Eolian Deposits of the Matanuska Valley Agricultural Area Alaska

By FRANK W. TRAINER

CONTRIBUTIONS TO GENERAL GEOLOGY

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By Frank W. Trainer

ABSTRACT

Wind-blown silt and sand in the Matanuska Valley agricultural area of south-central Alaska constitute widespread deposits that are still being formed. The modern eolian sediment is blown chiefly from bare glacial-outwash flood plains, and locally from exposures of older eolian deposits and sandy glacial drift; it is deposited in nearby vegetation, which is largely forest. The formation of crusts of sediment in bark and on fallen leaves helps hold the fresh dust in place until it becomes incorporated in the soil; these crusts are formed by alternate wetting and drying in summer and autumn and by the melting of dust-laden snow in winter and spring. Once covered by vegetation, the material is stable except in roads, excavations, and cultivated fields, where it is eroded by wind. Erosion by water is unimportant even in fields, probably because the silt and sand are porous and permeable and because rainfall intensity is low. In general the sandy eolian deposits occur beside modern or late-glacial flood plains; the silt is widely distributed over the more distant terrain. In one part of the area sand in dunes and horizontal beds beside a bare flood plain and silt farther from the plain are facies of a single sedimentary unit. Deposition of the eolian sediment began during or after recession of the last glacial ice (probably of late Wisconsin age) that covered this area. The character of the deposits shows that the direction and intensity of winds, the source areas, and the environment of deposition have been similar to those of the present throughout the period of deposition, and strongly suggests that there has been no major interruption of deposition since it began. Thin buried humus bands and other stratigraphic features in the deposits may indicate repeated brief episodes of flood-plain stability, however. These inferred periods of stability are thought to have followed changes in outwash-stream regimen, which in turn were related to growth and shrinkage of the glaciers or to eustatic changes in sea level. The essentially continuous nature of the eolian deposition is believed to show that the principal streams have been glacial-outwash streams continuously since the last glaciation and, hence, that the major source glaciers did not melt completely after that glaciation.

INTRODUCTION

Eolian silt and sand are widely distributed in the Matanuska Valley agricultural area of south-central Alaska, and deposition of the windblown sediment continues at present. The deposition and stabilization of the modern sediment, sedimentary facies in some of the deposits, and the inferred history of the deposits and their significance in the interpretation of the late Quaternary history of the surrounding region are the subject of this paper.

The term "Matanuska Valley agricultural area" is used for the lowland north and east of Knik Arm, an estuary at the head of Cook Inlet (fig. 1). It is one of several lowland areas of agricultural development in Alaska and is the site of the Matanuska Valley colony, established in 1935. The principal communities are Palmer and Wasilla. Rugged mountains flank the lowland on the north and south. Two wide mountain valleys join at its eastern end; the Matanuska and Knik Rivers, modern glacial-outwash streams in these valleys, flow into the head of Knik Arm. To the west this lowland merges with the main part of the Cook Inlet—Susitna lowland of Capps (1940, p. 26).

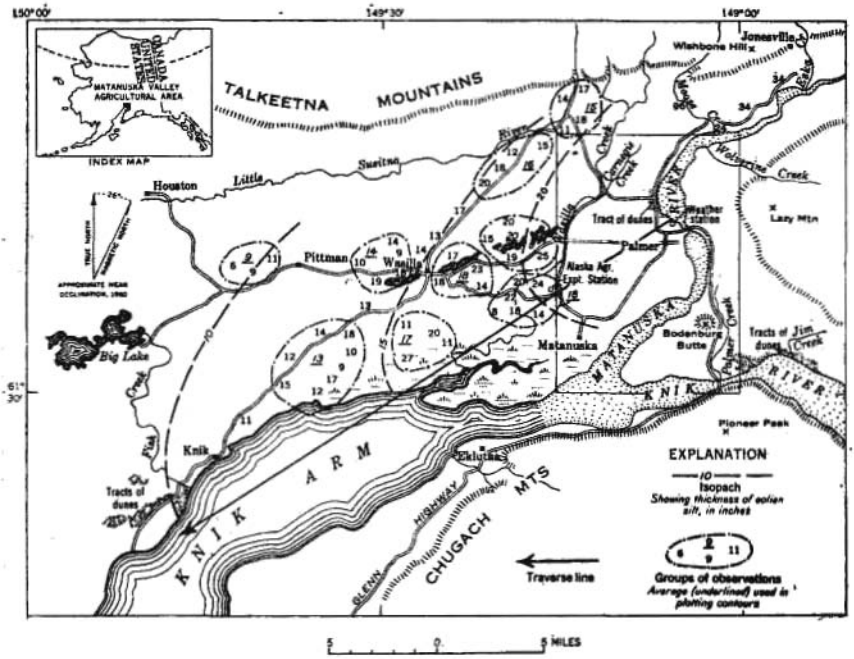

FIGURE 1.—Map of the Matanuska Valley agricultural area. Index map in upper left corner. Boxed area shown in detail in figure 4.

The entire Cook Inlet-Susitna province has been glaciated, and drift underlies most of the land surface. Although bedrock is exposed at only a few places in the lowland, available data suggest that in the agricultural area it is largely Cretaceous and Tertiary sandstone and shale. The rocks in the nearby mountains are of igneous and sedimentary origin, largely metamorphosed, and are chiefly of Mesozoic age.

During the last major glaciation ice covered the entire Matanuska Valley agricultural area, extending westward past Big Lake (fig. 1) in a broad tongue formed by the coalescence of the Matanuska and Knik Glaciers. During the deglaciation, melt-water streams greatly modified the ground moraine on the valley floor. Numerous drainage courses were formed and then abandoned. These changes are most evident in the central and southern parts of the area, where broad terraces are preserved along former courses of the Matanuska River, but changes are also shown elsewhere by smaller terraces and abandoned drainage courses. Knik Arm occupies part of the lowest Matanuska-Knik drainage course. For the purpose of this paper the landscape of the valley floor may be considered to consist of three elements: (1) gently rolling to flat terrain—ground moraine, terraces, and abandoned channels—mostly forested, which is an area of eolian deposition; (2) flat terrain—flood plains of the Matanuska and Knik Rivers—that is bare and provides most of the modern eolian sediment; and (3) flat terrain—surfaces of estuarine deposition bordering Knik Arm—where eolian sediment is deposited but either is eroded or is masked by other deposits. Windborne silt generally covers the terrain of element 1 and extends to altitudes of 2,000 feet and higher on some of the adjacent mountain slopes. The sand occurs locally in dunes and in horizontal beds.

These deposits of silt and sand have been discussed by Tuck (1938), Rockie (1946), Black (1951), Trainer (1953), Stump, Handy, Davidson, and Roy (1956), Stump, Handy, Davidson, Roy, and Thomas (1956), and Stump and Roy (1956). Tuck gives a concise statement of their eolian origin. He describes the parallelism of the surface of the eolian mantle and the surface on which the mantle rests, the greater thickness and coarser texture of the sediment near the bare flood plains from which dust is now blown, and the presence in the sediment of buried woody material and old plant roots. He describes wind transport of dust and concludes that the older deposits accumulated under conditions similar to those of the present. Stump, Handy, Davidson, Roy, and Thomas (1956) doubt that the hypothesis of eolian origin adequately explains the deposits. The author follows Tuck in considering them to be of eolian origin.

ACKNOWLEDGMENTS

The observations on which this paper is based were made during the course of an investigation of the geology and ground-water resources of the Matanuska Valley agricultural area by the U.S. Geological Survey. D. J. Cederstrom, D. M. Hopkins, T. N. V. Karlstrom, Clyde Wahrhaftig, G. W. Whetstone, and J. R. Williams, all of the Geological Survey, discussed many problems with the author and made many helpful suggestions; R. E. Wilcox examined samples of volcanic ash from the Knik Arm region; and D. J. Casey drafted the illustrations. The author gratefully acknowledges the encouragement and criticism of the late Kirk Bryan and H. C. Stetson, and of M. P. Billings, K. F. Mather, and J. P. Miller of Harvard University, and of C. E. Stearns of Tufts University; the opportunity of discussing the Matanuska Valley silt deposits with C. J. Roy, R. W. Stump, and L. A. Thomas of Iowa State College during their investigation of these deposits; and discussion with and critical review by A. H. Mick, W. M. Laughlin, and N. E. Michaelson of the Alaska Agricultural Experiment Station and H. T. U. Smith of the University of Massachusetts.

MODERN EOLIAN SEDIMENTATION

DEPOSITION

On windy days dust is blown along the flood plains of the Matanuska and Knik Rivers and into the adjacent forests. Stronger winds and storms move the dust farther and form clouds that extend over much or all of the agricultural area. After some of these storms fresh sand and silt (fig. 2) may be found in the forest several hundred yards from the edges of the flood plains. Tuck (1938, p. 649) notes that certain survey markers were buried by several inches of windblown sediment between 1913 and 1935. These markers are near the Matanuska River (D. L. Irwin, Alaska Agr. Expt. Sta., oral communication, 1949). The author has found freshly deposited dust on trees and fallen leaves at distances of several miles from the nearest source.

Events that followed a fall of volcanic ash in July 1953 at Anchorage and in the Chugach Mountains, south of Knik Arm, are of interest for their bearing on the deposition of windblown dust. The ash settled from a cloud formed by the eruption of Mount Spurr, in the Alaska Range about 80 miles west of Anchorage, on July 9, 1953 (Juhle and Coulter, 1955). The resulting layer was an eighth to a quarter of an inch thick near Anchorage, and the quantity of ash was therefore sufficient to permit ready observation of the processes that followed deposition. The fresh, dry ash was reworked by wind after its initial deposition, but the first rain settled it and left it as a crust on the ground, on fallen leaves, and in the bark of trees. Little of

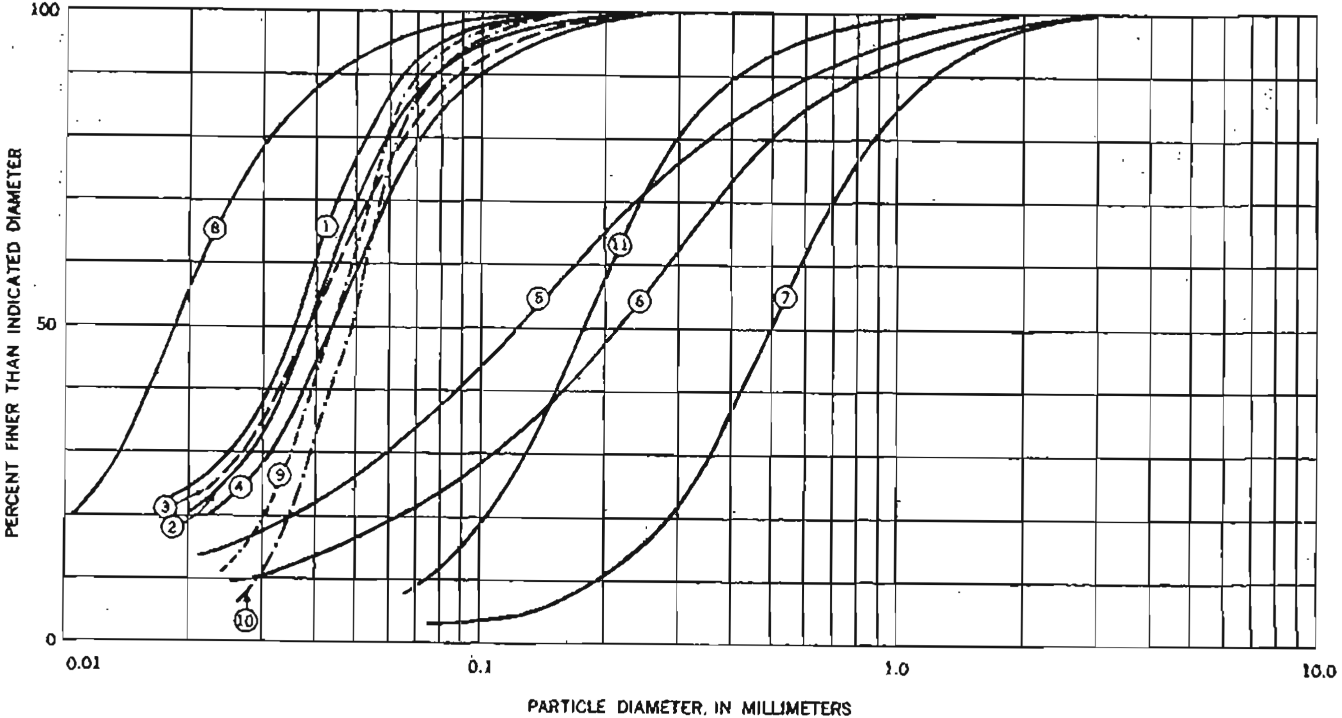

FIGURE 2.—Particle-size distribution in samples of eolian sediment from the Matanuska Valley agricultural area. Samples from within the eolian mantle (see fig. 6) are: 1, locality 15; 2, locality 10; 3, locality 8; 4, midway between localities 8 and 9; 5, locality 9; 6, locality 3; 7, locality 5. Samples of modern eolian sand and silt are: 8, dust in hollow tree 400 feet north of Knik River flood plain, half a mile east of the highway bridge; 9, dust from fallen leaves 600 feet from Matanuska River flood plain near the mouth of Wolverine Creek; 10, dust from fallen leaves 200 feet north-northeast of locality 4 (fig. 6); 11, sediment from snow dune on the right side of the Matanuska River flood plain, 3 miles north of Palmer, 1950.

the ash was disturbed in the forest thereafter until the following spring, when ash was seen for a few days in runoff from melting snow. During the summer of 1954 a thin crust of ash could still be found in crevices in the bark of dead trees and on old, partly covered, fallen leaves. Part of this ash is now being added to the soil; more will be added as the dead trees fall to the forest floor.

In the Matanuska Valley agricultural area the author has found similar crusts of silt on fallen leaves and in bark in the forests near the present flood plains. The formation of these crusts by alternate wetting and drying of the dust after its deposition appears to be a significant factor in the deposition of eolian dust in the agricultural area. (The accumulation of blown dust in the bark of trees has been noted in other areas. See, for example, Udden, 1898, p. 48, 50; and Lutz, 1941, p. 120.) The encrusted material remains in place except when thoroughly wetted by rain or snowmelt, or when the fallen leaves are blown. Deposition of dust in the forest is thus readily followed by its addition to the litter of rotting plant debris on the ground and its incorporation in the soil.

The winter snow cover is also significant in the deposition of eolian sediment, at least near the source of the material where enough is deposited to affect the manner in which the snow melts. The dust, warmed by the sun, melts its way into the snow and is thus protected from being reworked as long as the snow remains.

Locally, downwind from long reaches of bare flood plain, winds are strong just above ground level in the forest. The snow cover is sometimes removed by a combination of processes: blowing, if the snow is loose; erosion by blown sand and snow, if it is hard; and sublimation. The first two processes move the sand and silt with the snow. The blowing of sediment and snow together has been considered an important process in the interpretation of certain Pleistocene deposits in Europe.[1] It is generally not important in this area except locally near cultivated fields and beside bare flood plains. A dune built of mixed sand, silt, recrystallized snow, and plant debris and covered by a protective layer of sand, was found beside the Matanuska River 3 miles north of Palmer during the summer of 1950. Sample 11, figure 2, was recovered by melting "dirty snow" from this dune.

SOURCE AREAS

Observations made during windstorms indicate that the bare flood plains of the Matanuska and Knik Rivers are the chief sources of the

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[1] Vink, A. P. A., 1949, Bijdrage tot de kennis van loess en dekzanded in het bijzonder van de zuidcoostelijke Veluwe [Contributions to the knowledge of loess and surficial sand, with special reference to the southeastern Veluwe]: Thesis, Wageningen Agr. Univ., 147 p. (in Dutch, with English summary).

fresh dust blown over the agricultural area. (Weathered sand and silt are locally blown from roads, borrow pits, and cultivated fields.) Sand from eroded dunes is redeposited by wind, both near Jim Creek (fig. 1) and on the west bluff of the Matanuska River. About 1½ miles north of Palmer, where the dunes on the bluff are being removed most rapidly, erosion is conspicuous where road cuts and borrow pits have been opened; however, other dunes nearby are being eroded, seemingly as part of the natural retreat of the bluff. Sandy glacial drift exposed in the face of the bluff provided part of the sediment blown up over this part of the bluff and is probably the chief source of small pebbles found in the dune sand.

WINDS

Winds in the agricultural area have been described by Dale (1956), on whose discussion this paragraph is based. The dominant winds in this area are from the northeast, down the valley of the Matanuska River, and from the southeast down that of the Knik River. The "Matanuska wind," as it is known locally, is characteristically a winter wind. During occasional storms, it blows continuously for several days. The "Knik wind" blows most frequently during spring and summer. These strong winds are pressure-gradient winds, moving from a region of high pressure to one of low pressure. The wind stream in a typical northeast storm is deeper and more turbulent, and the wind stronger and more gusty, than in a southeast storm. The maximum wind velocity at Palmer has not been recorded instrumentally. On April 4, 1945 a totalizing anemometer in the Matanuska Valley recorded a total of 601 miles in 24 hours at a position about 2 feet above the ground. A peak gust of 100 miles per hour was observed near Anchorage during this storm. Similar velocities are undoubtedly attained or surpassed in the agricultural area during many northeast and a few southeast storms. Weaker winds that are common in late spring, summer, and early autumn, particularly from the southeast, may be "glacier winds" formed by the down-valley drainage of cool air from nearby glaciers (Geiger, 1950, p. 213).

All the storm winds blow dust, and the author has observed many dust clouds that extended over half to all of the agricultural area. The northeast (winter) winds appear to carry considerably more dust, in single storms and in total, than those from the southeast, despite the fact that source areas for dust are in large part flooded and frozen in winter. From interpretation of climatological data Dale (1956, fig. 18 and p. 20) concludes that the part of the lowland across which the northeast winds blow most frequently is fan-shaped, widening southwestward, with the greatest wind frequency along the chain of elongate lakes that extends through Wasilla (fig. 1). Dale also concludes (1956, fig. 23 and p. 24) that the southeast winds do not blow nearly so far out over the agricultural area as do those from the northeast. During southeast storms the author has observed dust clouds being blown over one segment or another of the entire 90° arc between the two mountain fronts south and east of the agricultural area. It is not uncommon to see fairly distinct dust clouds, one to several miles wide, shift to several different positions in this arc during a single day. The arc over which the northeast winds blow dust, on the other hand, is relatively narrow and the winds blow more consistently.

It is impossible to estimate with assurance the rate at which the dust is blown and deposited. The quantity of dust in the air during a given storm is probably much less than it appears upon casual observation. Deposition is most rapid near the bare flood plains, and at one place, as noted by Tuck (1938), amounted to several inches in 22 years. Perceptible deposition occurs as far as 2 miles from the Knik flood plain at the southeast corner of this area, and probably 5 or 6 miles from the Matanuska flood plain west of Palmer, although the significance of deposition there is difficult to judge because at least some of the newly-deposited dust was blown from nearby roads and fields. The nature of the soils in the eastern part of the agricultural area, within 8 to 10 miles of the flood plain near Palmer, suggests that the deposition of dust has kept pace with soil formation. Farther west deposition is undoubtedly very slow.

The environment in this area provides an example of the three conditions necessary for the formation of extensive eolian deposits (Bryan, 1945, p. 245; Hack, 1941, p. 243): a source of dust, wind to move it, and an area suitable for its deposition and preservation. These conditions, so well developed near some Pleistocene glacial outwash flood plains, led to the formation of many of the important loess deposits of the world.

THE EOLIAN MANTLE

GENERAL CHARACTER AND SURFACE FORM

The most striking characteristic of these eolian deposits is their occurrence as a continuous mantle that covers the older land surface and generally conforms to its topography. This mantle is present throughout the area except on recent flood plains and tidal flats, some young terraces, and steep slopes on a few bedrock hills. In most of the area the mantle consists of silt; near major flood-plain source areas it is made up of sand in the form of dunes and horizontal beds.

The thickness of the silt is relatively constant on level ground within local areas but appears generally to be greater in depressions than on adjacent slopes and hilltops. Its topographic effect is therefore to produce a more gently rounded land surface than that formed by the underlying glacial drift before the silt covered it.

Unlike the silt layer the dunes have conspicuous topographic form, rising above the surrounding terrain as low hills that bear no relation to the upper surface of the underlying drift. The horizontally bedded sand thickens toward the source of the sand and in some places has topographic expression. One to two miles north of Palmer it forms a low ridge along the upper edge of the river bluff; half a mile southeast of Palmer, however, similar bedded sand rests on a surface that slopes toward the river (Stump, Handy, Davidson, Roy, and Thomas, 1956, p. 84-85, fig. 20), and the present land surface is essentially flat.

The important dunes are in three places (fig. 1): between Fish Creek and Goose Bay; north of the Knik River, especially east of the highway bridge; and on the west bluff of the Matanuska River, 1 to 2 miles north of Palmer. Small dunes have also been found near Moose Creek and on abandoned flood plains in the western part of the agricultural area. All the dunes are downwind from long reaches of flood plain or of terraces or abandoned drainage courses which represent old flood plains.

The dunes between Fish Creek and Goose Bay are old; they are covered by weathered silt and have evidently been stabilized for a considerable time. The field of dunes extends west and southwest; this trend, with the presence of ground moraine to the north and west, shows that the sand was blown from the northeast and east. Flood plains that are now preserved as terraces near the community of Knik were probably the source of the sand.

Active and recently-stabilized dunes border part of the Knik River flood plain on the north, chiefly east of the highway bridge, and extend upstream beyond Jim Creek; west of the creek they also extend west-northwest, away from the river. The dunes occur singly and in clusters and their long axes trend west or northwest. The sand is not weathered beyond slight rusting at the surface. Except immediately along the river the dunes are covered by cottonwood and spruce. The dunes west of the creek are of particular interest because they seem to present an example of the way in which a dune field may be extended upwind until the space available to it is covered. A small tract of bare flood plain remains west of the mouth of Jim Creek, but the few small dunes built here are destroyed each season by the Knik River. As Stump, Handy, Davidson, and

Roy (1956, p. 481) note, the creek is a barrier to the transport of sand by saltation. Blown sand covers several square miles of the river flood plain east of (upwind from) Jim Creek, but of that brought to the creek only a small part appears to cross it, probably chiefly in winter and early spring before the ice goes out. The creek bed is quicksand that is being moved steadily downstream to the Knik River.

Cliff-head dunes as high as 30 feet fringe the top of the west bluff of the Matanuska River, 1 to 2 miles north of Palmer. During retreat of the bluff the dunes have moved inland, probably in part by migration and in part by destruction and rebuilding. Near the road junction 1½ miles north of Palmer the dunes lie on horizontally bedded blown sand that is 37 feet thick at the bluff. This sand, together with sandy glacial drift exposed beneath it in the bluff, has been an important source of sediment for the dunes.

Although there is a considerable range in the age of the eolian mantle as it is represented in several different places in the agricultural area (for example, the dunes near Fish Creek are older than the silt farther east or are contemporaneous with only the older part of it, but deposits in many places are being formed at present), the greater part of the mantle appears to be a single deposit that covers most of the valley floor from Lazy Mountain to Goose Bay and Houston (fig. 1). Bands of volcanic ash that are exposed throughout much of the eastern part of the area permit tentative correlation of sections about as far west as Wasilla. In the area shown in figure 6 this evidence is conclusive; two pairs of closely spaced ash bands and one or two single bands above them may be seen in more than 20 exposures. The presence of this distinctive succession of ash layers in the horizontal beds of sand, in the overlying cliff-head dunes, and in the silt shows that the sandy deposits are the near-source facies of the silt farther from the river. (Compare, for example, sections 4, 5, 12, and 14, fig. 6.) The relation between the near-source sand and the silt farther away is thought to be one of lateral gradation.

TEXTURE

As Tuck (1938) points out, the material is coarse near the modern flood plains and fine at greater distance. This change is conspicuous because of the presence of the beds of sand and dunes, but the silt itself becomes finer with increasing distance from the source. As part of a detailed study of the engineering properties of the eolian sediment of this area Stump, Handy, Davidson, and Roy (1956, fig. 15) show the areal change in grain size near Palmer by means of a sand-percentage contour map. Figure 3 shows a similar map con-

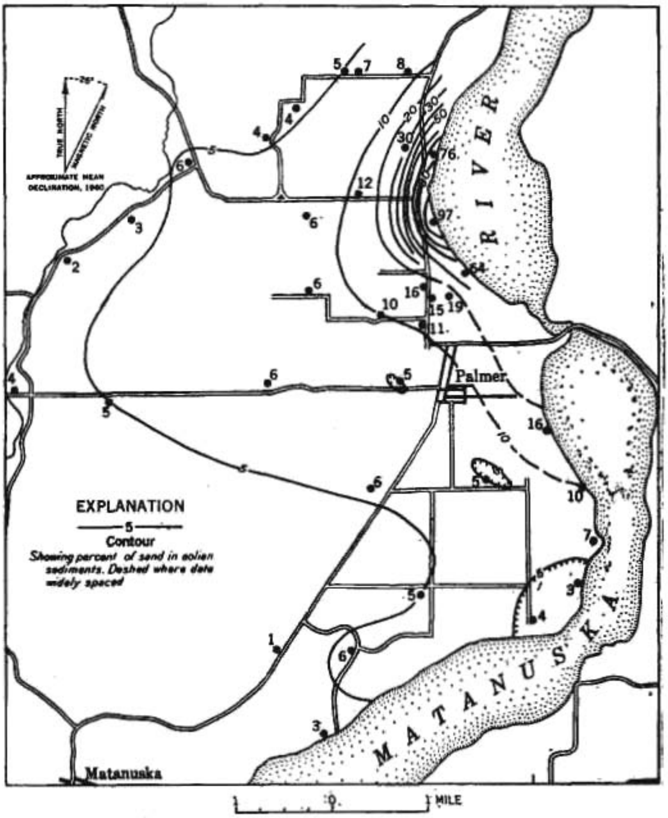

FIGURE 3.—Percentage of sand (particles coarser than 0.074 mm diameter) in eolian sediment near Palmer, Alaska.

structed by the author from independent data. The samples on which the two maps are based are comparable stratigraphically. Stump's samples were collected at the midpoints of his sections. The author's were taken halfway between the upper pair of ash bands and the next higher single band, in sections where these features were identified, and at the midpoint of the section where they were not. The two maps are similar, although that of Stump and others is based on a larger number of samples and is more detailed. The sand-percentage contours (based on sample fractions with grain diameter coarser than 0.074 mm) form a prominent lobe that extends west and southwest from the Matanuska River north of Palmer, roughly parallel to the average direction of the dominant northeast wind. In each map this prominent lobe changes to an irregular pattern near the river south of Palmer, probably because part of the sediment there came from the southeast. Stump, Handy, Davidson, and Roy (1956, fig. 19) also present a clay-percentage contour map (sample fractions with grain diameter finer than 0.005 mm); the contour pattern is strikingly similar to that of the sand-percentage map (but with the contour values increasing away from the source).

The author has not made detailed studies of the texture of the silt in the western part of the area. Stump, Handy, Davidson, and Roy (1956, fig. 16c) found the proportion of the clay-size fraction to increase uniformly, and that of the sand fraction to decrease somewhat, along a traverse from the Matanuska River to a point about 4 miles west of Wasilla. Neil Michaelson (Alaska Agr. Expt. Sta., oral communication, 1954) states that in many of the sections he has examined in the area west of Wasilla the silt below a depth of about 3 inches is sandier than that near Palmer. The author's samples collected 2 miles east of Pittman (fig. 1), at Pittman, and 1 mile southeast of Houston contain 17, 25, and 17 percent material coarser than 0.074 mm, respectively. Each of these sample localities is on or beside a drainage course occupied temporarily during the last deglaciation, however, and the author believes that in these places locally derived, coarser eolian sediment is mixed with finer material transported from greater distance. Sand and silt blown from nearby sources may be present over much of the area west of Wasilla; there are many abandoned drainage courses in that region. In addition, a slight westward thickening of the silt mantle, west of Pittman, suggests that some of the dust there may have been blown from the flood plain of the Susitna River to the west and northwest.

The cumulative curves in figure 2 show the particle-size distribution in samples of the silt and sand. The high degree of sorting commonly considered characteristic of wind-blown sediments is well shown by most of the curves. The relatively poorly sorted samples (5 and 6) were collected from 1- to 2-inch sections (measured vertically) of bluff face in which no grain-size differentiation could be seen in the field; other parts of both exposures contain interbedded sandy and silty materials, however. Krumbein (1937, p. 586) attributes the formation of interbedded eolian sand and silt to transport of sand by traction and dust in suspension. Presumably these modes of transport are alternately more effective in bringing sediment to a locality, perhaps for considerable periods, so that conspicuous interbedding occurs. The materials in samples 5 and 6 are thought to have been deposited during periods when, or at places where, any alternation in mode of transport occurred rapidly so that mixed deposits were formed.

Alternating layers of conspicuously different textures may be seen in some sections of the mantle in this area. Most commonly, thin layers of fine-grained material alternate with thicker beds of sand. The layers of fine material, which are regular and extensive in several exposures along the Matanuska River north of Palmer, are important in the interpretation of the history of eolian deposition. Several of the contrasting layers are shown by the dune sections (4 and 5) in figure 6.

THICKNESS

Figures 1 and 4 show the thickness of the eolian mantle over much of the agricultural area. The conspicuous lobate pattern of the isopachs, convex away from the Matanuska River north of Palmer, indicates that the chief source of the sediment has been to the northeast, where a long reach of bare flood plain is exposed to the dominant northeast wind. The present river bluff at the northeast end of the traverse shown by the long arrows in figures 1 and 4 is thought to be within a few tenths of a mile of its position throughout the period of eolian deposition. An isopach map of silt thickness, for about the same area as that represented by figure 4, is given by Stump, Handy, Davidson, and Roy (1956, fig. 4); the two maps agree fairly closely.

Figure 5, representing the thickness of the mantle along the traverse indicated in figures 1 and 4, suggests that the relation between thinning of the deposit and distance from the Matanuska River is logarithmic. Several authors (for example, Krumbein, 1937; Smith, 1942; Hutton, 1947; Simonson and Hutton, 1954; and Ruhe, 1954) conclude that the eolian deposits they studied show logarithmic relations between thickness and distance from source. Graphs in several of their papers show breaks in slope that imply changes in the relations between distance and thickness. Krumbein (1937, p. 585–586) attributes these changes to differences, along the traverse shown by his plotted measurements, in the mode of transportation and deposition of the sediment. The author's interpretation (fig. 5) of the relations of the distance to thickness in the Matanuska Valley deposits is tentative because there are not sufficient points very near the source and very far from it to give conclusive results. Field observations during storms and study of figures 3 and 5 suggest that the change in the distance-thickness curve inferred to be half a mile from the river bluff is probably related to the transport in suspension of considerable amounts of fine sand and coarse silt by exceptional gusts during northeast storms.

A graph showing distance and thickness should presumably fit the field data well if all the sediment has been brought from one direction. Smith (1942) attributes a poor fit of graph and data to deposition by winds from two directions. The Matanuska Valley data suggest

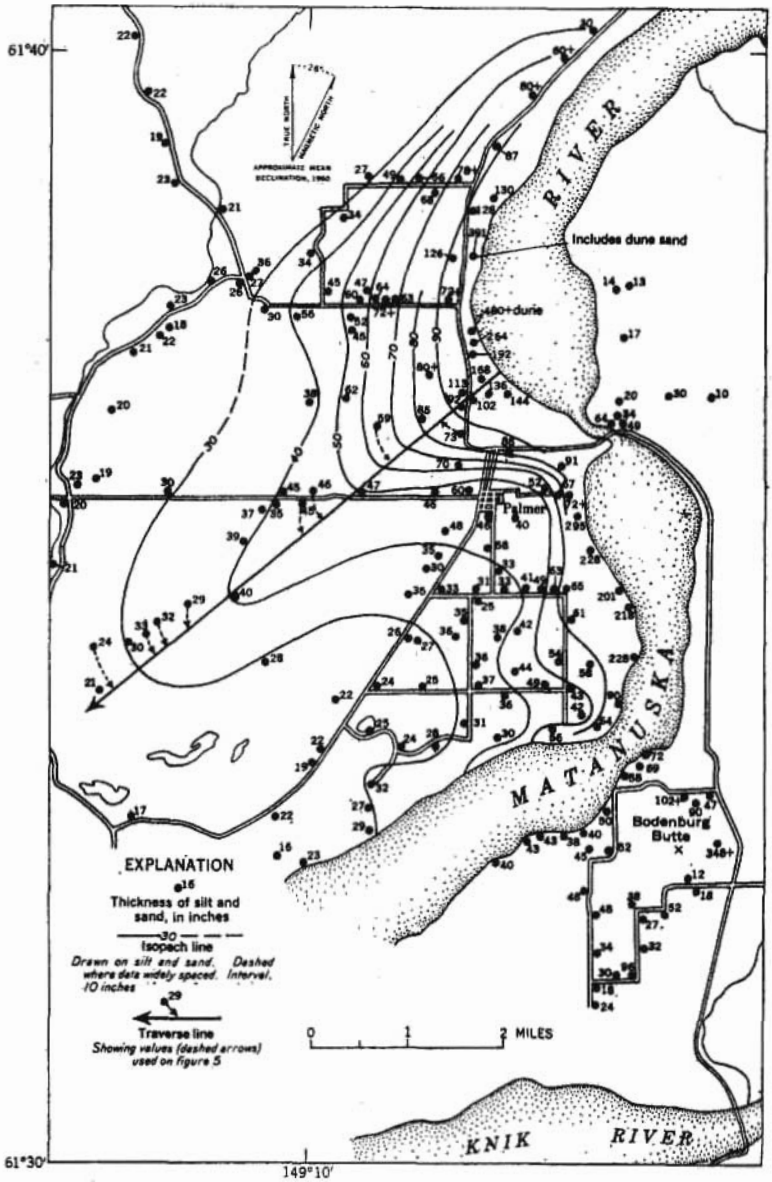

FIGURE 4.—Contours showing the thickness, in inches, of the eolian silt and sand near Palmer. For location of mapped area, see inset, figure 1.

that a fairly good fit of graph to data can be obtained even where the sediment was brought by winds blowing from two directions, or that Knik dust is of minor importance in the area of the major isopach lobe. The second alternative is considered the more likely. Stump,

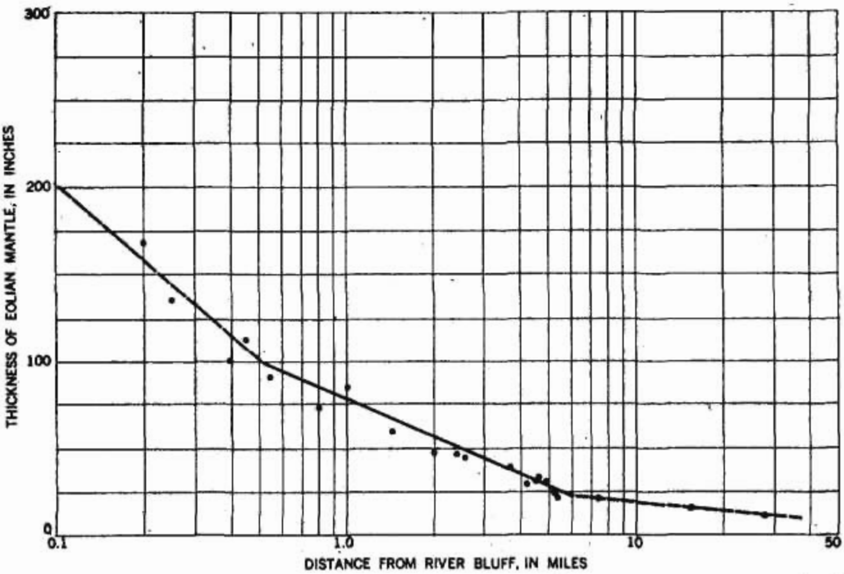

FIGURE 5.—Relation of thickness of the eolian mantle to distance from the present bluff of the Matanuska River north of Palmer, plotted along the traverse shown by the long arrows in figures 1 and 4. Graphs dashed where based on few or scattered data.

Handy, Davidson, and Roy (1956, fig. 22) present a sorting-coefficient contour map that shows a prominent area of relatively poor sorting of the silt at and particularly south of Palmer. This tract probably represents the major area of overlap of the Knik and Matanuska dust. However, the contours on the thickness map are fairly regular, so the Matanuska component of the sediment is thought to be large even in this area of overlap.

The silt mantle is thin or absent in most of the tract between Lazy Mountain, Jim Creek, and Bodenburg Butte. In part of this tract the land surface is formed by alluvial deposits too recent to have received much dust. The absence of thick alluvial deposits on older alluvial deposits (north and northeast of Bodenburg Butte) is attributed to two causes: nearly complete shielding of this tract from northeast winds by the mountain mass east of the agricultural area; and the higher frequency with which the southeast winds probably blow across Bodenburg Butte than to the northeast of this hill. Thick deposits of silt on and near Bodenburg Butte are thought to be due both to more frequent occurrence of winds across the vicinity of the hill than to the north and south of it and to interception of dust by the hill, which rises more than 700 feet above the surrounding lowland. Stump, Handy, Davidson, Roy, and Thomas (1956, p. 9) found 23½ feet of silt at the southeast end of Bodenburg Butte. Because this thickness was measured on a knoll it must represent primary deposition. The author found that the silt is more than 29 feet thick (base of deposit not reached with auger) in a low depression on the southeast end of the hill; this silt may contain material transported from the flanking slopes. The maximum thickness of silt on the top of the hill was not determined, but it is more than 6 feet.

EROSION OF THE EOLIAN MANTLE

MODERN EROSION

The author has been unable to find evidence of significant recent erosion of the mantle anywhere in areas covered with plants except on a few terrace scarps. Cultivated fields near Palmer are eroded by wind, but even on slopes there appears to be little or no mass movement and little erosion by water. Several factors may be important in determining the nature and extent of water erosion at a given locality. These include slope of the land surface, vegetation, porosity and permeability of soil and subsoil, and character of precipitation. Because the silt is not subject to erosion by water even on slopes with no plant cover it appears that slope and vegetation are here unimportant in their effect on erosion by water. The porosity and permeability of the material and the character of the precipitation are the most significant factors in controlling erosion.

The silt is relatively porous. Neil Michaelson (Alaska Agr. Expt. Sta., oral communication, 1955) states that samples of two soil series developed in it have total pore space as high as 50 to 60 percent by volume. Field tests by the author, using a variable-head permeameter of the type described by Wenzel (1942, p. 64–65), indicate that for downward flow the permeability of the eolian sand is comparable with that of much of the glaciofluvial sand in this area. The silt is considerably less permeable but transmits water readily. The results of the tests, expressed in Meinzer's units (gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot, at 60° F.; see Wenzel, 1942, p. 9) are as follows:

	Samples	*Units*
Glaciofluvial sand	6	50–3,400
Dune sand	4	90–190
Compact silt	3	0. 7–1. 0

Some of the silt is undoubtedly much more permeable than these data suggest, particularly near the source and near the land surface where it is coarse and contains so much plant debris that it is very porous.

Weather records (U.S. Weather Bureau) show that the average annual precipitation at the Weather Bureau station at the Agricultural Experiment Station (fig. 1), then called Matanuska 14, was 15.96 inches for the period 1921–52. A quarter to a third of the precipitation falls as snow and the remainder as rain. Each of the 5 months, June through October, receives on the average between 1 and 3 inches of rain; August has the highest average, 2.92 inches. These averages are exceeded in many years, and occasionally during single storms.

The author could find no evidence of important erosion of the eolian mantle during and after heavy rains in June 1949 and in September 1951. During 6 days, June 17–22, 1949, 3.17 inches of rain fell at Matanuska 14; 1.61 inches was recorded June 21. A second station, at Palmer (Palmer 1 North, then named Matanuska 12), received 1.76 inches on June 21. Matanuska 14 reported 1.06 inches on September 4, 1951, and Matanuska 12, 1.40 inches. Hourly precipitation rates have not been measured in the agricultural area, but daily totals such as those cited above commonly fall during periods of 12 to 24 hours.

Both single-storm rainfall and the frequency of the heavier storms are relatively low in the agricultural area. Storms bringing more than an inch of rain per day occur only occasionally—once a year or even less frequently. By way of comparison, the total rainfall for single storms is considerably higher throughout much of the United States, and the frequency of storms bringing several inches of rain is greater.

The porosity and permeability of the eolian mantle in the agricultural area are such that all the rainfall of the heaviest storm can be received and stored or passed on the underlying material. Vegetation-covered tracts in which the force of the falling rain is broken before it reaches the ground could probably receive many times the recorded rainfall without significant surface runoff and erosion.

EROSION IN THE PAST

The evidence relating to past erosion of the eolian mantle is less conclusive than that relating to present erosion. On the basis of available data, however, the author believes that there has been little erosion of the material once it has become incorporated in the mantle.

In many exposures where layers of volcanic ash and other stratigraphic markers can be distinguished it is evident that part of the mantle has been disturbed since it was formed. (See discussion of weathering, p. 21.) However, one of the striking aspects of these exposures is the remarkable continuity of the stratigraphic markers on hillsides and on flat ground. (This continuity of the bands of volcanic ash in many exposures may be due only in part to lack of erosion after the ash had been incorporated in the mantle. Observations at Anchorage suggest that the ash deposited there in 1953 will form a continuous band in the silt only locally. The thin layer of ash was eroded by wind before the first rain came, and the encrusted layer formed was both thin and patchy. It seems likely that the ash bands in the agricultural area represent layers of fresh ash at least several inches thick.) So far as the author has been able to determine from partly covered exposures, the stratigraphic markers are continuous over terrace scarps that are covered by silt.

Conversely, depressions examined by the author contain thicker silt than the adjacent higher ground. The mantle at ice-block pits in a terrace half to three-fourths of a mile west of Palmer was investigated with a soil auger to determine whether its rate of downhill thickening is related to slope angle or to direction of prevailing winds. No evidence of such relations was found. Nor does there appear to be asymmetry of the thickness of the silt on opposing slopes, such as that reported by Simonson and Hutton (1954, p. 100) and by Woldstedt (1954, p. 175). However, the mantle, which is of relatively uniform thickness on the flat terrace, generally thins on the upper slope of the pit and thickens on the lower slope. At one pit, about 12 feet deep, 150 feet long, and 100 feet wide, the thickness of the silt on the terrace was found to average 46 inches in 12 measurements. In 6 traverses across the pit thinning of the silt was found on the upper slope, while in 2 traverses the thicknesses of the silt on the upper slope and on the terrace were found to be the same. In the center of the pit the silt is 89 inches thick. Continuous ash bands in nearby road cuts show evidence of little if any downslope movement of material in the mantle. Such movement is therefore thought to have been unimportant in producing the differential thickness of the silt in the pit. Local variations in dust deposition may have occurred near the source of the sediment if topographic irregularities influenced the flow of the dust-bearing wind just above the surface. The uniform thickness of the silt around the pits suggests, however, that the dust was deposited uniformly over this part of the agricultural area. It seems more likely that part of the newly-incorporated dust was moved downhill before becoming incorporated in the soil. Three processes that might have produced such movement over short distances are erosion of fresh dust by raindrop impact, erosion by runoff from melting snow, and the movement by wind of leaves bearing encrusted silt toward the centers of the pits.

Minor erosional features were found in a few places. Old gullies, covered by younger windblown silt and sand, cut the mantle on the west bluff of the Matanuska River north of Palmer, but the author has seen such gullies only on retreating bluffs. A few small gullies are being formed in silt on Bodenburg Butte by collapse of the roofs of tunnels. These tunnels, which are as much as a foot in diameter and trend down gentle valleys on the hillside, seem to lack surface outlets and thus differ from tunnels in silt in British Columbia (Buckham and Cockfield, 1950). Clyde Wahrhaftig (U.S. Geological Survey, oral communication, 1952) has suggested that the silt may have been deposited locally upon moss-covered talus, and that "blind" tunnels could have been started by the washing or falling of overlying silt into cavities formed as the moss decomposed.

WEATHERING AND SOIL FORMATION

The fresh windblown sand and silt are gray. Beneath the humus-rich layer at the surface, the color of the older sediment ranges from dark brown or gray brown to ocher, and in many places these colors alternate in streaks and mottled zones. Many exposures where the mantle is thick show buried, dark-brown to black, humus-rich layers a fraction of an inch to 2 or 3 inches thick. Bits of charcoal and of wood in all stages of decomposition occur in many places; they are most common in the humus-rich layers. Such humus layers have been found in many eolian deposits and are commonly interpreted as buried soils. (See Lutz, 1941, and literature cited therein.)

Wind-deposited silt and sand are the parent material of the soils formed on well-drained land in most parts of the agricultural area. (The bog soils contain considerable wind-deposited dust, but they are not included in this discussion because their essential characteristics are due to local drainage conditions and do not reflect the regional environment.) Indeed, agriculture is practicable here largely because of the presence of the eolian mantle. The sand and gravel that lie beneath this mantle in the terrain most suitable for cultivation would be unfavorable for agriculture, partly because they are less fertile than the silt but particularly because they retain much less soil moisture than the silt and are very sensitive to drought.

Rockie (1946) and Kellogg and Nygard (1951) have described the soils in detail. The nonbog soils are silt loams and sandy loams of two types, the podzols and the subarctic brown forest soils. Both are characteristically formed beneath a forest cover. The soil profiles provide important evidence of the manner of deposition of the sediment.

Podzol profiles are found over much of the western part of the agricultural area, where the silt mantle is generally less than 12 to 18 inches thick, and also in some localities to the east where it is thin (as, for example, on part of the lower slope of Lazy Mountain, east-northeast of Palmer). Horizons characteristic of podzols—the surface, humus-rich layer (A_1); the gray, leached horizon (A_2) beneath it; and the underlying rusty zone (B_2) in which iron oxide has accumulated—may be recognized in many exposures. In some places the zone of humus enrichment (B_1) just beneath the gray layer is also present. Where podzolization is well advanced, ash bands and other layers, if originally in the mantle, have been masked by iron-staining. In many places this staining has also affected the till or gravel immediately beneath the silt; where the till is not stony, its contact with the silt is inconspicuous.

The subarctic brown forest soils are so named (Kellogg and Nygard, 1951, p. 58) because of their similarity to the brown forest soils of temperate regions. In this area they are developed on thicker silt or sand than the podzols. They are gray brown to dark brown; their subsoils are rusty and gray to brown, streaked and mottled. Kellogg and Nygard (1951, p. 58) state that the subarctic brown forest soils resemble the podzols in some features, and that there are soils transitional between the two types. Kellogg and Nygard (1951, p. 72 and fig. 29) believe that podzolization is the dominant soil-forming process in this area, but that both the characteristic podzols near the land surface and the humus layers deeper in the mantle have developed only where deposition of wind blown dust has been slow enough to permit soil formation to keep pace with the addition of new material. This concept of the relation between rates of eolian deposition and of weathering has been used by several other authors (Smith, 1942; Frye, 1951; Thorp, Johnson, and Reed, 1951; Brunnacker, 1957; and Frankel, 1957); indeed, Frankel (1957, p. 651) suggests that the idea probably can be applied to all areas of loess deposition.

The author believes that rate of deposition has been the most important factor controlling the rate of soil formation in the Matanuska Valley agricultural area, although other factors have undoubtedly accentuated the development of differences between the soils. For example, the mantle is well drained everywhere except in bogs, and thin deposits are better drained than thick ones. This better drainage is due to more effective evaporation and transpiration from the thinner mantle, to the presence of seasonal frost in it for shorter periods, and perhaps to other factors. Where the sand and silt are well drained they are most effectively aerated and oxidized, and in these places humus is least likely to be preserved. The distribution of podzols and subarctic brown forest soils might be explained by assuming that sand and silt were deposited continuously over a relatively short period of time, and that differences in drainage conditions have since led to the development of the different soil profiles. However, the author accepts the explanation of the preservation of the humus layers given by Kellogg and Nygard and therefore believes that deposition was neither brief nor completely uninterrupted.

The slight degree of weathering of the subarctic brown forest soils is shown by the results of differential thermal analyses and X-ray diffraction studies of three samples of soil. Stump, Handy, Davidson, Roy, and Thomas (1956, p. 29) conclude that the clay minerals, dominantly chlorite (thought to be a direct product of the parent material of the silt), have not been influenced by soil-forming processes.

Analytical data presented by Kellogg and Nygard (1951) show that both the podzols and the subarctic brown forest soils are characterized by low concentrations of calcium carbonate. In the present investigation, field tests with dilute hydrochloric acid indicated only slight concentrations of calcium carbonate in the mantle beneath the modern soils, except near buried snail shells, where the calcium carbonate commonly forms casts of roots. The alluvial sediment that provides the wind-blown dust is also not markedly calcareous. The concentrations of calcium carbonate have probably been derived from snail shells by solution and redeposition. The low content of calcium carbonate may be a significant factor in the general absence in the Matanuska Valley of the conspicuous vertical jointing that characterizes many loess deposits.

Minor folding or crenulation of buried humus layers and bands of volcanic ash may be seen in many exposures. The folding is common in silt but not in sand. The amplitude of the folds is commonly a fraction of an inch to 2 or 3 inches. The arches of the folds are typically pointed and the troughs broadly rounded. There seems to be little or no relation between folds in successive layers. The deformation is attributed to lateral push and upward relief of stress in the near-surface material during refreezing, after partial thawing of seasonal frost; it probably occurred most commonly during spring while the underlying material was still frozen. Perennial frost is not necessary to explain this minor folding.

There seems to have been little mixing of the eolian sand and silt with the glacial drift beneath it. In some exposures where silt rests on gravel, stones occur in the basal foot or two of the silt. Their presence is thought to be due to the overturn of trees and the tearing out of roots (Lutz and Griswold, 1939, p. 392); deposits of mixed silt and stones have been found in the modern forest where trees rooted in thin silt have been overturned. No evidence of extensive slope movement was found in the silt. In a few exposures sandy streaks and other stratigraphic markers wrap around stones in the basal silt, indicating disturbance of that part of the mantle, but these stones have been rotated rather than translated; and exposures of stones in the silt seem to be as common on flat ground as on slopes.

HISTORY OF THE EOLIAN DEPOSITS

AGE

All the eolian deposits of the Matanuska Valley agricultural area have been formed since the last glaciation of the area. Tentative correlations (Karlstrom, 1952; Péwé and others, 1953, p. 12–13; Trainer, 1953, p. 14) have suggested that the youngest till is of late Wisconsin age. A radiocarbon age of 11,600±300 years (W–540), recently determined for outwash deposits of this last glaciation laid down outside the end moraine near Anchorage (Miller and Dobrovolny, 1957), confirms this correlation. The prefix "W" indicates that the sample was dated in the radiocarbon laboratory of the U.S. Geological Survey in Washington, D.C.

Widespread stagnation of the glaciers accompanied deglaciation of the agricultural area. The greater part of the valley floor near Palmer was terraced by outwash streams, and most of the terraces were heavily pitted by the melting of buried masses of glacial ice. The mantle of eolian sediment covers this terraced and pitted terrain, and the relation between mantle and pits is therefore significant in dating the eolian deposits. Several cuts just west of Palmer along the Palmer-Wasilla road and along side roads from it show that volcanic-ash bands are continuous down the upper slopes of pits. These data, together with measurements of silt thickness in pits west of Palmer, already described, show that the mantle is continuous from level ground into the pits and suggest that much of the silt was deposited after the pits had been formed. On the other hand, Stump, Handy, Davidson, Roy, and Thomas (1956, p. 54) found that the bottoms of several pits in the southern part of the terrace on which Palmer is situated contain little or no silt. They (1956, p. 76) therefore believe that major silt deposition had ended before the buried ice in the terrace south of Palmer had completely melted. The author believes that these pits are probably only slightly younger than the pits just west of Palmer, and that the data thus appear to be contradictory. However, one pit (about 1¾ miles southeast of Palmer) in which the silt is thicker than on the surrounding terrace was reported also by Stump, Handy, Davidson, Roy, and Thomas (1956, p. 54). Additional data are needed to determine the significance of the pits south of Palmer in the problem of dating the eolian mantle. The author believes that deposition of this eolian sediment has been essentially continuous from its beginning to the present except for brief interruptions or decreases in rate; this conclusion is based on the continuity of the mantle in the pits described and on the presence in the mantle generally of the subarctic brown forest soils and the buried humus zones.

Eolian deposition evidently began at different times in different parts of the area, and consequently the age of the basal eolian material differs somewhat from place to place. The author believes, however, that the greater part of the eolian mantle, in the tract where correlation is reliable, is of the same age. As Stump, Handy, Davidson, Roy, and Thomas (1956, p. 75) note, if the silt deposits on different parts of the valley floor are contemporaneous, the greater part of the deposition must have taken place after formation of the surface on which Palmer is situated. A minumum age for that surface is suggested by recent dating of a peat deposit near the Matanuska Glacier (Williams and Ferrians, 1958; Rubin and Alexander, 1958, p. 1481): the peat, from the base of a bog deposit on a 100-foot bluff beside the Matanuska River, 6,000 feet in front of the present terminus of the Matanuska Glacier, is 8,000±300 radiocarbon years old. The absence of glacial drift above the peat, and the fact that the peat and ash bands in it have not been deformed, show that the ice has not covered this site since a time before deposition of the peat. Near the glacier the outwash flood plain has evidently stood less than 100 feet above its present position throughout this 8,000-year period; moreover, the Matanuska River has probably been an integrated stream over essentially its present length during this period. The lowest extensive terrace that stands above the level of the modern Matanuska flood plain and is covered by the eolian mantle is that on which Palmer is situated; it is nearly 100 feet above the river at its northern end. Several higher, conspicuously pitted terraces lie to the north and west. The uppermost gravel in each of these terraces contains boulders 1 to 2 feet or more in diameter that are considerably larger than any stones the author has seen in modern flood-plain deposits near Palmer. For this reason the terraces are thought to have been formed when the Matanuska Glacier stood much closer to this area than it does now (its terminus is about 50 air miles from Palmer, measured along the river); hence the Palmer terrace must be older than 8,000 years.

The flood plain slopes about 26 feet per mile downstream over nearly its entire length; the Palmer surface slopes about 35 feet per mile, and the higher terraces near Palmer about 40 feet per mile. This difference in gradients is tentatively thought to be due in part to progressively increasing distance of the glacier from the agricultural area, with time; and, on the basis of incomplete study of the terraces, in part to late-glacial rise of sea level. Part of the difference may be due to warping after the region was freed of the bulk of its former load of ice, but terraces upstream from the agricultural area are too few and too widely separated to permit the correlation necessary for testing the hypothesis of warping.

The available data do not show how long after formation of the terrace on which Palmer is situated the deposition of eolian sediment began. It appears reasonable to assume that deposition began as soon as a suitable source area had been formed, and that the deposits were preserved as soon as ice-free, vegetation-covered areas were available as sites of deposition. The deposition appears to have been general over much of the agricultural area by the time the older double ash band had been formed. Correlation of these basal eolian deposits with peat that overlies the 11,600-year deposit near Anchorage has been attempted, but without success. Peat at that locality and at several other places near Anchorage, and dune sand at one locality near Anchorage, contain four to six bands of volcanic ash. Mr. Ray E. Wilcox, of the U.S. Geological Survey, studied samples of the ash from Palmer and Anchorage. He found (written communication, Nov. 3, 1954) that samples of ash from different layers are similar, and that differences in refractive indices of glass shards and in phenocrysts are too slight to justify correlation of any of the ash bands on a petrographic basis. Furthermore, the ash bands at Anchorage do not seem to occur in a characteristic sequence, as they do near Palmer, so that correlation cannot be made on that basis.

From all these considerations, and assuming the radiocarbon ages to be correct, the author concludes that deposition of the eolian silt and sand near Palmer began between 11,600 and 8,000 years ago and that it has continued to the present.

ENVIRONMENTAL SIGNIFICANCE

Two aspects of the history of eolian sedimentation in the agricultural area are significant in the interpretation of the regional environment during deposition: the sedimentation has been characterized by repeated changes in rate that, in some places, have brought about slackened deposition and finer sediment, and in other places brief cessation of deposition; and there seems to have been no major interruption of the deposition since it began.

Eolian silt and sand are interbedded in many bluffs downwind from Pleistocene outwash flood plains. (See, for example, Krumbein, 1937; Schönhals, 1953; Leonard and Frye, 1954.) In the Matanuska bluff north of Palmer (sections 4 and 5, fig. 6) thin beds of fine sediment are interbedded with coarser material. These thin beds may be correlated with the humus layers in some of the other sections shown by the map, and in section 5 the thin beds themselves contain humus layers. As was noted in the discussion of soils, these humus layers probably formed during periods of slackened deposition. The beds of fine-grained material must have been deposited under the same conditions. Each of these inferred episodes of slackened deposition was part of a larger episode of changing character of sedimentation. The particle-size data for section 5 show that the formation of a bed of fine-grained material and any accompanying humus layers was the first expression of a period during which the sediment being deposited gradually became coarser. The lower boundaries of the beds of fine-grained material are fairly sharp (distinct within a quarter to half an inch or less) but the upper boundaries are less sharp (gradational over as much as several inches). At the beginning of a sequence, deposition slackened rather sharply and the sediment was finer than that deposited before and after. In general each sequence of coarsening sediment in section 5 is succeeded by a similar younger sequence that begins with fine material. The period of slackened deposition must have been relatively brief; otherwise more pronounced weathering would have taken place. Thin rusty zones observed along the tops of humus layers in some exposures show that weathering was effective locally. The rusty zones do not have general significance, however, because they are commonly discontinuous laterally and do not seem to be correlative from one exposure to another. Conversely the humus layers are widely distributed and occur in a wide range of topographic positions. The cause of the cycles of sedimentation is therefore considered to have been of general rather than local significance. Moreover, the number of sequences implied by the data in figure 6 is too large to be explained by chance changes in the conditions of sedimentation. The sections in figure 6 indicate that there were several cycles; section 5, in a depositional locality that is presumably very "sensitive" to environmental changes, shows nine of these sequences of deposition.

The cause of these inferred changes must have been a change in one of three environmental factors, wind, plant cover in area of deposition, or nature of source area. There is no evidence of changes in wind pattern and strength sufficient to produce the effects noted; such changes in winds would have required considerable shifts in the distribution of high- and low-pressure centers, repeated many times over presumably short periods. In the area of deposition the land surface must have been continuously covered by vegetation, and probably was forested, since the beginning of eolian deposition. This conclusion is based on two lines of evidence: although the silt mantle is easily eroded by wind where it is not protected by vegetation, no evidence of conspicuous erosion was found in the many sections examined; and the mantle contains buried charcoal and woody debris

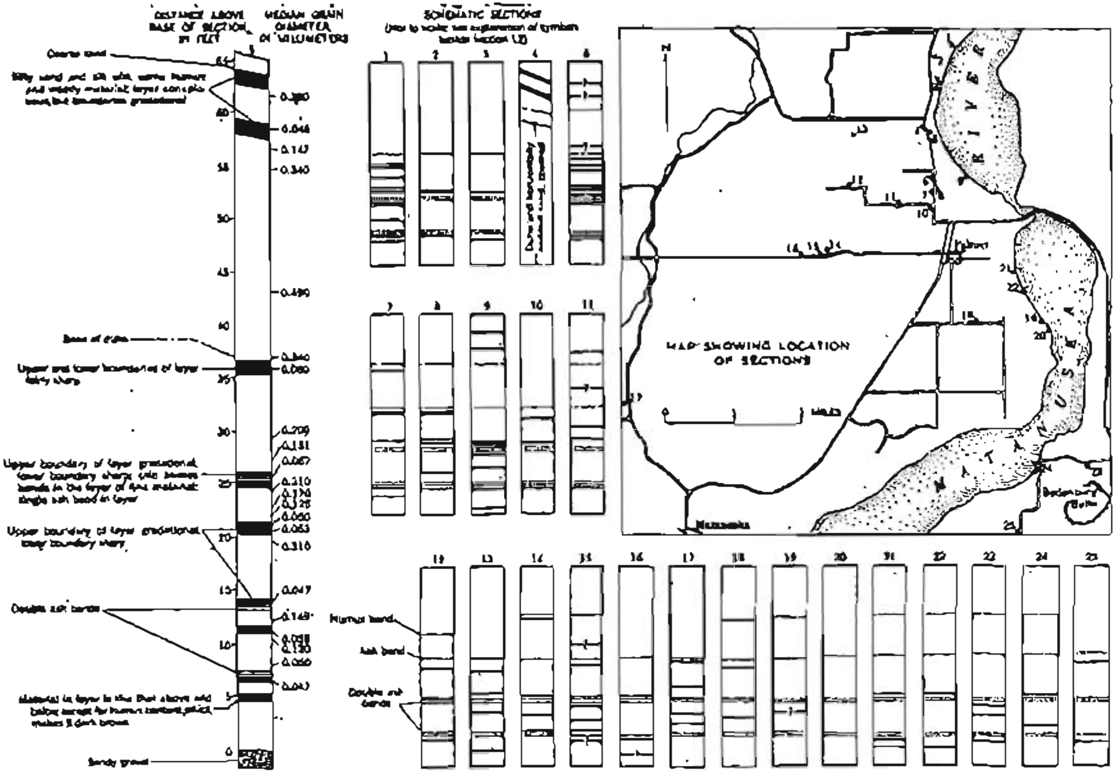

FIGURE 6.—Stratigraphic features of the eolian deposits near Palmer. Schematic sections 1 to 4 and 6 to 25 (not to scale) show number and relative positions of humus bands and layers of volcanic ash in sections through the eolian mantle. Section 5 shows details at one locality.

in many places, and the podzol and subarctic brown forest-soil profiles developed in it are characteristically formed beneath forest. Some evidence, noted in the following paragraphs, suggest that the character of the source areas of the eolian sediment has undergone changes in the recent past. The author believes that such changes present the best explanation of the observed features and inferred events, and that the changes have consisted of the alternating formation and destruction of stabilized flood-plain surfaces. The required changes in stream regimen are thought to have been related to the growth and recession of the glaciers from which the outwash streams flow, or to eustatic changes of sea level accompanying the changes in the glaciers. These conclusions are based on field observation of stabilized alluvial features that appear not to be in equilibrium with the modern Matanuska River, and on evidence that the Matanuska Glacier has recently been shrinking.

Forested tracts of flood plain are common in somewhat protected places (downstream from narrow reaches constricted by bedrock outcrops) along the sides of the bare plain of the Matanuska River. The top of the gravel in these tracts is level with or is 1 to 2 feet higher than the highest nearby bars on the bare ("active") flood plain. Large tracts of this forested flood plain that were examined east of the Matanuska River for 1 to 2 miles north and south of the highway bridge near Palmer, and between the mouths of the Matanuska and Knik Rivers, are crossed by shallow channels. Some of these channels now contain streams or have done so recently, but many others are partly filled by leaves and fallen trees, or have trees growing in them, and have evidently not been occupied in recent years. Sufficient information is not available to show indisputably whether these forested bars are part of the bare flood plain, temporarily stabilized, or whether they represent an older and slightly higher flood plain. The presence of trees and brush of a wide range in size, and of a surface layer of leaves and other debris, show that the river has not topped the stabilized bars for many years. The author believes the forested bars have not been flooded and eroded to a marked degree during the life of the oldest trees on them, which, according to evidence described below, is probably 150-200 years. The annual flood (highest discharge during the year) of the Matanuska River was the order of 20,000 cubic feet per second during the period 1950-56 (U.S. Geological Survey, 1958a, p. 138-139; 1958b, p. 119-120). Such a flood inundates much but not all of the bare flood plain. Where the stabilized bars were examined, the bare flood plain is as much as a mile wide, and the bare and forested tracts together have a total width as great as 1¼ miles. This means that, assuming a velocity of flow of 3 to 4 feet per second and considering the deepening of channels that occurs during floods, a rise of river stage to a foot above the general surface of the bare flood plain would increase the discharge to more than twice, and possibly several times, that of the annual floods observed during 1950-56. Higher rises would result in even greater floods. Unusual floods may occur in the Matanuska River at long intervals, as they are known to do in some other streams. However, the observation that such floods have apparently not occurred here during a period of perhaps 150-200 years seems to favor the interpretation that the forested tracts of flood plain represent a stage of the Matanuska flood plain older than that represented by the bare, active plain.

A gently sloping alluvial surface south of Bodenburg Butte, which Stump, Handy, Davidson, Roy, and Thomas (1956, p. 50-51) describe as a fan complex, appears to be the southward extension of the stabilized flood plain south of the Matanuska Bridge near Palmer. A spring-fed stream, Palmer (Bodenburg) Creek, now flows down this fan in a channel that appears too wide and deep to have been cut by the present stream. Highway fill and a low barrier of planks prevent the flow of water from the Matanuska River southward between several bedrock hills, of which Bodenburg Butte is the largest, and into Palmer Creek; however, such flow did occur, at least occasionally, in recent years before construction of the highway (Harold Thuma, Palmer, oral communication, 1950). At the time of formation of the low fan complex the drainage course at the east end of Bodenburg Butte was evidently an important part of the Matanuska flood plain.

Intricately channelled alluvial terrain, thought also to represent the postulated older flood plain, lies north of the present flood plain near the community of Matanuska. Some of the channels carry water from the Matanuska River during high stages of that stream, but many and perhaps most of the streams that flow across this tract arise within it from springs.

No similar stabilized alluvial features were found during reconnaissance of the Knik River flood plain between Jim Creek and the Knik Glacier. If they were present, they have probably been modified by the Knik River, which floods each season in late summer during the draining of a lake impounded by the glacier.

Alluvial fans at the mouths of tributaries of the Matanuska River, now being eroded by the river and by their own streams, appear to have been graded to a level slightly higher than that of the flood plain. Low, tree-covered terraces along these tributary streams stand 1 to 2 feet above the modern stream deposits. The author believes that the forested tracts of river flood plain, the fans, and the low terraces are equivalent and relatively recent features. Equivalence is suggested by the apparent common height of the features above the recent deposits. A similar forest cover on all the features also suggests equivalence, but this evidence is less conclusive than it appears at first sight. Reed and Harms (1956) examined 44 poplar (cottonwood) trees in typical sites in the Anchorage-Matanuska Valley area in 1955. Of these, three were about 150 years old and the rest were less than 100 years old. Of 71 white spruce trees studied, 22 trees were older than 150 years; two, about 210 years old, were older than 200 years. It thus appears that in the agricultural area these trees commonly do not reach ages greater than 150–200 years. The author found by counting growth rings that cottonwoods on the fan of Moose Creek were as old as 140 years when cut in 1951. (Larger stumps with rotten centers are probably older.) White spruces on dunes that lie on the fan-complex deposits about a mile west of the month of Jim Creek, cut during the period 1949–51, were as old as 126 years. Trees elsewhere on tracts of stabilized flood plain along the Matanuska River and on low terraces of tributaries attain the same size as the trees whose rings were counted and may thus be of about the same age. It is possible that several topographic features bearing trees 150–200 years old might be older than the trees, but of different ages. Nonetheless, the presence of the fans, terraces, and flood-plain remnants in places exposed to lateral erosion suggests that they are not old and seems to strengthen the inference that they may be correlated.

Much of the terminus of the Matanuska Glacier is covered by ablation moraine formed as a result of recent melting of the ice. Photographs in the files of the U.S. Geological Survey, the oldest taken by W. C. Mendenhall in 1898, show that the end of the glacier has had much the same appearance for more than 50 years but that the ablation moraine has grown somewhat during this period. Apparently the ice front advanced to a temporary maximum position at some time before 1898 and then began the excessive melting that brought it to its present position. Ablation moraine and a small recent end moraine in front of the Knik Glacier show that it, too, has undergone recent net melting. This melting is part of the recent general glacial recession. Matthes (1942, p. 200) believed that this recession in Alaska occurred during the 50 or 60 years preceding 1940. According to Lawrence (1950, 1953) there has been general recession since about 1750, with the most rapid recession after about 1870. Karlstrom (1955, p. 1582) states that a recent glaciation began about 1500 A.D.

The author found no evidence of a causal relation between the glacier shrinkage and the apparently recent formation and erosion of the alluvial features. Because the Matanuska Rivers is a glacial-outwash stream, however, and flows into an arm of the sea, it is apparent that any considerable change in stream regimen must be dependent upon changes in the glacier, in sea level, or in both, and hence ultimately upon changes in climate. The hypothesis of causal relation explains the features observed in the eolian deposits. Episodes of flood-plain alluviation may be inferred to have alternated with episodes of degradation. It is probable that relatively little eolian sediment would have been provided by the flood plain at its temporary high level after the stream began downcutting because the available dust would have been blown from the exposed high bars relatively quickly and not replenished by the stream and because vegetation would have invaded the high bars and covered them until such time as they were destroyed by lateral stream erosion. (See Leonard and Frye, 1954, p. 403.) Moreover, stabilization of part of the flood plain would have led to stabilization of long reaches of the river bluffs, which provide much coarse eolian sediment today and probably have done so in the past. And if this sequence of events is extended to encompass repeated episodes of alluviation and degradation it explains the formation of the series of humic layers and beds of fine-grained material observed in the eolian mantle.

A critical step in the further development of this hypothesis would consist of relating the inferred episodes of flood-plain modification to the glacial and sea-level changes that have occurred since the last major glaciation. One may infer on theoretical grounds that aggradation near the glaciers would occur during glacial advance, and degradation during recession. On the other hand aggradation near the estuary should have occurred during times of relatively high sea level, that is, times of glacial recession, and degradation during times of lower sea level. Well preserved terraces might therefore show a crossing of the grade lines of flood plains formed during alternating episodes of glacial advances and recession. The author has been unable to establish such a crossing relationship by means of terrace studies. Relations at present suggest that outwash-stream regimen in the agricultural area must be strongly influenced by sea-level changes. The present Matanuska and Knik Rivers are tidal somewhat farther upstream than the community of Matanuska. The Matanuska and Knik Glaciers, however, are about 50 and 22 air miles, respectively, from Palmer (measured along the rivers), and the Matanuska Glacier is known to have been that far away for more than 8,000 years. Moreover, alluvium near the community of Matanuska overlaps estuarine deposits which now stand above high tide; this relationship suggests that the postulated older flood plain was formed during a time when sea level was higher than it is now. This observation is offered tentatively because the high estuarine deposits may reflect uplift rather than eustatic changes of sea level. On the basis of the available evidence, however, the author favors the interpretation that a higher Matanuska River flood plain in the agricultural area was formed during an episode of glacial recession and high sea level, that it was trenched during the most recent episode of glacial advance and lower sea level, and that the trenched parts are being aggraded during the present time of glacial recession and rising sea level. The author was unable to establish even a tentative correlation between specific events inferred from the eolian deposits and specific events in late Quaternary history (such as the post-Wisconsin altithermal episode) established elsewhere.

Despite repeated changes in rates of eolian deposition, as inferred in foregoing paragraphs, there has been no major interruption of the deposition since it began—otherwise weathering features in the mantle near the source areas would be much better developed than they are. The Matanuska and Knik Rivers are therefore thought to have remained braided streams, essentially similar to their present form, throughout the period of eolian deposition. Moreover, the author believes the continuity of eolian deposition further implies that these rivers have been outwash streams throughout this period, and hence that the Matanuska and Knik Glaciers have been in existence continuously since the last major glaciation of this region.

Outwash streams are widely known for their sharp fluctuations in discharge and for their large sediment loads during flood stages. Nonglacial streams which receive much of their water from melting snow also show sharp fluctuations in discharge; depending on the accessibility during the melting period of material suitable for erosion, they may or may not carry large sediment loads. Small snow-water streams in the nearby mountains (there are no large, entirely nonglacial streams in this region), the Matanuska River, and several of its tributaries that carry large snow-water components during the melting season were observed, and the author believes most of the sediment carried by the Matanuska River to be derived from the Matanuska Glacier. The nonglacial runoff seems to carry relatively little sediment. Moreover, many stream banks and bluffs and the land surface generally in even much of the mountainous part of the region are now well protected from erosion by plants or by a thin cover of windblown or other porous material. Probably the plant cover would have been more complete and more effective in preventing erosion during any nonglacial episode than it is now, provided base level were relatively stable. From all these considerations the author concludes that glacial and nonglacial streams in this region during Quaternary time would have differed markedly in sediment load; that a nonglacial Matanuska River would not have received a large and constantly renewed supply of sediment, especially rock flour that provides the eolian dust; and consequently that the essentially continuous eolian deposition since the late-Wisconsin deglaciation of the agricultural area requires that the Matanuska and Knik Glaciers (and by inference the other large glaciers in the surrounding region) did not melt completely after that deglaciation.

The general significance of glaciation in the formation of many eolian deposits is well known. Tuck (1938) emphasized this significance with reference to the Matanuska Valley deposits. If the arguments given in the preceding pages are valid, they provide an additional illustration of this significance and of the complexity of recent climatic fluctuations.

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