot spacing of the parallel ridges is characteristic. This spacing could not be produced by annual backwasting of a continental glacier throughout the diverse climatic regions of nothern North America.

The minor moraine mechanism also does not explain the lack of proglacial outwash on the uplands and the origin of transverse ridges. Studies of patterns and composition of intersecting ridges suggest that both types were formed by variation of a singular mode of origin.

Hypothesis 2: Superglacial Crevasse Origin

A superglacial crevasse fill origin for linear or sinuous ridges has been discussed by Flint (1928), Gravenor and Kupsch (1959) and Clayton and Freers (1967). The hypothesis is that a system of crevasses oriented parallel and perpendicular to the margin will develop during active glacial flow and will provide sites for the accumulation of debris during stagnation and deglaciation.

The work by Meier (1955, 1958, 1960) on the orientation and mechanics of crevasse formation for the Blue Ice glacier, Greeland can be directly applied to the study area. Using reasonable values of flow velocity and surface strain rate a series of parallel crevasses spaced 350 ft. is reasonable. Longitudinal crevasses in the Blue Ice Glacier were found to form parallel to flow lines due to lateral expansion of the lobe. Parallelism of transverse features with Cary flow lines has been postulated for the Des Moines Lobe.

Unfortunately hypothesis 2 is not compatible with either the composition or fabric of parallel and transverse ridges. Crevasse fill features exhibit a chaotic texture, with steeply dipping beds and clast imbrication transverse to the crevasse axis and dipping away from the axis (Suttner 1967). This has not been found for linear ridges in the study area except for the axial transverse ridge associated with the Squaw Creek Scalloped belt.

Hypothesis 3: Thrust Plane Origin

To account for the orientation and lodgement till fabric of washboard moraines in Manitoba, Canada, Elson (1957) proposed a thrust plane origin. Till ridges are deposited subglacially by the "lodgement of till at a line (zone) where the brittle upper ice extended down to the sole of the glacier" resulting in thrusting of active ice over marginally stagnant ice. Elson speculated that the interval between ridges (350 feet) represented annual (?) retreat of th thrust zone.

Marginal thrusting of active over stagnant ice has been observed in Antarctic glaciers (Hook 1968), yet the formation of parallel ridges in previously glaciated areas has not been found. To produce variations in the rate of marginal shearing and shear zone retreat necessitates a cyclic retreat of the active-stagnant ice margin. This cyclic variation can only be controlled by seasonal or climatic variations but as previously mentioned equally spaced ridges could not be formed over diverse climatic regions.

This hypothesis does not explain the origin of graded or stratified sand bodies found in linear ridges within the study area. Also not explained is the origin of transverse ridges which would likely not be formed while the ice were still actively flowing.

Hypothesis 4: Subglacial Till-Ice Boundary Phenomenon

This hypothesis proposes that the origin of swell-swale thopography is related to the interaction of the till-ice boundary. If ice and till are both treated as viscous or semi-viscous materials, flow of the glacier will set up waves at the till-ice boundary. These waves result in the formation of swell-swale topography.

Theoretical treatments of glacier sliding has been given by Weertman and Lliboutry (in Scheidegger 1961). Glacier sliding is a result of two related factors, pressure melting and stress concentrations. If a glacier is to effectively slide over its bed with relatively high velocities it must become detached, in part, from its base. An idealized glacier bed, therefore is molded into parallel sine waves which are formed to reduce frictional drag.

Drawbacks to the above hypothesis are that the mechanism proposed operates at a much smaller scale and on bedrock surfaces and can not be directly applied to till-ice boundaries. This mechanism has yet to be observed in operation and it will not account for the formation of transverse ridges and the composition of parallel and transverse ridges.

Hypothesis 5: Subglacial Crevasse Origin

Parallel and transverse ridges are a result of previously deposited unfrozen, supersaturated, ground moraine being forced or squeezed into either subglacial crevasses or surficial crevasses which have perforated the base of a stagnant ice mass. The mechanism of crevasse formation has been previously mentioned.

The mechanism of subglacial squeezing would account for the spacing and orientation of linear ridges, and intervening depressions. The depression results from the loss of material by flowage into basal crevasses (Stalker 1960). The sand and gravel bodies possible represent subglacial streams established along the crevasses. As the ground moraine is squeezed into the basal crevasse these sand bodies will become distorted and plunge away from the crest of the ridge (observed in Highway Commission borings).

This mechanism must be ruled out on the basis of fabric studies. Andrews (1963) has shown that the cross-valley moraines of the Baffin Island are a product of subglacial squeezing. These features exhibit a fabric which is perpendicular to the ridge axis and plunging away from the crest on either side.

Conclusions

This study indicates that the origin of the glacial topography of the Des Moines Lobe is yet to be fully explained. Intersecting lineament topography is not limited, nor unique, to the Des Moines lobe but can be found throughout much of northern North America glaciated during late Wisconsinan time. The regional similarities of the features suggest that their origin is related to the dynamics of flowing ice. The ridges were either formed during active flow or during ice stagnation as controlled ice-disintegration features. The internal relationships and intersecting patterns of ridges along with modern concepts of continental deglaciation indicate that a controlled ice-disintegration origin is most likely. The significance of the till fabric is not fully known but appears to suggest a subglacial, lodgement origin for the ridges.

More work is needed in this area before fabric characteristics can be evaluated and used as a diagnostic criterion.

It can be concluded that all the data indicate that the "minor moraines" are neither end moraines nor ice marginal features. The exact origin of Des Moines lobe glacial topography can not be determined with the present information.

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