First prize paper ($1,000 award) AAG Participation Fellowships, 19th International Geographical Congress, Stockholm

LINEAR TOPOGRAPHY IN THE SOUTHWESTERN PALOUSE, WASHINGTON-OREGON[1]

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THE Palouse region of the Columbia Basin is an area of rolling loessial hills which differs conspicuously from the mountains and basaltic scablands which surround it. Within the Palouse, however, there are major topographic differences. The northeastern part is an area of stream-dissected topography in a mature stage of erosional development, and the drainage pattern is characteristically dendritic. In the southwest, by contrast, topography is markedly aligned, with a system of linear hills and valleys trending approximately N. 30° E. with great regularity (Figs. 1 and 2). The purpose of this paper is to explain the origin of the linear topography, and to provide reasons for its geographic distribution.

The area of aligned topography totals about two thousand square miles and comprises almost half of the Palouse. Boundaries of the area are usually indistinct, especially to the northeast where the pattern of parallel ridges and valleys grades into the dendritic pattern which characterizes the remainder of the Palouse. The area is fragmented by large stream valleys and scabland channels, but lineation is a dominant feature of the landscape throughout large tracts, with the trend of alignment maintaining a constant and uniform direction. Taken as a whole, the linear area of the southwestern Palouse forms a discrete and unmistakable topographic entity, despite its discontinuity and vaguely defined boundaries.

The dimensions of individual hills vary considerably from one to another but rarely go beyond certain upper limits. Few of the ridges are more than three hundred feet from base to crest, and except where large streams are deeply entrenched, local relief seldom exceeds that figure. The length of a hill occasionally reaches three or four miles, but a mile or two is more common. Any estimate of "average" size, however, is likely to be unreliable, for many of the loessial ridges are much dissected.

Although the Palouse has been the subject of a voluminous literature,[2] I know of no discussion or even mention of the linear topography which is so characteristic of the southwestern sector. Geomorphic work in the Palouse has been based largely on observations in the northeastern part, and most investigators there, noting the dendritic drainage pattern and the intricate system of graded streams, have agreed with I. C. Russell's observation in 1897 that "the controlling features in the topography . . . are due to stream erosion."[3] Thus, while conceding the eolian origin of surface *material*,[4] most geomorphologists have

[1] This paper is an outcome of field work in the Palouse during 1957–58, made possible by a National Science Foundation Post-Doctoral Fellowship at the University of Washington. The Central Fund for Research, The Pennsylvania State University, provided aid for laboratory work. Special thanks go to J. Hoover Mackin for his invaluable suggestions and critical commentary. G. F. Deasy, L. H. Lattman, and E. W. Miller read the paper and provided helpful criticism.

[2] Extensive bibliographies are found in the following: Kirk Bryan, "The 'Palouse Soil' Problem," *U. S. Geological Survey Bulletin 790* (1927), pp. 21–45; Virgil R. D. Kirkham, "Bibliography of Chief Publications on the Geology and Geography of the Inland Empire," *Northwest Science*, Vol. 1, No. 2 (June, 1927), pp. 33–38; R. F. Flint, "Summary of Later-Cenozoic Geology of Southeastern Washington," *American Journal of Science*, 5th Series, Vol. 35, No. 207 (March, 1938), pp. 223–30; Samuel Rieger, "Development of the A_2 Horizon in Soils of the Palouse Area," unpublished Ph.D. dissertation, Dept. of Agronomy, State College of Washington, 1952; Virgil W. Carmichael, "The Relationship of the Soils of the Palouse to the Columbia River Basalt," *The Compass of Sigma Gamma Epsilon*, Vol. 34, No. 1 (Nov., 1956), pp. 6–28; and Carl R. Schroeder, "The Physical Geography of the Palouse Region, Washington and Idaho, and Its Relation to the Agricultural Economy," unpublished Ph.D. dissertation, Dept. of Geography, U. C. L. A., 1958, pp. 24 ff.

[3] Israel C. Russell, "A Reconnaissance in Southeastern Washington," *U. S. Geological Survey Water Supply Paper 4* (1897), p. 67. See also Schroeder, *op. cit.*, p. 86.

[4] E.g., Paul D. Krynine, "Age of Till on 'Palouse Soil,' from Washington," *American Journal of Science*, 5th Series, Vol. 33, No. 193 (Jan., 1937), pp. 205–16.

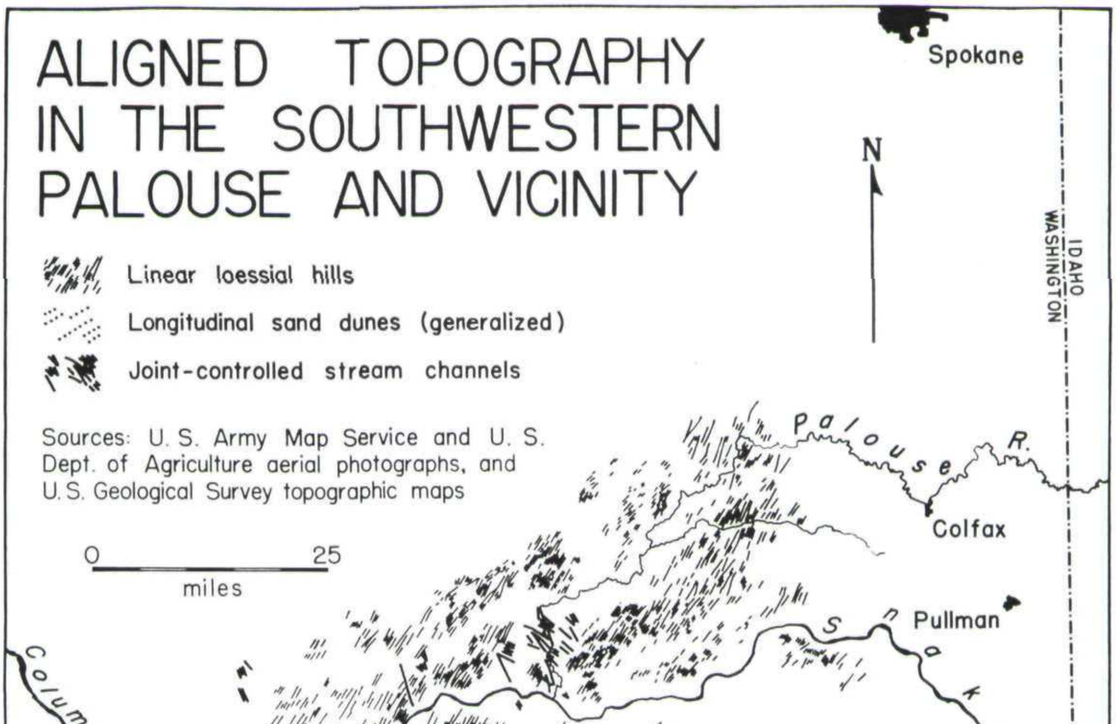

FIG. 1. Aligned topography in the southwestern Palouse and vicinity.

viewed wind action as having had, at most, only superficial effect on surface *forms*, with no influence at all on the main patterns of drainage and topography.

This paper agrees with these views, provided they are explicitly restricted to the northeastern Palouse. It will argue, however, that the classical explanations of topographic origin in the northeast cannot be applied to the southwest with its linear hills—that, in fact, the alignment and essential form of the linear topography has resulted from deposition of loessial material by the wind, more rapidly in some places than in others.

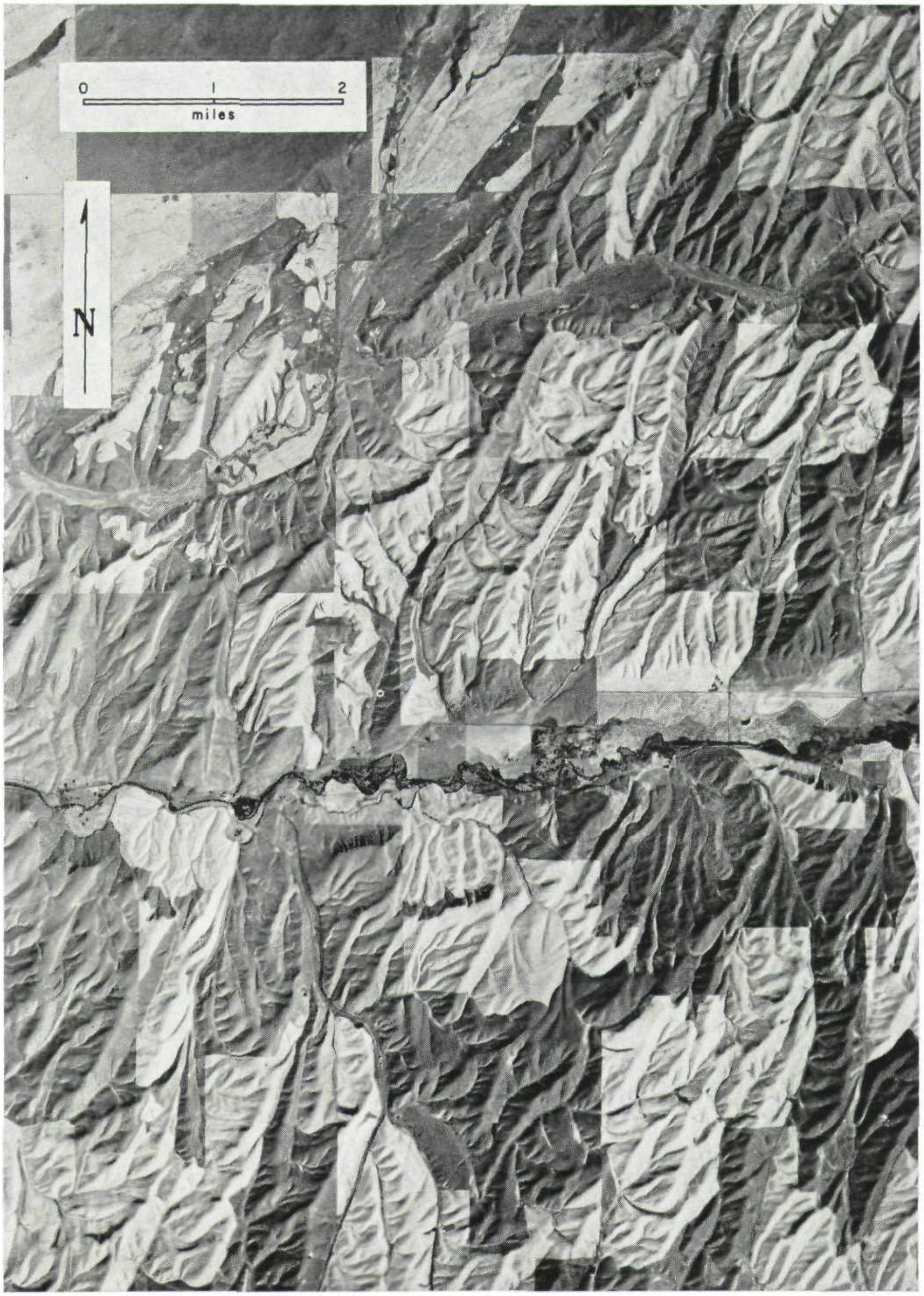

FIG. 2. Aerial photograph of typical linear topography in the southwestern Palouse, about twenty miles north and slightly west of Walla Walla, Washington. Note the consistency with which major ridges trend approximately N. 30° E. Note also that small streams commonly conform with the pattern of lineation, whereas large streams do not. The main stream, seen in the center of the photograph, is the Touchet, flowing east to west. The area of low relief to the northwest is Eureka Flat; alternate dark and light patterns are due to fallowing of wheat fields. (Source: Army Map Service, Western U. S. High Altitude Project 100-B, Roll 2, No. 64, 22 Aug. 1952).

FIG. 3. Composite photograph, showing road cut through the crest of a linear loessial ridge, Walla Walla County, about 2 mi. north of Shaw, Washington (T. 10 N., R. 35 E., Sec. 30). Caliche layers are visible here, mainly accordant with the present surface. The white streaks are surficial lime deposits, associated with two very dense caliche layers. Other layers beneath have been partly obliterated by slumping but can be traced in part by shadows cast on the side of the road cut. The cut is about forty feet deep where it transects the axis of the ridge. Note other linear ridges in the distance to the left.

THE PROBLEM OF LINEAR TOPOGRAPHY

This paper poses two basic questions. The first is genetic: what kind of mechanism will explain the formation of these linear loessial ridges, uniformly over a large area? The second is a question of geographic distribution: why, when the whole surface of the Palouse is underlain by loess, is linear topography found in the southwestern part and not in the northeast? Both questions have more than local implications, for if given conditions will produce linear hills in the southwestern Palouse, then similar hills should occur in loessial regions elsewhere if the same conditions are fulfilled.

ORIGIN OF THE LINEAR HILLS

Alternative Hypotheses

Alignment of topography can be produced by any of several agencies of erosion or deposition. Before stating the main argument, therefore, it is appropriate to consider certain alternative hypotheses and the reasons for rejecting them.

It is conceivable, first of all, that the loessial ridges were produced by erosion, but stratigraphic evidence proves that it cannot be so. Several deep road cuts through the crests of loessial ridges expose conspicuous layers of caliche, lying approximately parallel to one another and to the present surface of the ridge (Fig. 3). One such road cut about fifteen miles north of Walla Walla, Washington, displays at least six such layers, the deepest of which is over fifty feet below the surface. Because caliche is a surficial phenomenon, associated with soil-forming processes in the "B" horizon, it is necessary to conclude that these deep-lying layers mark the approximate surfaces of earlier ridges, which were stable long enough to permit caliche to develop. The parallelism of the caliche with the present surface makes it evident that the hills had essentially their present form throughout the time of loessial accumulation—in short, that the linear ridges were formed by accretion.

It is possible to narrow the range of inquiry still more by considering two further alternatives. On the one hand, linear landforms may predate the deposition of loessial material, the loess being merely a superficial blanket. This alternative contends that the present topography is a slightly altered copy of something older—that the linear pattern is not genetically related to the existence of loess, because the lineation was already there.

The second and contradictory hypothesis would hold that the alignment of topography was produced because loess accumulated most rapidly in certain elongate areas, eventually producing linear hills. Although this hypothesis does not reject the possibility of some pre-loessial alignment, it denies that the present topography is a copy of earlier lineation. This hypothesis asserts that the presence of loess was essential to the formation of these linear hills, and that without the loess there would have been no such alignment as is found today.

If lineation of topography existed before the loess accumulated, it is reasonable that such lineation should be visible in nearby areas which are not covered by the loessial blanket. Neighboring nonloessial areas of the Columbia Basin were examined, therefore, in an attempt to discover other types of linear topography, which, had they been covered by loess, might have produced aligned hills like those of the southwestern Palouse. Three types of nonloessial lineation were found.

One kind of alignment occurs where consequent streams flow parallel to one another down a steep regional slope. Such streams have produced a conspicuous linear pattern where they flow down the south flanks of the Horse Heaven Hills, an anticlinal ridge just west of the Palouse. If such stream alignment is to explain the linear pattern of the southwestern Palouse, however, one should find a steep regional slope there, either toward the south-southwest or toward the north-northeast. Furthermore, this slope should become gradually more gentle toward the nonlinear northeastern Palouse. No such slope exists, and the idea is rejected.

A second kind of aligned drainage occurs where subsequent streams have eroded headward along parallel joints in the Columbia River basalts. Joint-controlled stream channels are prominent features of a scabland tract along the lower Palouse River (Fig. 4);[5] they present an almost identical pattern at Wallula Gap, fifty-five miles to the southwest; and they are visible at several intervening points (Fig. 1). They have no apparent relationship with the loessial hills, however, for they trend in quite a different direction. Aerial photographs, moreover, reveal many places where joint-controlled channels disappear beneath a loessial cover and immediately lose all topographic expression (Fig. 4).

Longitudinal sand dunes compose the third and last kind of linear landforms to be examined for possible relationships with the loessial ridges. Along the Columbia River, notably near Pasco, Washington, and Umatilla, Oregon, strong southwesterly winds have formed blowouts in shallow sand which overlies terrace and floodplain gravels. These blowouts advance downwind and leave behind them two straight ridges of sand, between which is a furrow which marks the blowout's earlier path. These dunes, similar to those which Hack has called "parabolic dunes,"[6] produce a strikingly linear pattern which, when seen from the air, looks as if a giant rake had been drawn across the surface (Fig. 5). It is conceivable that such longitudinal dunes might have formed before the loessial blanket was deposited, and that the linear hills of the southwestern Palouse are really sand ridges with a loessial veneer. Today's active dunes are aligned in a slightly different direction than the loessial ridges (Fig. 1), but a change in wind direction within the past few thousand years could easily explain the discrepancy. There are two reasons, however, for believing that such longitudinal dunes have nothing to do with aligned topography in the southwestern Palouse. In the first place, all linear ridges should have cores of dune sand, but there is no evidence that they do. Wherever the base of the loess is exposed, it almost invariably rests directly on basalt; in no place was dune sand found at the contact. In the second place, the longitudinal dunes are of a totally different order of magnitude than the loessial hills. Whereas the Palouse ridges commonly measure two or three hundred feet from base to crest, the dunes in question are seldom more than ten feet high, and are usually much less. These dunes do not rise to great heights chiefly because the veneer of sand is thin. About twenty miles northeast of Pasco, Washington, the sand gradually becomes thicker, and the dunes grow higher, but as they do so, they cease to be either longitudinal or linear. Instead, large "transverse dunes"[7] have developed, crudely scalloped in groundplan and aligned northwest-southeast. In sum, even though they have been blanketed by loess, neither longitudinal nor transverse dunes

[5] Donald E. Trimble, "Joint Controlled Channeling in the Columbia River Basalt," *Northwest Science*, Vol. 24 (May, 1950), pp. 84–88. See also Trimble's *Geology of the Haas Quadrangle, Washington*, U. S. Geological Survey Geological Quadrangle Map GQ 43, with text (1954).

[6] John T. Hack, "Dunes of the Western Navajo Country," *Geographical Review*, XXXI (1941), p. 242.

[7] *Ibid.*, p. 241.

FIG. 4. Aerial photograph of the lower Palouse River scabland tract and adjacent loessial areas. The Palouse River can be seen in the center of the photo, flowing southward to join the west-flowing Snake River. The conspicuous angulate pattern was caused by differential fluvial erosion, controlled by two sets of joints in the basaltic floor of the scabland channel. Linear loessial ridges can be seen in the eastern part of the photo, and also in the southwest on an "island" in the scablands. Note the contrast between the orientation of loessial ridges and joint-controlled channels, and the apparent absence of joint control of loessial topography. Note also the truncation of loessial ridges, evidently caused by the same fluvial erosion which produced the scablands. (Source: Army Map Service, Western U. S. High Altitude Project 100-B, Roll 3, No. 311, 28 Aug. 1952).

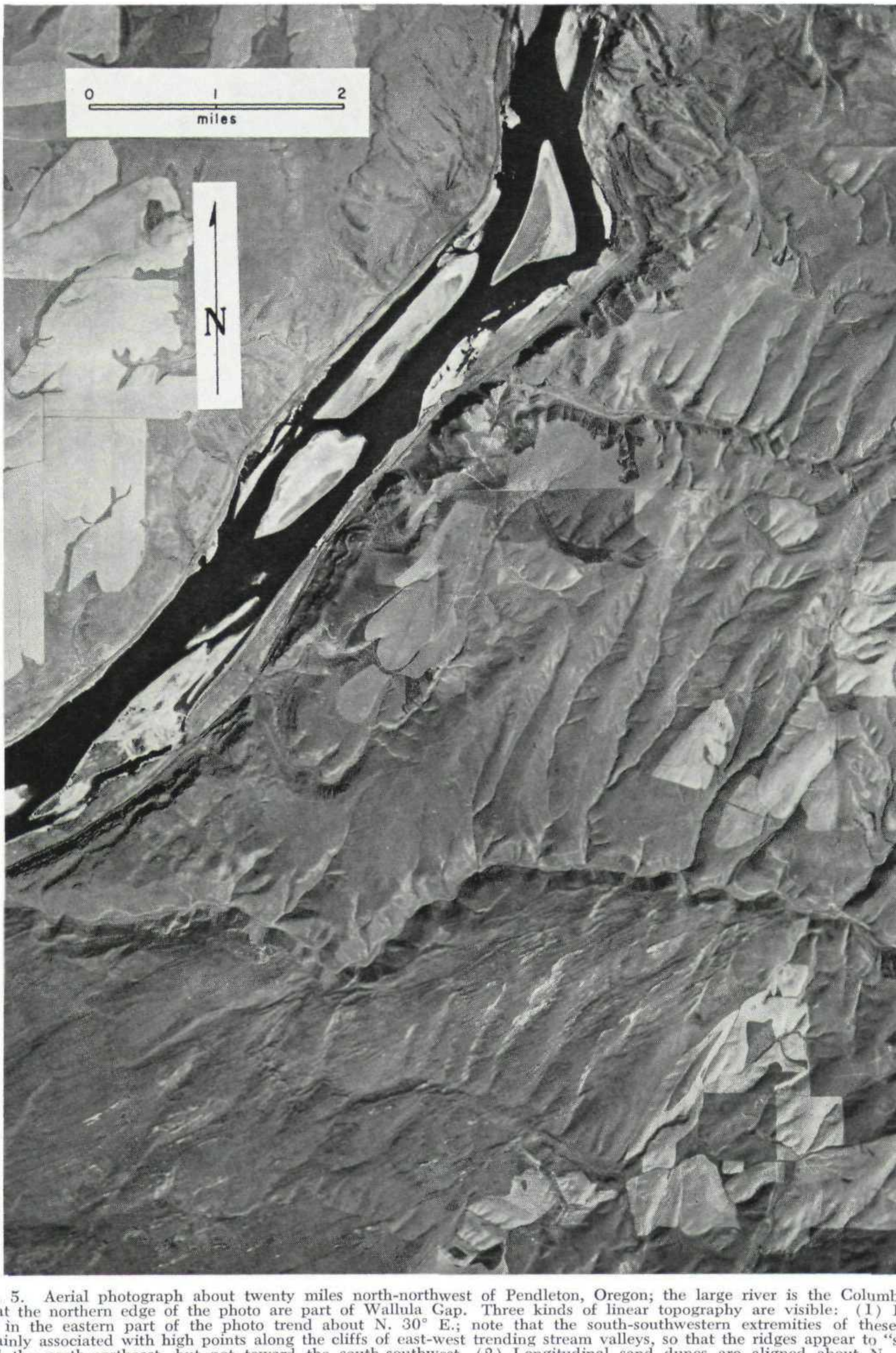

FIG. 5. Aerial photograph about twenty miles north-northwest of Pendleton, Oregon; the large river is the Columbia; the cliffs at the northern edge of the photo are part of Wallula Gap. Three kinds of linear topography are visible: (1) Loessial ridges in the eastern part of the photo trend about N. 30° E.; note that the south-southwestern extremities of these ridges are mainly associated with high points along the cliffs of east-west trending stream valleys, so that the ridges appear to "stream" toward the north-northeast, but not toward the south-southwest. (2) Longitudinal sand dunes are aligned about N. 55° E. in the southwestern quarter of the photo; where the dunes have advanced farthest eastward, they have crossed loessial ridges, causing superposition of one kind of lineation on another. (3) Traces of joint-controlled lineation are visible in the dissected basalt just to the east of Wallula Gap; cf. Figure 4, showing similar joint-control on a larger scale. (Source: Army Map Service, Western U.S. High Altitude Project 100-B, Roll 5, No. 570, 1 Sept. 1952).

are likely to have formed ridges such as those in the southwestern Palouse.

The "Wind-Shadow" Hypothesis

Of the three kinds of linear topography to be seen in the Columbia Basin outside the loess-covered areas, all appear unrelated to linear ridges in the loess itself. It is reasonable, therefore, to set aside the notion that lineation in the Palouse is a contemporary copy of a pre-loessial alignment, and to consider the alternative hypothesis—that the linear ridges were formed because the loess accumulated more rapidly in some places than in others.

If the wind is carrying loessial material in suspension, deposition will occur wherever wind velocity is sufficiently reduced. The eroded basaltic surface which predates the loess must certainly have presented many obstacles to the wind, and in the lee of such obstacles there would have been zones of reduced wind velocity wherein loess would accumulate more rapidly than elsewhere. Such zones—or *"wind-shadows"*—would be of elongate shape, tapering downwind from the obstacle. Hence, if silt-bearing winds blew again and again from approximately the same direction, an elongate ridge would develop in the wind-shadow of each obstacle, each ridge lying parallel to wind-direction and aligned with other ridges developing at the same time.

Evidence in Support of the Wind-Shadow Hypothesis

Three lines of evidence lend support to the wind-shadow hypothesis. The first is based on analysis of the drainage pattern, the second on examination of individual ridge forms, and the third on a reconstruction of past wind behavior.

1. Throughout much of the southwestern Palouse there is a marked tendency for small streams to be aligned in conformity with the topographic pattern. More sizeable streams, by contrast, show no apparent relationship to the trend of lineation (Figs. 1 and 2).

The wind-shadow hypothesis provides a reasonable explanation for this peculiarity of drainage. During the time when loess was accumulating, there must have existed a contest between eolian and fluvial processes for control of topographic form, eolian processes tending to produce a linear pattern, fluvial processes tending to keep the main pre-loessial pattern intact. In order for a stream to maintain its course against the encroachment of a growing linear ridge, a stream had to be large enough to erode the loess more rapidly than it accumulated. Even at times of greatest deposition the wind could make no progress in extending a fragile loessial ridge across a major stream channel. Upvalley, however, there must have come a place where streams, carrying water only at rare intervals, were so small that they could remove no appreciable amount of loess. If such a stream lay transverse to wind direction, its valley would act as a trap for wind-borne silt; eventually, the valley would be buried and drainage rerouted into parallel channels between the newly-formed linear hills. Stream valleys which chanced to lie parallel to wind-direction, however, would serve as funnels for the wind, and relatively little deposition would occur. In time, a characteristic drainage pattern would develop, where streams in their lower courses followed irregular paths, but in their headwaters followed the alignment of the linear hills. In short, the pattern would be much like that which is seen today in the southwestern Palouse, and which contrasts so sharply with the dendritic drainage of the northeastern part (Figs. 6 and 7).

2. The loessial ridges, when considered individually, likewise exhibit peculiarities of shape. Viewed in long profile, many of the ridges are consistently asymmetrical, terminating abruptly at their south-southwestern extremities, but sloping off more gently toward the north-northeast. Such asymmetrical ridges are especially conspicuous where relatively large streams cross transversely the trend of loessial alignment and have cut into the underlying basalt. In such places, the clearly marked south-southwestern ends of the hills abut directly on the edges of the transverse valley, but as the ridges extend to the north-northeast, they lose identity very gradually. Where several such hills occur side by side, a distinctive topographic pattern results, the parallel ridges resembling a row of banners with narrowed ends, streaming out from a flagpole in a strong south-southwesterly wind (Fig. 5).

This peculiar pattern is clearly consistent with the wind-shadow hypothesis. The dissected basaltic walls of the transverse valley would confront the wind with a whole series

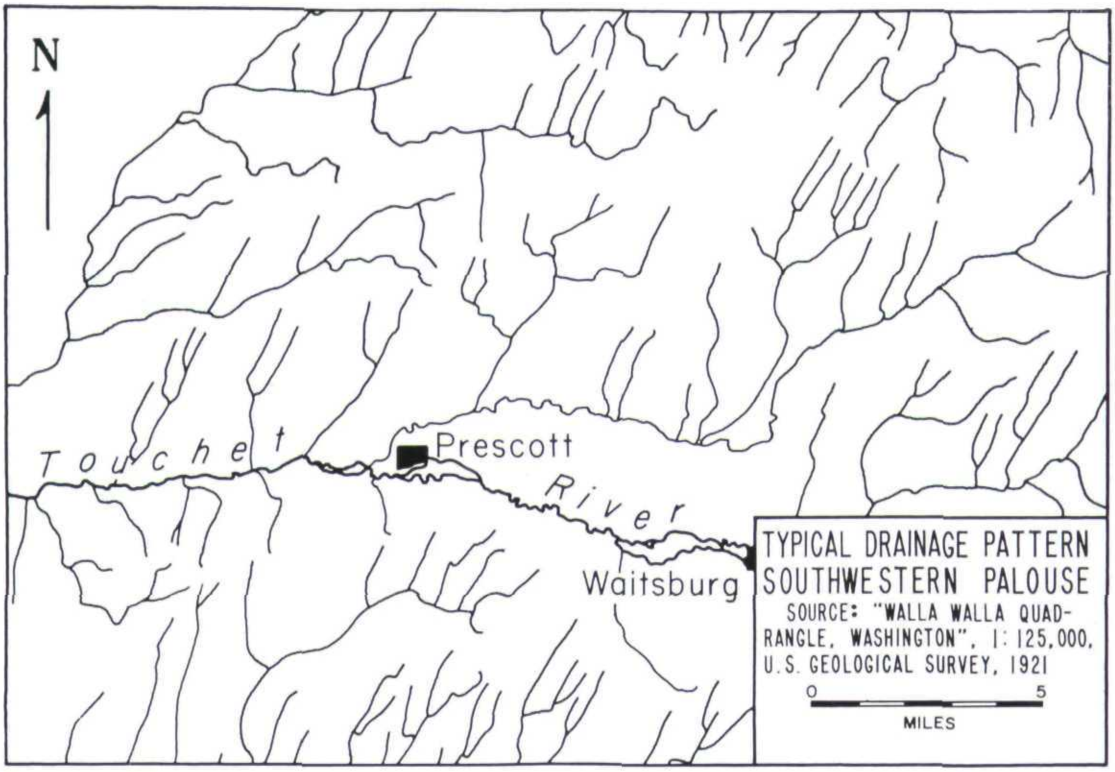

FIG. 6. Characteristic drainage pattern in lineated portions of the southwestern Palouse. Note that the alignment of drainage is best developed where streams are smallest.

of high obstacles, each with its wind-shadow, and each serving as a fixed point from which a loessial ridge might extend downwind. The shape of the ridge would conform to the characteristic shape of the wind-shadow, sharply outlined in the immediate lee of the obstacle, but increasingly diffuse with greater distance from it.

3. If the wind-shadow hypothesis is valid, the orientation of asymmetrical ridges clearly demands acceptance of a corollary proposition, namely, that silt-bearing winds must have blown from the south-southwest with great consistency. Absolute proof of such a proposition is obviously impossible, but field evidence suggests that it is not unlikely.

Although most investigators apparently believe that the loessial material originated from water-laid sediments to the south and west of the Palouse, opinion is by no means unanimous. Campbell, for example, has expressed the belief that the bulk of loess could not have come from the southwest, and suggests that northerly winds, possibly associated with a glacially-induced anticyclonic system, might well account for the deposition of silt.[8] If Campbell's view is correct, the wind-shadow hypothesis is obviously untenable. In an attempt to determine the direction of silt-bearing winds, therefore, the loess itself was examined.

Determination of wind-direction was based on the premise that median grain-size of loessial material must decrease with increasing distance from the source area. Samples of loess were collected for grain-size analysis[9] from

[8] Charles D. Campbell, "Introduction to Washington Geology and Resources," *Information Circular 22*, Div. of Mines and Geology, Dept. of Conservation and Development, State of Washington, Pullman (1953), pp. 146–47.

[9] Samples were analyzed for grain-size by use of a Bouyocos hydrometer, after a technique modified from that recommended by the American Society for Testing Materials in *Procedures for Testing Soils*, A. S. T. M. (April, 1958), pp. 67–68, 83–93. Because standard A. S. T. M. techniques did not produce complete disaggregation of loessial samples, the following adaptations were introduced: (1) solution of $CaCO^3$ aggregates in a dilute (1:10) solution of hydrochloric acid at 100°F. (acid was added until no further reaction occurred, and was then removed by filtration

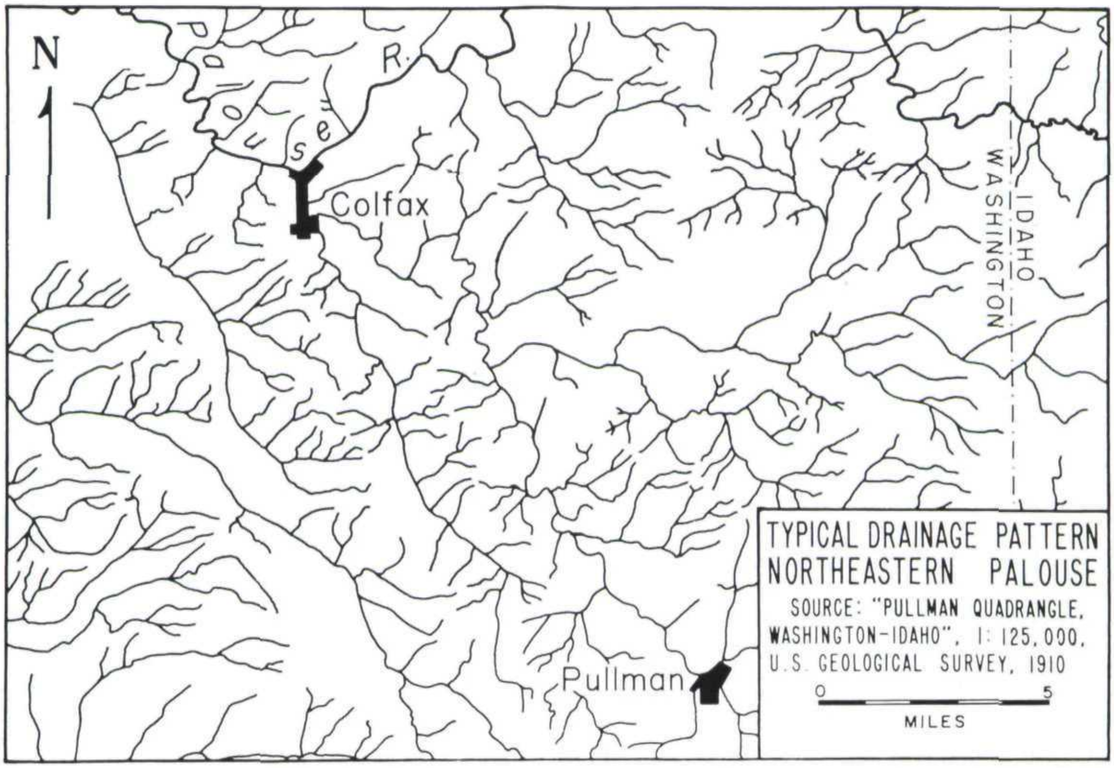

FIG. 7. Dendritic drainage pattern of the northeastern Palouse. Note the difference, compared with Figure 6, which shows the linear pattern of the southwest. Note also that the drainage texture is finer here than in the southwestern Palouse, mainly attributable to greater rainfall in the northeast. In addition, average grain-size of loess is larger in the southwest, which may increase permeability and reduce potential runoff.

twenty-three sites, composing a traverse across the Palouse from southwest to northeast. Wherever possible, at least two samples were taken from each site, one at about six feet below the present surface to reflect the most recent episodes of deposition, and a second at depths ranging from fifteen to thirty feet, representing earlier episodes. A base-line was then drawn at the southwestern margin of the Palouse, perpendicular to the trend of lineation, and the median grain-size of each sample was plotted as a function of distance from the base-line. The resulting graph (Fig. 8) shows the change in grain-size from southwest to northeast, both in surficial materials and in materials at depth. Also included in the graph were data collected by P. D. Krynine from two sites near Spokane, Washington, on the extreme northeastern margin of the Palouse.[10]

The general decrease in grain-size from the southwestern to the northeastern Palouse shown by the graph is confirmed by statistical analysis.[11] Data from other sources support the same conclusion. Rieger has collected samples along two east-west traverses from the Columbia River to the foot of the Idaho Rockies,[12] and Kraszewski made a shorter east-west traverse in the region between the

and rinsing); (2) mechanical disaggregation of clay by placing each sample in a high-speed kitchen blender for five minutes, in combination with 125 ml. of standard concentration wetting-agent (40 g. of sodium-hexametaphosphate to 1000 ml. of water). L. H. Lattman and the College of Mineral Industries, The Pennsylvania State University, graciously made available the facilities of the Soils Geology Laboratory, and Mr. Gerald J. Karaska assisted in the laboratory work.

[10] Krynine, *op. cit.*, p. 208.

[11] For data from surficial samples, $n = 18$ and $r^2 = 0.6471$, where n is number of samples, and r^2 is coefficient of determination; for data from samples at depth, $n = 16$ and $r^2 = 0.4592$; r is significant beyond the 1% probability level in both cases. Prof. John C. Griffiths, Dept of Mineralogy, The Pennsylvania State University, aided in manipulation of these data.

[12] Rieger, *op. cit.*

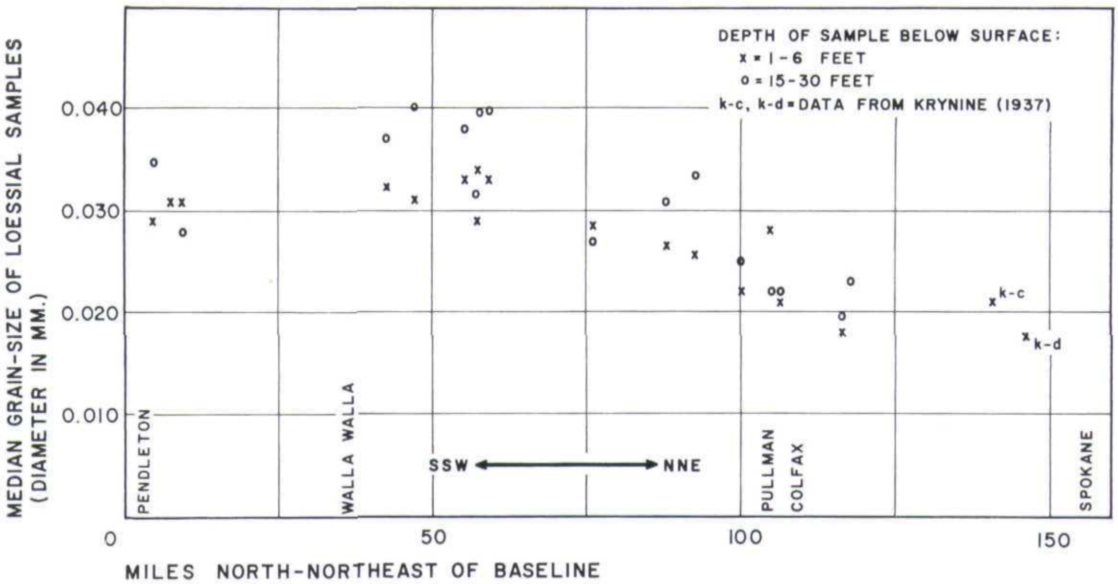

FIG. 8. Variation in median grain-size of Palouse loess from south-southwest to north-northeast.

Touchet and Snake rivers.[13] The results of both investigations support the thesis that loess from the southwestern Palouse is coarser than that in the northeast. Flint, likewise, has concluded "that the average grain-size (of the 'Palouse soil') decreases conspicuously from the Pasco Basin northeastward toward Spokane . . . , Pullman, and Colfax."[14] In short, silt-bearing winds did not blow from the north or east for any appreciable span of time; almost certainly their main direction was southwesterly, or nearly so, as the wind-shadow hypothesis demands.

The hypothesis also requires that silt-bearing winds were highly consistent in direction, for if they had varied substantially, the location of wind-shadows also would have varied, and loessial ridges would never have formed. Direct proof of such consistency is obviously impossible without access to Pleistocene weather records, but data from three weather stations near the Palouse show that winds which carry dust today almost invariably blow from the same quarter. Records of dust storms for the period from January, 1949, to June, 1957, were obtained from the U. S. Weather Bureau Stations at Walla Walla, Washington, and Pendleton, Oregon.[15] The direction and velocity of winds were tabulated for each storm, and the data recorded in graphic form (Fig. 9). Similar data, collected at Spokane by Bryan for the period 1905–1925, were also plotted on the same basis.[16] The consistency of wind direction during dust storms is obvious from an examination of all three graphs: at Walla Walla, 84 percent of all dust storms originate from one quarter of the compass; at Pendleton the figure is 88 percent, and at Spokane it is 95 percent. It cannot be maintained that contemporary wind behavior duplicates that of the past, and especially that wind direction was the same then as now. Present-day data, however, do show that silt-bearing winds of highly persistent direction cannot be regarded as unlikely in the past.

LINEAR TOPOGRAPHY IN OTHER LOESSIAL AREAS

Linear topography, evidently similar to that of the southwestern Palouse, has been noted by investigators in loessial regions elsewhere. W. L. Russell has described an area in the western Great Plains where at least 125,000 square miles exhibit a marked alignment of

[13] Stefan Kraszewski, "Morphology and Development of Palouse and Related Series," unpublished Ph.D. dissertation, Dept. of Agronomy, State College of Washington, 1952, pp. 17–56.

[14] Flint, *op. cit.*, p. 227.

[15] Thanks is expressed to Mr. Lester B. Larson, Meteorologist-in-charge, U. S. Weather Bureau, Walla Walla, and to Messrs. Rex J. Hess and Louis M. Jones of the Weather Bureau at Pendleton for their cooperation in making these data available.

[16] Bryan, *op. cit.*, p. 39.

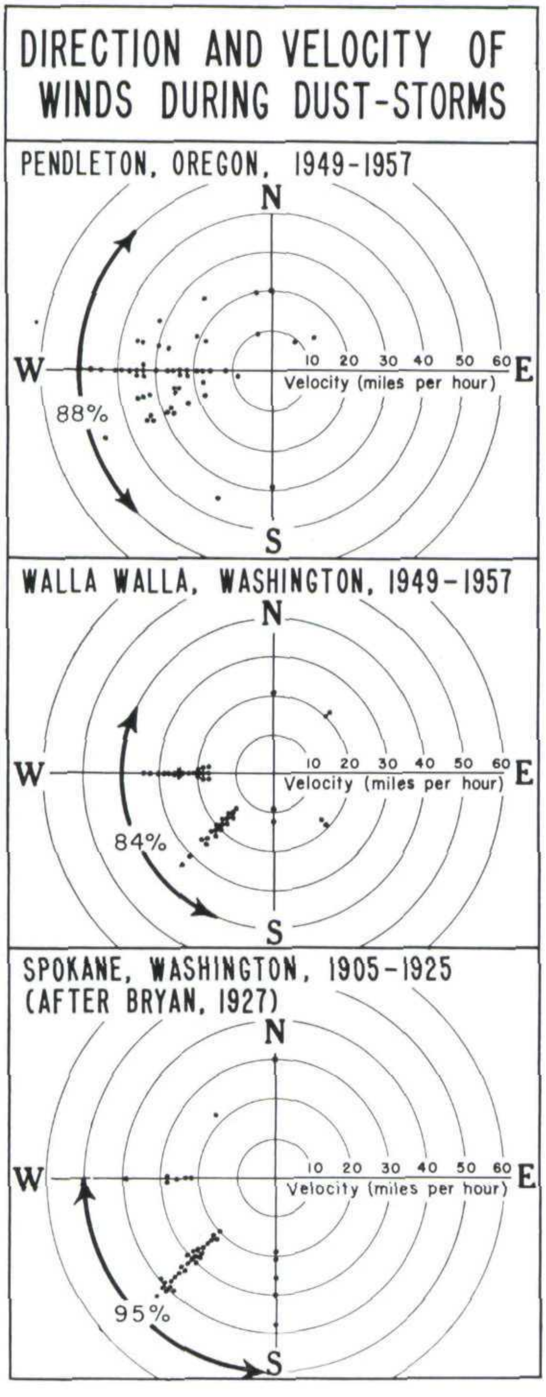

FIG. 9. Each dot represents direction of winds at peak velocity during one recorded dust storm. Data from the three stations are not strictly comparable. Winds at Spokane and Walla Walla are recorded on an eight-point compass, whereas Pendleton's are on a sixteen-point compass. Also, weather instruments at Walla Walla are located downtown and are partly sheltered by large buildings; recorded velocities are higher at Pendleton, where instruments are located at an exposed position at the airport. The source of Spokane data is Kirk Bryan's "The 'Palouse Soil' Problem," *U. S. Geological Survey Bulletin 790* (1927), p. 39.

valleys and ridges in a northwest-southeast direction. Russell attributed the linear pattern to the concentration of wind-borne material downwind from surface irregularities.[17] Although the brevity of Russell's analysis permits no detailed comparisons, his views concerning the origin of alignment in the Great Plains seem essentially to correspond with my findings in the southwestern Palouse.

Apparently similar lineation has also been recognized in the loessial areas of central Europe. Alfred Jahn has described "longitudinal streaks of loess" and "loess bridges" which extend across river valleys on the Lublin Plateau of Poland. Jahn refers to these linear features as "primary phenomena" which owe their origin to deposition of silt by easterly winds.[18] Linear hills, called *zavieja,* also occur in the loess of Czechoslovakia. Their origin has been ascribed to deposition of wind-borne silt in the lee of pre-existing hills by winds which blew primarily from the southwest.[19]

RECENT CHANGES IN LINEAR TOPOGRAPHY

Most linear ridges in the southwestern Palouse are extensively dissected by small streams, and some have been altered almost beyond recognition. There is no doubt that at least some of these ridges were once continuous, for road cuts through ridge crests exhibit caliche layers, mainly accordant with the present surface, but abruptly truncated where tiny streams have eroded headward into the flanks of the ridges. The extent of dissection by very small intermittent streams indicates the possibility that the eolian processes which built the linear hills are no longer acting to perpetuate them. This possibility is supported by the certain knowledge that the loess

[17] "Drainage Alignment in the Western Great Plains," *Journal of Geology,* Vol. 37, No. 3 (1929), pp. 249–55.

[18] Alfred Jahn, *Wyżyna Lubelska* (Warszawa, 1956), pp. 447–48.

[19] Alfred Jahn, personal communication, Sept. 12, 1959. See also V. Ambrož, "Sprase Pahorkatin," *Sbornik Státního Geologického Ústavu Československé Republiky,* XIV (Praha, 1947).

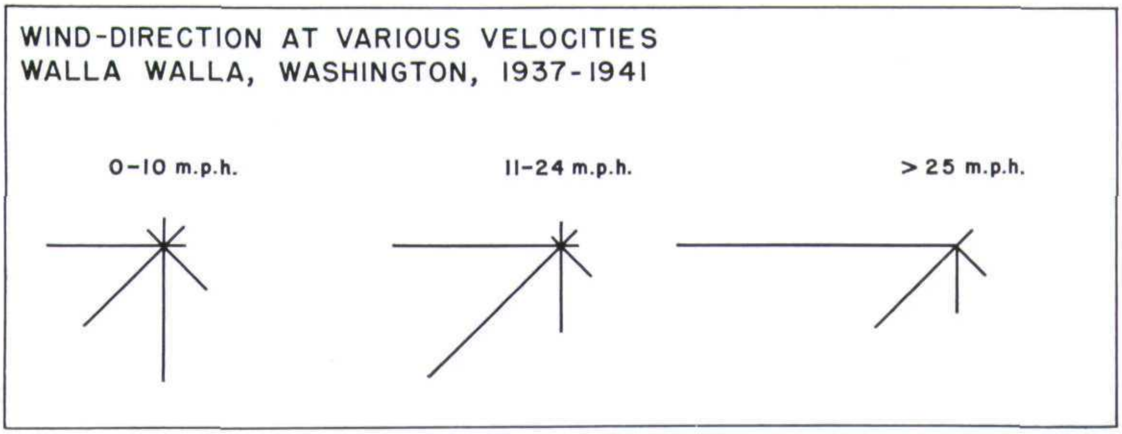

FIG. 10. Wind direction at various velocities, Walla Walla, Washington, 1937–41.

has long since ceased to accumulate in the southwestern Palouse. It follows, if the wind-shadow hypothesis is valid, that linear topography has likewise ceased to form.

It might be difficult to convince a person who has experienced a blinding Palouse dust storm that silt is no longer being deposited. The testimony of persons familiar with the region, however, indicates that dust storms of present-day intensity were unknown before the 1890's, when farmers first settled in the Palouse, broke the sod, and exposed the friable loess to the full blast of the wind.[20] Intense as they are, the recent dust storms have produced only a negligible accumulation of loess by contrast with earlier episodes of deposition. Indeed, glacial drift and scabland channels are very nearly free of wind-borne silt, and Bryan has concluded that "the present dust storms probably deposit dust at a greater rate than at any time since the Wisconsin glaciation."[21] With no renewal of the loessial blanket, fluvial processes would have gained the ascendancy everywhere, dissecting the linear hills at a rate far in excess of that previously, and in a manner which apparently continues at the present time.

DISTRIBUTION OF LINEAR TOPOGRAPHY

This paper has raised two major questions, the first concerned with origin of linear hills as such, for which the wind-shadow hypothesis has been offered as an answer. The second question, now to be considered, asks why linear topography is distributed the way it is—widespread throughout the southwestern Palouse, but practically nonexistent in the northeast.

Either of two possibilities might explain the difference in distribution. The presence of linear hills presumably required (a) a certain kind of wind behavior, and (b) a certain kind of material. While it is practically impossible to reconstruct past wind behavior with any certainty, the velocity and direction of winds during present-day dust storms appear to be much the same in the northeast as in the southwest, and it may well have been so in the past. Loessial material, however, is not the same.

Forty-four samples of loess taken from linear areas show a range in median grain-size between 0.0270 mm. and 0.0405 mm., with an average of 0.0329 mm. The median sizes of twenty samples from nonlinear areas range between 0.0175 mm. and 0.0280 mm., with an average of 0.0232 mm. It would appear that lineation in the Palouse is associated with loess whose median grain-size exceeds 0.0270–0.0280 mm. Conversely, if median grain-size is less than that figure, linear topography does not develop. Russell suggests a similar situation in the linear ridges of the Great Plains, describing the material which composes the ridges as loess-like in appearance, but "slightly coarser" than ordinary loess.[22]

It becomes possible, therefore, to rephrase the main question as follows: why is linear topography in the Palouse found only in as-

[20] Bryan, *op cit.*, p. 41.
[21] *Ibid.*, pp. 44–45.
[22] W. L. Russell, *op. cit.*, p. 255.

sociation with coarse-grained loess? If winds of the past were similar to those which blow today (a supposition which is likely but not provable), the wind-shadow hypothesis provides a framework for a possible answer.

Since the linear hills are composed of relatively coarse material, wind velocity must have been relatively great in order to have carried it. Data from the Walla Walla Weather Bureau show that high-velocity winds today are extremely preferential in direction, whereas low-velocity winds are considerably more variable (Fig. 10). If the same tendency existed in the past, wind-shadows would have been oriented consistently in the same direction when strong winds were blowing. Although silt would be dropped wherever wind velocity decreased below a certain point, the coarse fractions would be the first to be deposited. The presence of consistently aligned wind-shadows would cause just such reductions in velocity, thus resulting in the selective deposition of coarser fractions in the form of linear hills. These hills would necessarily be located closest to the loessial source area—in the Palouse, toward the southwest. Finer fractions, however, carried farther to the northeast, would be deposited only when winds reached a lower velocity, and such winds today are relatively variable in direction. With shifts in wind direction, the location of wind-shadows would also have shifted, and linear hills would never have formed.