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Wind-aligned Drainage in Loess in Iowa

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Analysis of stream valley alignment reveals that first-order valleys, which are formed entirely within Wisconsinan loess, show a strongly preferred orientation of N40-50°W, within an otherwise random distribution. This alignment is present in NW, W Central, and Central Iowa. It is not apparent in S Iowa. In NE and E Iowa wind-aligned features change to a N60-70°W orientation. This is interpreted as wind-alignment of the low-order valleys within the loess, created by prevailing NW winds during or shortly after loess deposition. Higher order streams are controlled by the till landscape beneath the loess. The four directions of preferred orientation in these higher order valleys are coincident with till joints.

INDEX DESCRIPTORS: Loess, eolian processes, stream valleys, drainage development, joint patterns.

In November 1973 the National Aeronautics and Space Administration (NASA) acquired high altitude color infrared imagery (CIR) of a portion of west-central Iowa. The imagery covered an east-west band, approximately 30 miles wide, from about Des Moines, Iowa, west to the Missouri River (see Anderson, et al., 1974, for details). Examination of the CIR imagery revealed a strong northwest to southeast lineation in the central part of the area covered. This lineation was most strongly expressed in parts of Carroll, Crawford, Shelby, and Audubon counties, between the divides of Brushy Creek on the east and the Boyer River on the west (fig. 1). The lineation becomes less obvious in the more dissected loess-mantled terrains to the east and west and reappeared to a lesser extent in the bluffs immediately adjacent to the Missouri River. It was apparent from the imagery that this lineation occurred because of alignment within the low order stream valleys. This lineation was not obvious or apparent on other maps, such as, 1:24,000 topographic maps or on soils maps. The imagery was acquired in late afternoon and this provided a low sun angle (in November) from the southwest, which enhanced the northwesterly lineation.

During this same time, the author, in conjunction with Dr. Gerald A. Miller, of Iowa State University, and Mr. John Wooster and Mr. Max Sherwood, of the U.S.D.A., Soil Conservation Service, was conducting investigations into the relationships of soils, Pleistocene materials, and landscapes in this same area. Figure 2 shows a landscape transect from Carroll County in this area of aligned drainage. It is a rather extreme case which shows high local relief along a rather short interfluve. Field observations and drilling transects throughout the area reveal the typical sequence of stepped (loess-mantled) erosion surfaces: Yarmouth-Sangamon divides; Late-Sangamon erosion surface; lower-Wisconsinan age Iowan erosion surfaces; and loess-mantled Wisconsinan terraces above major alluvial valleys. This sequence of stepped surfaces is typical for this entire area of south-central and south-western Iowa (see also Ruhe, 1967, Ruhe and Cady, 1967, and Daniels and Jordan, 1966). These field observations revealed that there was nothing unusual about the landscape development in this area of aligned drainage. Field observations also pointed out that the first-order drainage has developed almost entirely in the thicker loess itself, with little regard to the underlying till and paleosol topography. The area of strongest lineation on the photography is mantled with 20-32 feet of loess on stable divides.

PROCEDURE

To analyze the nature of the drainage alignment, stream *valley* orientations were measured from modern county soil survey (U.S.D.A., Soil Conservation Service) maps. The soil maps were used, instead of 1:24,000 scale topographic maps because: 1. they are at a larger scale (1:15,840) and on an air photo base, and consequently provide more detail in the lower order drainage net; 2. the alluvial and colluvial soils are mapped which also provide better defination of the lower order valleys; and 3. the soils maps provide complete coverage over the area of interest — which the topographic maps do not. Again, the northwesterly lineation was not apparent on these maps.

The valleys were ordered, using the Strahler method (Strahler, 1952), and a line was drawn down the "mean linear axis" of the valley. In higher order streams the valleys must be subdivided into their linear segments. The orientations of the valleys were measured using a transparent overlay "rose diagram," subdivided into 10-degree intervals. The data was compiled by valley order and summarized into percentage of observation by these 10 degree increments (see fig. 4).

For each area studied, a soils field sheet was selected in an area of interest, and the entire sheet was coded in the described manner. This generally comprised an area of 10 to 16 square km (4 to 6 square miles). This included the measurement of from 260 to 380 first-order valleys per study area. In most cases (except C3 and W, fig. 3) the sites were chosen to avoid proximity to major streams. Sites were also chosen in areas where bedrock was deeply buried so that bedrock structures could not *directly* influence drainage patterns. Drainage density was also measured (Table 1) using the line-intersect method (described by McCoy, 1971).

RESULTS

Nine areas were analyzed in the loess-covered portion of Iowa (fig. 3). Three areas in Crawford County (C1, 2, and 3) were first studied and are covered by the CIR photography (fig. 1). C1 and C2 are in the area of prominent NW lineation in fig. 1. C3 is near the Boyer River (fig. 1) where the lineation is not apparent. Figure 4 summarizes the valley-orientation measurements for these sites on standard half-hemisphere rose diagrams. Drainage densities (Dd) are shown below the rose diagrams.

It is apparent from the diagrams that in the first-order drainage sites C1 and C2 show a strong preferred orientation of N 40-50°W in an otherwise rather "random" distribution. Conversely, site C3 shows weak tendencies for both NW and NE orientations. The strong NW lineation is apparently obscured by the local increase in drainage density and dissection of the landscape.

The first-order drainage is formed entirely in the loess without regard to the configuration of the underlying till-paleosol landscape which the loess mantles. The second-order drainage is partly developed in the loess, but is largely controlled (as are the third and higher order valleys) by the sub-loess topography developed in the till. The second-order valleys for C1 and C2 still show a very prominent N 40-50°W orientation, but other modes also become apparent. In the third and higher order drainage the NW orientation is not as strong and these other orientations become more distinct. They may be summarized as approximating two conjugate sets of orientations: 1. with orientations

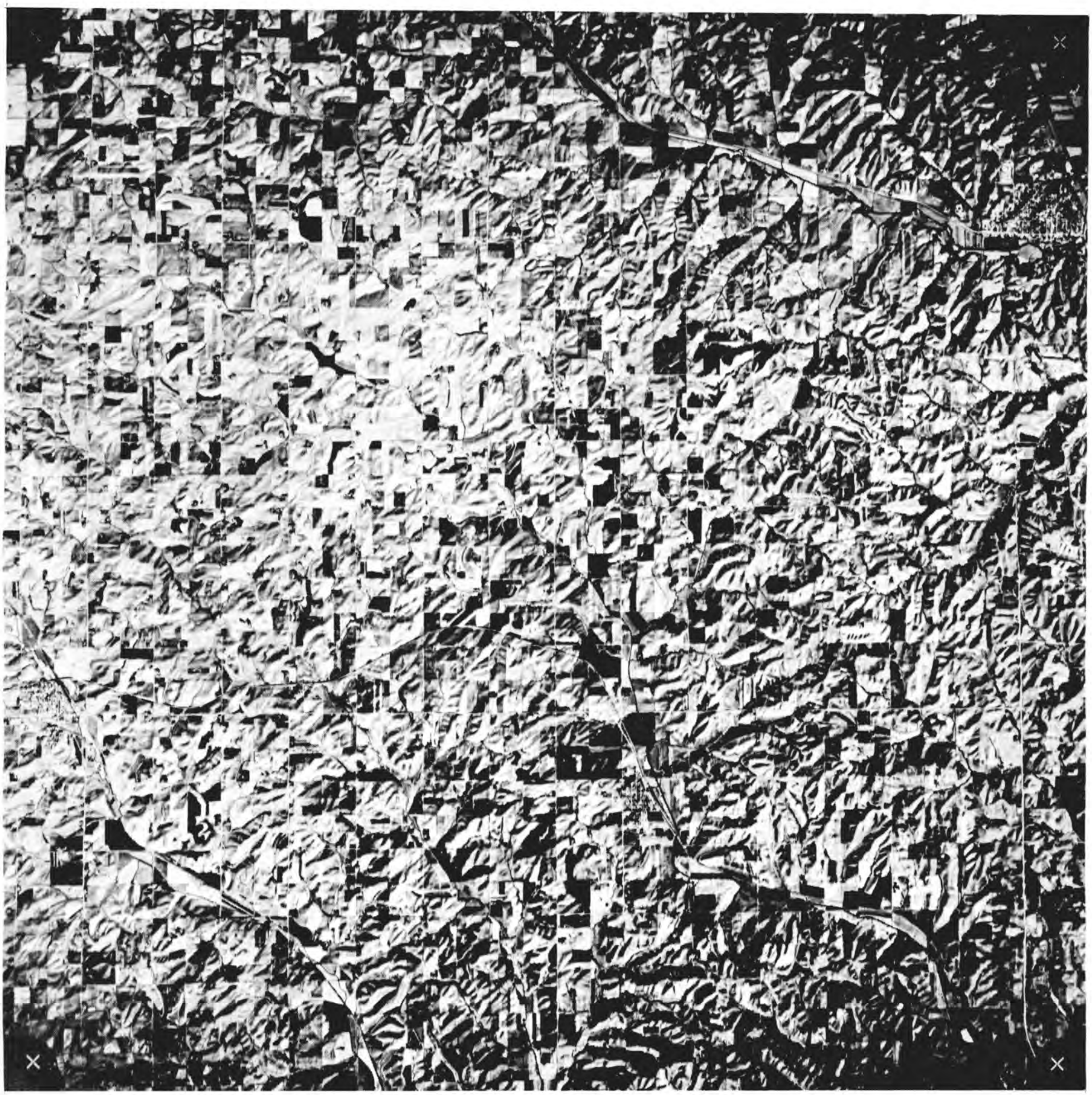

Figure 1. *Black-and-white copy of NASA hi-altitude (60,000 ft; 18,300 m) CIR aerial-photograph, showing NW-SE aligned drainage. Boyer River appears on the northwest side of the image; the town of Manning in Carroll County appears in the southeast portion. Image taken 28 November 1973; in mid-afternoon.*

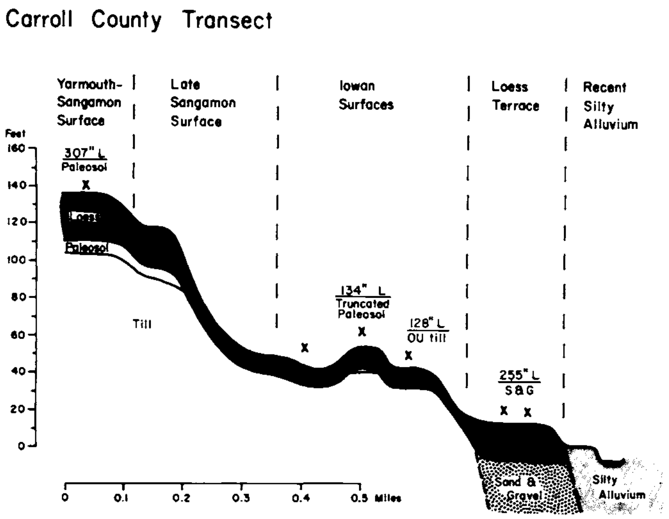

Figure 2. *Diagram of drilling transect in southwestern Carroll County, showing stepped erosion surface relationships (L – loess thickness).*

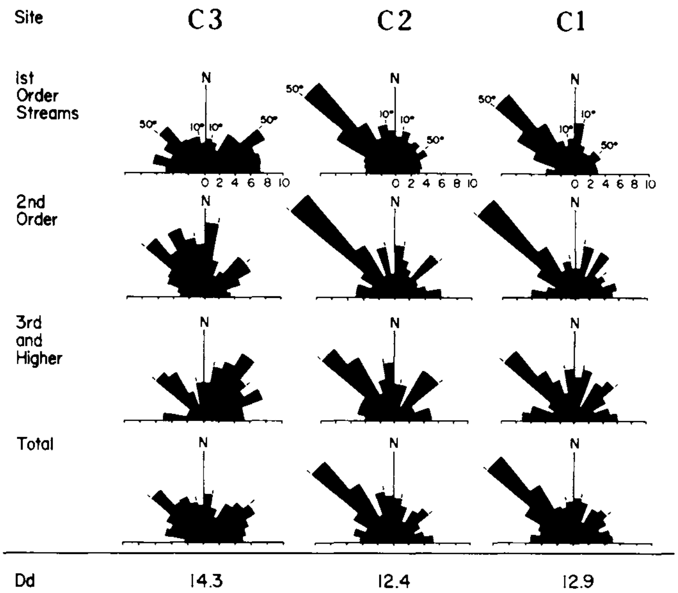

Figure 4. *Stream valley orientation and drainage density (Dd) for sites C1, C2, and C3.*

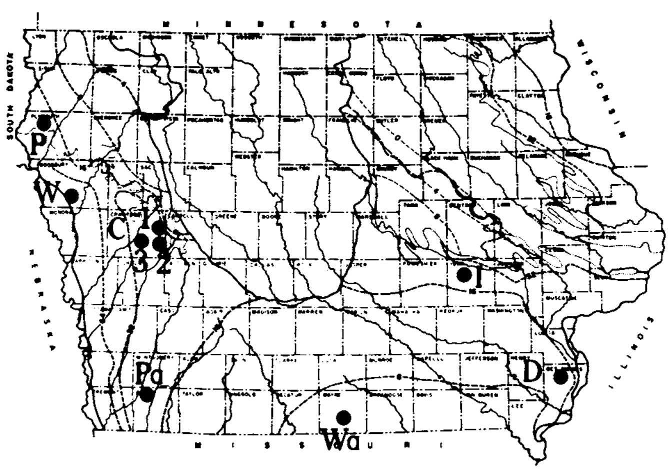

Figure 3. *Locations of study sites shown in text. Map shows loess thickess contours (after Ruhe, 1969) and Des Moines lobe (zero loess) – see fig. 5 for details.*

roughly N 40-50°W, and N 40-50°E; 2. with orientations rougly N-S and E-W. Although these orientations can be seen in the C3 data, again they are generally more obscure, because of the greater local dissection.

Several other sites around Iowa were also chosen for analysis, to see how widespread this phenomenon is. Locations are shown on fig. 3, and the first-order valley orientations are summarized on fig. 5.

For site W both the first- and second-order drainage (lower diagram) is shown. Site W is in the loess bluff area in the zone of extraordinarily thick loess (Handy, 1976), and even the second-order drainage is controlled entirely by the loess. (see fig. 5 for loess thickness). The northwesterly trend is most prominent in the northern sites. The 3 sites in southern Iowa, sites D, Wa, and Pa essentially show uniform distributions.

A simple chi-square test, comparing these multinomial distributions to a theoretical uniform distribution of 5.56% of observations per 10 degree increment, was performed to supplement the observations. The probabilities that these distributions are uniform are: P-82%; W-1 (1st order) 75%; W-2 (2nd-order) 1%; C1-10%; C2-5%; C3-97%; I-88%; Pa, Wa, and D all >99.5%. Again, the southern Iowa sites are statistically uniform, but the northern sites show greater probabilities toward non-uniform distributions. This, obviously, does not test the significance of the NW alignment. The geomorphic significance is shown by this same trend being repeated in each site.

The three Crawford County sites (C1, C2, and C3) indicate that the intensity of the NW alignment may be inversely related to drainage density. This may be, for the local increase in drainage density near a major stream (C3 near the Boyer River) but it does not hold true for the state as a whole. Comparison of fig. 5 with the drainage density data in Table 1 shows little relation.

Further, the intensity of the NW alignment does not appear to vary totally as a function of loess thickness. Where the loess is quite thick the NW alignment may appear strongly in both the first and second order valleys. Site Pa has thicker loess than either I or P, yet I and P show stronger NW alignments than does Pa.

The only consistent trend in variation of the NW alignment appears to be associated with latitude. The northerly sites show stronger orientations than do the southern sites. Unfortunately, it is impossible to test this hypothesis with further sites in northeastern Iowa because, either 1. the loess gets too thin, and the drainage is controlled by the underlying material, or 2. along the Mississippi River the topography is controlled by the deep dissection and local bedrock topography.

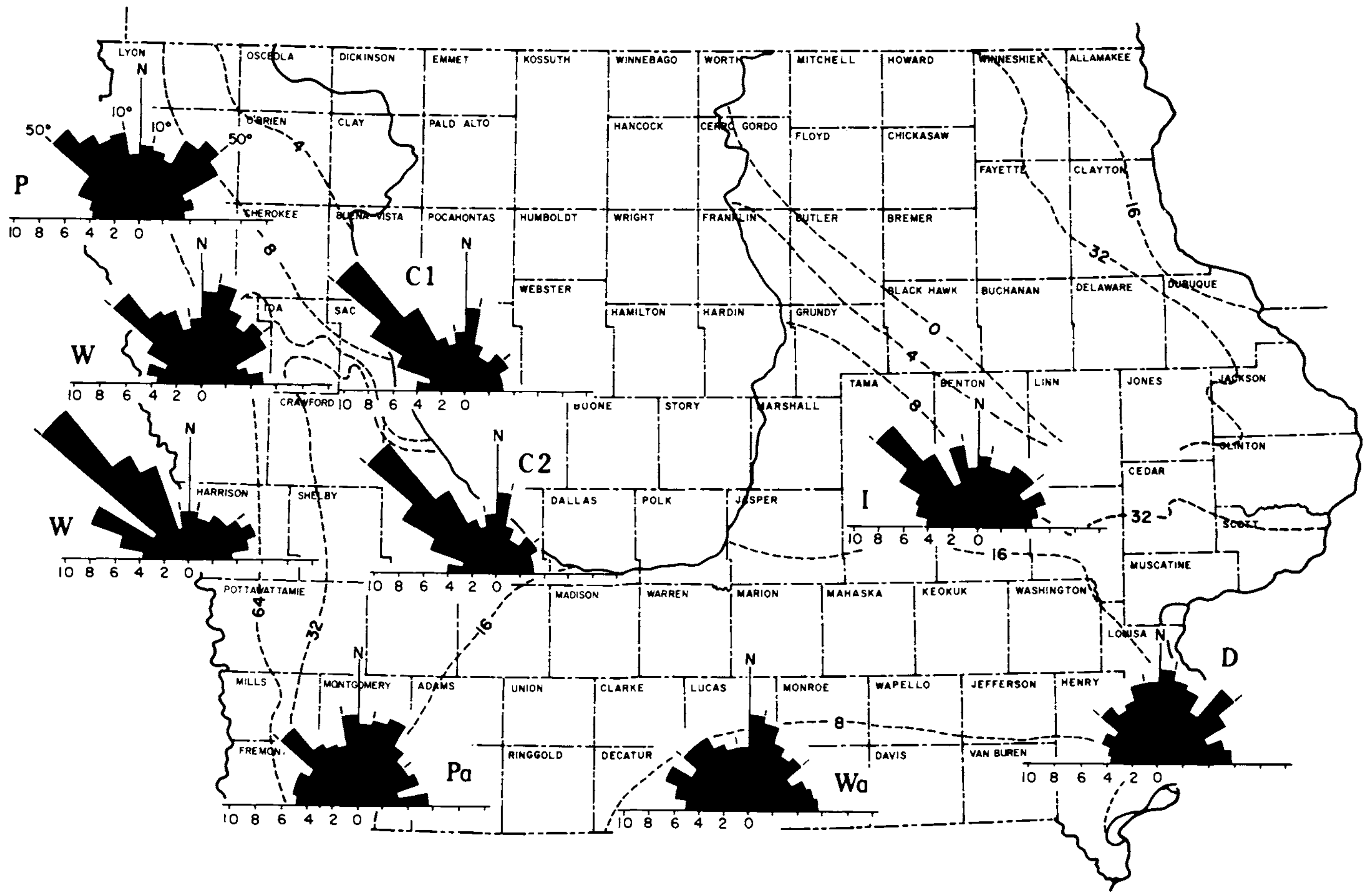

Figure 5. *First order valley alignment at study sites in Iowa; except lower W which is the second order valleys. Loess thickness contours as in fig. 3; locations shown on figure 3.*

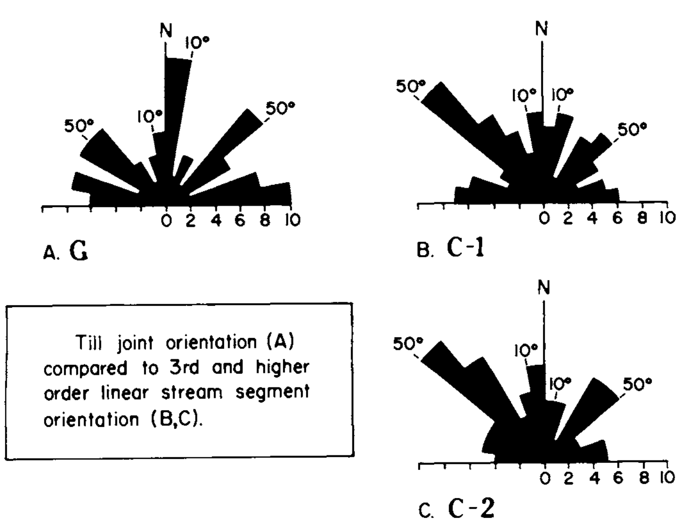

Figure. 6. *Till joint orientation compared to 3rd and higher order valley alignment.*

Table 1. *Drainage densities for study sites, calculated using line intercept method of McCoy, 1971.*

Site	Dd (mi/mi^2)
W	18.3
Wa	16.0 (13.8)*
I	15.5
D	14.6
C3	14.3
C1	12.9
C2	12.4
Pa	13.1
P	10.8

*Wa — Dd without (including) tabular divide area.

DISCUSSION

Northwesterly or westerly prevailing winds during loess deposition have been presumed by many researchers (see Kay and Graham, 1943; Kay and Apfel, 1928; Hutton, 1947; Simonson and Hutton, 1954) based on the thickness distribution of loess and eolian sands in relation to the Missouri Valley, the changes in loess properties over distance, the asymmetry of loess landforms and the orientations of divides in the loess bluffs, the pinnate drainage pattern in the bluffs, and other less important factors. The same N40-50°W alignment is indicated by eolian sands associated with the loess in NW Iowa.

Eolian sands in eastern Iowa, which are temporally or stratigraphically related to the loess also indicate a northwesterly wind direction. Wind-aligned features north and east of site I generally indicate a wind direction of N60-70°W instead of the N40-50°W orientation (for example Flemal, et al., 1972).

The strong, preferred, northwesterly orientation, shown in the first-order valleys within the loess, is interpreted as wind-alignment, created by strong northwesterly winds.

Previous discussions of the origin of wind-aligned drainage (White, 1961; Beaty, 1975) suggests that the alignment is caused by: 1. more rapid elongation of incipient drainageways aligned with the prevailing winds; 2. eolian deposition within, and even closure of unaligned drains; 3. initiation of surface furrows, by the wind, which are enlarged by fluvial action. Once developed, vortices in windflow may also aid erosion and elongation (Whitney, 1978).

Most studies of Wisconsinan wind alignment have shown that the glacial age prevailing winds were essentially the same as at the present time (see Moran, 1972; Beatty, 1975; Donahue, 1977). This is also true for the present study. It seems most likely, however, that the wind alignment of the drainage must have taken place during loess deposition to affect the incipient or evolving drainage. This timing also seems likely because the wind-action would be most effective in relatively fresh loess deposits, before vegetation could stabilize the new deposits. A Wisconsinan age is also suggested by the same N40-50°W orientation of eolian sand deposited concurrently with the loess. From a reconstruction of atmospheric circulation during this time period, Lamb and Woodroffe (1970) predict prevailing NW winds in the Midwest. Radiocarbon dates of 6,800 radiocarbon years-before-present have been reported from the base of gully-fill deposits in these low-order valleys (Ruhe and Cady, 1967). This date coincides with the period of maximum-dryness during the postglacial in Iowa (Hallberg, et al., 1974; Van Zant, 1976; Van Zant and Hallberg, 1976). These low-order valleys could have been actively eroding until that time.

The observed decrease in wind-aligned drainage from north to south may lead to the conclusion that the prevailing winds decreased in intensity from north to south. During at least part of the period of loess deposition, continental-ice sheets (Tazewell) occupied north-central Iowa, Minnesota and South Dakota (Ruhe, 1969). The massive continental glaciers likely had a dramatic local meteorological impact (see Moran, 1972; Lamb and Woodroffe, 1970). It is possible in the proximity of these ice sheets, with increased temperature and pressure gradients, that the strength of the prevailing winds may have increased. As the strength of the prevailing winds decreased to the south of the ice sheets, so also would the intensity of wind-aligned drainage. Alternatively, the north-south difference in wind alignment could also represent a less-effective vegetation cover to the north in closer proximity to the glacier front.

A mathmatical model for loess deposition was only recently developed by Handy (1976). This model indicates that the pattern of the loess distribution from the Missouri Valley must be explained by variable winds. There need be no disagreement between these findings and the interpretation of strong prevailing winds creating wind-aligned drainage during the Wisconsinan. Although a prevailing wind may have molded the landscape producing the aligned drainage, this same wind may not have prevailed during the seasons when loess was being deposited. Although, Handy's model does allow for the input of a prevailing wind, the loess distribution pattern in western Iowa, in relation to the model, suggests the influence of a prevailing wind in the north, but not to as significant a degree in the southern part of the state.

As previously mentioned the second, and particularly the third and higher order drainage, show 4 directions of preferred orientations. Well developed joints in the glacial till were measured in this area, and they also show systematic patterns with these same four — E-W, N-S, NW, NE — preferred orientations. (see fig. 6) These same four orientations are present in till and bedrock joints, and in valley orientations across Iowa. This coincidence suggests that the higher order drainage may be ''structurally'' controlled by this systematic jointing in the till. This will be a topic for a future discussion.

SUMMARY

Analysis of stream *valley* alignment reveals that first-order valleys, which are formed entirely within Wisconsinan loess, show a strong, preferred orientation of N40-50°W, within an otherwise uniform distribution. The intensity of this NW alignment varies somewhat with loess thickness, and especially with local differences in drainage density. The most significant variation is with latitude; the NW alignment is well developed in NW, W central and E central Iowa, but is essentially absent in S Iowa. In NE and E Iowa the orientation of wind-aligned features changes to about N60-70°W.

The oriented drainage parallels eolian sand deposits, and pinnate drainage in the loess bluffs, and is interpreted as wind-alignment of the low-order valleys within the loess, created by prevailing northwesterly winds. The mode of formation of such features and their parallelism with Wisconsinan eolian sands suggests that the wind-alignment formed during or shortly after loess deposition, during the late Wisconsinan.

The decrease in intensity or disappearance of the alignment in southern Iowa suggests that these prevailing winds were stronger to the north, in proximity to the large continental glaciers which were present.

The higher order drainage shows four directions of preferred orientations, which are coincident with systematic till joints, suggesting possible structural control in the valley alignments.

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