U. S. Geological Survey
Water Resources Division
1515 E. 13th Ave.
Anchorage, Alaska 99501

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

W. E. WRATHER, DIRECTOR

GEOLOGY AND GROUND-WATER RESOURCES OF THE MATANUSKA VALLEY AGRICULTURAL AREA, ALASKA

by Frank W. Trainer

Open-file report. Not reviewed for conformance with stratigraphic nomenclature and editorial standards of the Geological Survey.

54-315

February 1954

GEOLOGY AND GROUND-WATER RESOURCES

OF THE MATANUSKA VALLEY AGRICULTURAL AREA, ALASKA

CONTENTS

GEOMORPHOLOGY (continued)

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND-WATER RESOURCES OF THE MATANUSKA VALLEY AGRICULTURAL AREA, ALASKA

INTRODUCTION

Location and Extent of the Area

The Matanuska Valley is a part of the lowland lying north of the Chugach Range in south-central Alaska. The valley of Matanuska River and the lowland extending westward from it to Susitna River are in the Matanuska and Wasilla districts as defined by P. S. Smith (1939, pl. 3). The area described by this thesis, hereafter termed the Matanuska Valley agricultural area, is best known as including the site of agricultural colonization undertaken by the Federal Government in 1935. It is bounded on the north by the Talkeetna Mountains and Little Susitna River, and on the south by Knik River and Knik Arm (plate 1). It lies between Eska Creek on the northeast and Goose Bay on the southwest. As thus defined the area lies approximately between 148°55' and 149°50' west longitude and between 61°25' and 61°45' north latitude; it covers about 360 square miles.

Purpose and Scope of the Investigation

The field studies upon which this thesis is based are a part of the investigation of the ground-water resources of Alaska by the United States Geological Survey. The writer spent the 1949 and 1950 field seasons and part of the 1951 season in the Matanuska Valley agricultural area; the purpose of his field work was the geologic mapping of the area and the determination of the occurrence, availability, and quality of ground water in it. The need for the compilation and interpretation of geologic and hydrologic data became important after colonization in 1935, and this need has increased during the postwar period of continuing settlement.

The classification of map units used in this thesis is based chiefly on inferred origin. The map units are primarily landforms. Mapping was on the basis of topographic form and of the composition and structure of deposits revealed in stream banks, road cuts, wells, building excavations, and gravel pits. Shallow excavations were made by shovel in many localities where other exposures were lacking. Geologic mapping was done on aerial photographs, and the data were transferred to a base map with the aid of a vertical sketchmaster. The base used for the surficial geology map comprises parts of the Knik, Houston, Eklutna, Matanuska, and Sutton quadrangles of the Corps of Engineers, U. S. Army.

Several large-scale topographic maps were prepared to illustrate features of small size. These maps were made with alidade and plane table, hand level and plane table, or pace, compass, and hand level. Profiles of the channels of existing streams were plotted from map contours; profiles of terraces were based on map contours and on hand-level or altimeter data obtained with bench-mark control.

A well inventory and a water-level observation program were carried out as part of the field work, and observation of water levels in wells has been continued by the Geological Survey between field seasons. Ground-water samples were analyzed in Geological Survey laboratories to determine their chemical quality.

Samples of unconsolidated materials exposed in the area were collected for laboratory study. Mechanical analyses were made by the writer, using sieves for the coarser fractions and either hydrometer or pipette for the finer fractions. The permeability of small undisturbed samples was determined in the field by means of a variable-head permeameter (Wenzel, 1942, p. 64).

Previous Investigations

No published reports describe in detail the geology of the Matanuska Valley agricultural area, although parts of the area are discussed in several publications. Martin and Katz (1912) describe that part of the area in the vicinity of Moose and Wasilla Creeks, and Landes (1927) describes the district between the Knik and Matanuska Rivers, including part of the

Chugach Range. The geology of the general region i discussed briefly by Capps (1940), and the physiography by Martin (1942). Rockie (1946) gives the most complete description of the physical geography of the agricultural area. Karlstrom (1950) includes the area treated by this report in a map of the larger area bordering Cook Inlet. Other papers, including those by Black (1951), Rockie (1942), and Tuck (1938), treat special problems of the geology of the area.

Acknowledgments

The investigation on which this report is based was made under the general direction of A. N. Sayre, chief of the Ground Water Branch of the Water Resources Division of the Geological Survey. The field work was supervised by D. J. Cederstrom, district geologist of the Ground Water Branch. M. J. Slaughter, G. W. Whetstone, and Mrs. Arline Day, of the Water Resources Division at Palmer, did much to facilitate the field work. E. C. Casey, D. C. Phillips, Clifford Shaw, Mr. Slaughter, and Mr. Whetstone made a number of water-level measurements

Special thanks are due the late Kirk Bryan, and M. P. Billings, K. F. Mather, H. C. Stetson, and C. E. Stearns, of Harvard University, for their discussion of and many suggestions regarding the writer's work.

Several members of the Geological Survey, and other individuals, visited field localities with the writer or discussed local problems with him. A field visit and discussion with Clyde Wahrhaftig, of the Geological Survey, were particularly helpful.

Professor H. T. U. Smith, of the University of Kansas, read an early draft of the writer's discussion of eolian deposits.

For many courtesies the writer is indebted to W. A. Rockie, Soil Conservation Service, Portland, Oregon, to C. W. Wilson and T. H. Day, Soil Conservation Service, Palmer, and to D. L. Irwin and A. H. Mick, Alaska Agricultural Experiment Station, Palmer. James Hurley made available copies of well logs from the files of the Alaska Rural Rehabilitation Corporation. The Matanuska Valley Fair Association permitted the use of storage space.

Without exception, residents of the area willingly permitted access to wells on their property or provided information regarding them. Henry LaRose, A. R. and Thomas Moffitt, and James and Albert Frey, drillers, described their experience in the Matanuska Valley and gave the writer much valuable information. T. B. Bourne and Associates, Inc., consulting engineers, provided data obtained during construction of a test well for the city of Palmer. The owners of the wells used as observation wells permitted use of their wells for this purpose, and J. C. Baldwin, Henry LaRose, Oscar Tryck, F. B. Linn, Loren McKechnie, and G. E. Murphy,

and Noel Woods made periodic water-level measurements.

GEOGRAPHY

Climate

The climate of the eastern part of the Cook Inlet lowland, which includes the Matanuska Valley agricultural area, is the result of a combination of marine and continental influences. The lowland lacks both the high rainfall of coastal areas and the temperature extremes of the interior of Alaska.

Although weather data have been collected at several localities in the agricultural area in recent years, the only extended record is that for the Alaska Agricultural Experiment Station near Matanuska. Selected data for this locality are presented in table 1 (p. 7).

The departure from the mean annual precipitation and the seasonal distribution of precipitation (table 1) are significant climatic elements here. There is also a wide range in departure from the mean temperature. During the 10-year period 1939-48 the length of the growing season ranged from 67 to 151 days. The seasonal distribution of rainfall and the irregularity in the length of the growing season contribute a measure of uncertainty to crop yields in the area.

Midsummer temperatures in the agricultural area commonly

Table 1. - Climatological data for the Alaska Agricultural Experiment Station, near Matanuska, Alaska [a]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Precipitation (inches)													
Mean (1920-48)	0.87	0.73	0.56	0.42	0.68	1.13	1.96	2.86	2.66	1.76	0.94	0.97	15.54
Maximum (1939-48)	2.00	1.20	1.04	.88	1.71	2.10	3.75	6.37	4.81	3.48	2.33	1.74	21.13
Minimum (1939-48)	.26	.07	.14	.02	.17	.16	.99	.45	.51	.39	.10	.05	11.07
Snowfall (inches of unmelted snow)													
Mean (1936-46)	7.5	5.3	6.8	2.9	.5	0	0	0	0	5.0	8.1	8.0	44.0
Maximum (1936-46)	21.4	10.3	13.8	17.5	5.3	...	...	...	T[b]	18.0	15.7	27.5	70.3
Minimum (1936-46)	.6	0	0	0	0	...	...	...	0	0	1.5	.4	29.5
Temperature (degrees F.)													
Mean (1939-48)	10.6	23.3	24.8	37.2	47.0	55.3	57.2	54.6	47.2	35.5	20.1	12.8	35.5
Maximum (1939-48)	25.7	30.2	33.5	44.4	51.4	57.6	59.4	59.0	52.0	39.6	31.8	26.6	38.7
Minimum (1939-48)	-4.0	13.2	15.8	33.0	43.8	52.5	56.0	52.6	44.8	29.6	13.2	1.2	32.8

a/ Data from U. S. Dept. Agr. (1941) and U. S. Weather Bur. (1936-48). Data for 1949-52 are incomplete.

b/ T = trace, less than 0.1 inch.

range from 45° to 70° F.; temperatures as high as 80° F. are unusual. The winters are moderately cold; periods during which the temperature reaches -20° to -30° F. are usually short. The freeze-up comes in October or November. Seasonal frost commonly reaches depths of 6 feet or more. The ground begins to thaw in April or May, but seasonal frost may persist beneath the surface in protected spots as late as July.

The dominant wind of the agricultural area, known locally as the "Matanuska wind", is from the northeast. It is an autumn and winter wind. During storms it may blow more or less continuously for periods of several days; Weather Bureau records indicate that gusts reaching velocities of 50 miles per hour or more occur during the more severe storms. The "Knik wind", oceanic air from the south moving down the Knik Valley, is relatively warm. During late winter and spring it brings mild weather and, together with rain, may remove much of the snow cover from the agricultural area before the ground begins to thaw.

Topography and Drainage

The Matanuska Valley agricultural area lies in a wide, flat-floored valley formed by the merging of the Matanuska and Knik Valleys at the eastern end of Knik Arm. The valley is bounded by rugged mountains that rise abruptly from its level to altitudes of 3,000 to 6,000 feet. Although the altitude of the valley floor ranges from tide level at Knik Arm to 1,000 feet at the base of Wishbone Hill (see pl. 1), local relief generally is not more than 100 to 200 feet. Features providing greater relief include Bodenburg Butte, which is almost 800 feet higher than the surrounding lowland, and several other hills of bedrock. The bluffs along Matanuska River north of Palmer rise 200 to 300 feet above the river.

The greater part of the valley floor, extending westward from Matanuska River north of Palmer, is a gently rolling surface. In much of it the hills and valleys have a southwestward trend. In the northwestern part of the agricultural area, west and northwest of Pittman, the hills and valleys trend south-southwest. Two tracts, one between Eska and Moose Creeks and extending west of Moose Creek, and the other between Palmer and the Agricultural Experiment Station, are characterized by irregular hills and swales and conspicuous ridges. Local relief in these tracts is as great as 150 feet. A conspicuous belt of hills which rise 50 to 150 feet above the surrounding country extends southwestward past Pittman. A group of similar hills borders Big Lake on the south and is continuous topographically with an arcuate north-south band of hills whichlies to the west of the agricultural area.

Palmer is situated on a wide bench. Other benches lie east of Matanuska River south of Wolverine Creek, between

Knik and Matanuska Rivers, and along part of the top of the bluff overlooking Knik Arm. Smaller benches north of Palmer and throughout the rolling country to the west are locally conspicuous. The rolling country and benches north of Knik Arm are separated from it, and from the low-lying flat ground near it, by a conspicuous bluff 50 feet or more high; this bluff extends from Goose Bay eastward and is continuous with the bluff along Matanuska River.

Most of the drainage of the agricultural area is controlled by Matanuska and Knik Rivers, but several small streams flow directly into Knik Arm. Little Susitna River drains part of the northern section of the area. The drainage in many interstream areas is poor because of the irregular topography and the vegetative cover. There are large areas of swampy ground, and shallow lakes occupy many of the hollows. The oriented lakes west of Pittman and the two southwestward-trending series of lakes near Wasilla are among the prominent features of the valley floor.

Knik River is in flood annually in July or August when Lake George, impounded by Knik Glacier, is drained as a result of its overflow and the resulting erosion of the ice along one edge of the glacier.

Vegetation

In its natural state most of the area described by this thesis was forested. White spruce, aspen, cottonwood, and birch are characteristic of the better-drained soils. Willow is found on all types of deposits. Black spruce is common only in bogs. Alder is common both in moist spots on the lowland and, with willows, on the mountainsslopes bordering the valley. The altitude of tree line depends upon exposure; locally it is above 2,000 feet. The middle slopes of the mountains flanking the valley bear a cover of moss and low or prostrate shrubs; near the summits there is no vegetative cover.

Fire, probably in part natural but largely accompanying settlement and railroad construction, has burned over many parts of the valley floor. Extensive burned areas are now covered by second growth.

The ground cover in the forest consists of shrubs, herbs, grasses, and other small plants. Mosses and grasses are characteristic of poorly drained areas. Fireweed is the commonest plant on newly burned land.

The flats along Knik Arm are, or recently have been, subject to tidal flooding; over most of their surface they bear only small salt-tolerant plants. The wide flood plains of Matanuska and Knik Rivers are practically bare of vegetation because at some time during every season or two the gravel bars either are submerged or are removed and rebuilt during the channel-shifting that accompanies flooding.

Culture

Palmer, with a population of about 800, is the chief community of the agricultural area. Wasilla is much smaller, and Matanuska and Knik are largely abandoned. The farm population, 2,000 to 3,000 persons, is distributed chiefly around Palmer. Development of agriculture has continued here since establishment of the agricultural colony. Dairying and vegetable growing are the most important types of farming. The history of the agricultural colony is the subject of a recent study by Stone (1950).

MESOZOIC AND TERTIARY ROCKS

The nature of the bedrock underlying the greater part of the Matanuska Valley agricultural area is unknown. The writer estimates that it is exposed at the surface in less than 1 percent of the area; elsewhere the bedrock is covered by unconsolidated deposits whose thickness is known at relatively few places. Exposures of bedrock are indicated on plate 2.

The bedrock exposed in and adjacent to the agricultural area has been described by Martin and Katz (1912), Landes (1927), and Capps (1940). The Talkeetna Mountains, to the north, are composed largely of igneous rocks. Granitic intrusive rock (Mesozoic?) predominates, and lava and tuff are present to a lesser extent. A belt of Cretaceous and Tertiary sedimentary rocks forms the south flank of the mountains.

Mesozoic rocks in the Chugach Range, to the south, include granitic intrusives, metamorphosed sedimentary rocks (chiefly graywacke, slate, and argillite), and greenstone.

Cretaceous sedimentary rocks extend down the Matanuska Valley to Moose Creek and possibly to the Matanuska River highway bridge; they are sandstone (including graywacke) and shale. Conglomerate and sandstone (graywacke) exposed in small hills south of Palmer may be the southwestward extension of these rocks. Tertiary conglomerate, sandstone, shale and coal are exposed in the Eska Creek-Wishbone Hill-Moose Creek area. Tertiary coal-bearing rocks also occur at Houston, just beyond the northwestern corner of the area described in this thesis.

Martin and Katz (1912, pp. 72-75, pls. 15, 16) describe the straight front of the Talkeetna Mountains as a zone of faulting; they believe that the course of Little Susitna River is approximately along the fault, downstream from the point where the stream emerges from the mountains. Recent work by F. F. Barnes, of the U. S. Geological Survey, shows the presence of coal-bearing Tertiary rocks north of Little Susitna River; this, with other evidence, suggests that the mountain front rather than the streamcourse marks the western extension of the fault (Barnes, F. F., personal communication, 1952). Martin and Katz (1912, p. 74) also suggest that the relatively straight front of the Chugach Range, to the south, may be due to faulting, but find that there is not enough information to permit a definite conclusion. Exposures along Matanuska River and along Moose and Wolverine Creeks show that the folded sedimentary rocks strike northeastward and are faulted. The available information is insufficient to permit conclusions regarding the structure of the sedimentary rocks underlying the valley floor to the west, or their depth of burial beneath the overlying unconsolidated deposits.

QUATERNARY DEPOSITS

Unconsolidated deposits of both glacial and nonglacial origin form the valley floor in most of the area described in this thesis. The glacial deposits consist of till, glaciofluvial gravel and sand, and fluvio-estuarine deposits. The nonglacial deposits include wind-blown material, frost-disturbed deposits, talus, and alluvial fans.

It has not been determined whether the existing Matanuska and Knik Glaciers are remnants of the more extensive Pleistocene ice tongues from which most of the glacial deposits in this area originated. Separation of the Pleistocene and Recent Epochs in this area is therefore not possible. In this thesis all unconsolidated materials overlying bedrock are designated simply Quaternary deposits.

The surficial geology map (pl. 2) shows the distribution of unconsolidated deposits exclusive of swamp deposits and the mantle of wind-blown material. The distribution of eolian deposits is shown by figure 16.

Glacial Deposits

Till

Till in the Matanuska Valley agricultural area is commonly gray or blue-gray. It is composed of angular to rounded stones in a matrix that is chiefly mixed sand and silt. The stones, some of which are striated, range from granules to boulders. Figure 1 (p. 16) shows the grain-size distribution of the fragments smaller than 2 mm. in diameter in 3 samples. The poor sorting of the till is shown by the spread of the frequen[illegible]rves over a wide range of size fractions. One sample (2J) from beyond the limits of the agricultural area is included because it is typical of much of the till found near the walls of the valley. This sample contains many angular fragments of schist, of sand size or larger. It has not been as finely comminuted as the till seen in most exposures on the valley floor; this may be due to shorter distance of transport of the debris now plastered against the valley walls.

The writer made no attempt to study the lithology of the till in detail. The stones in it consist of greenstone, graywacke, slate, schist, and felsic intrusive rocks characteristic of the adjacent mountains, and of the sedimentary rocks exposed in the Matanuska Valley.

Silt-rich till is compact and tough. It is difficult to excavate, and is known locally as "hardpan".

Approximately horizontal zones containing more stones,

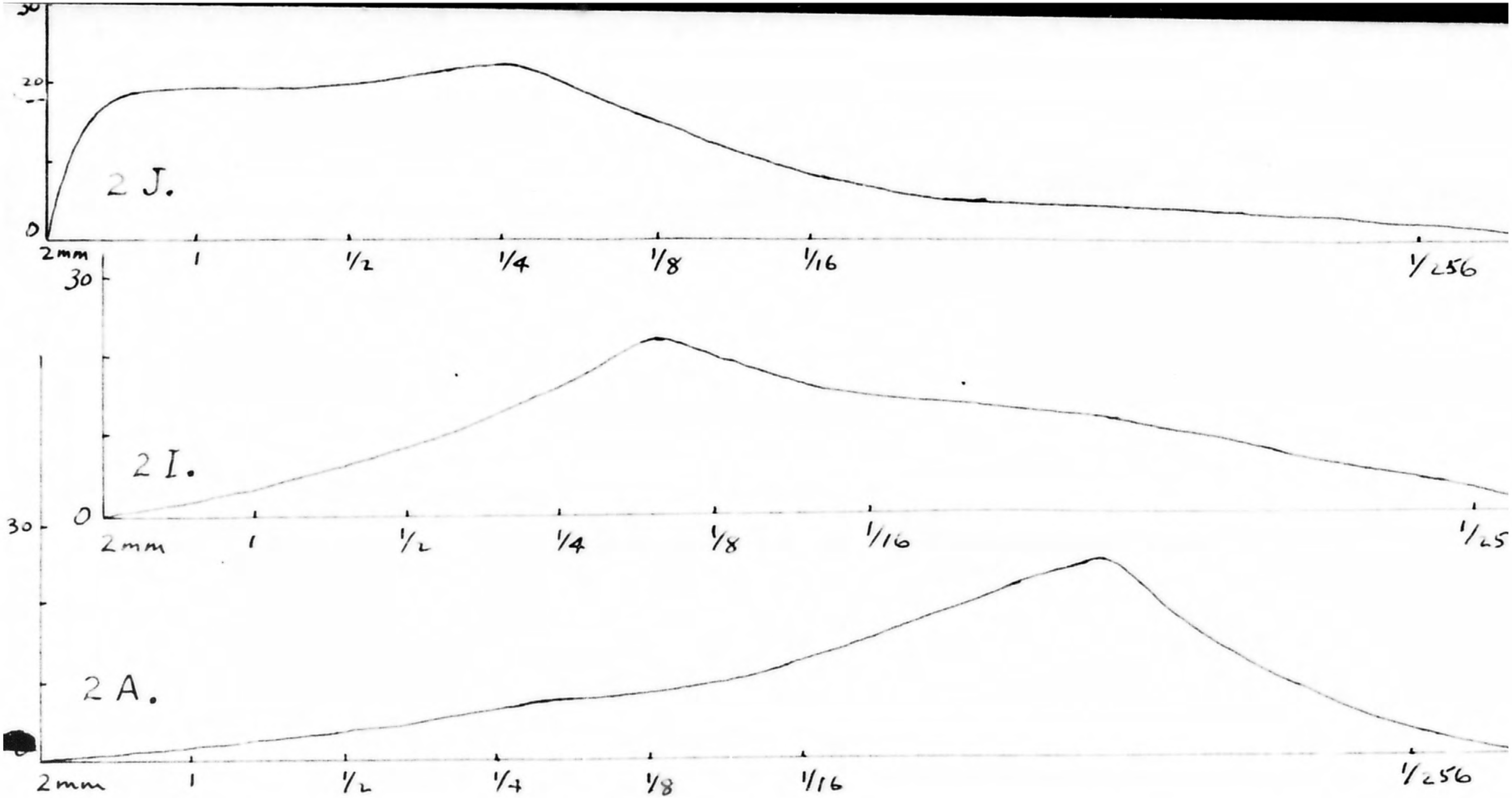
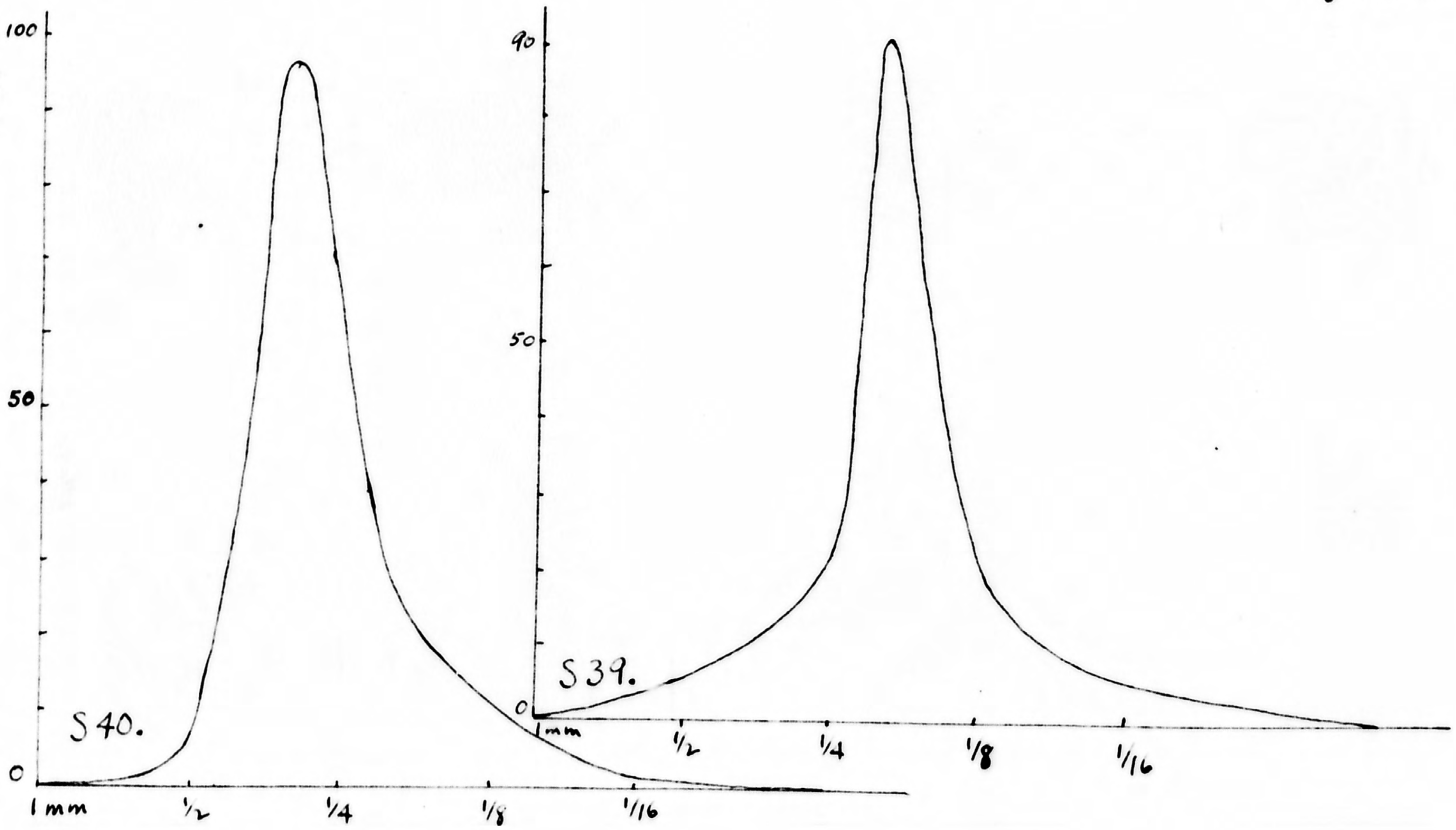

2 J.
20
0
2mm
1
1/2
1/4
1/8
1/16
1/256
30
2 I.
0
2mm
1
1/2
1/4
1/8
1/16
30
2 A.
2mm
1
1/2
1/4
1/8
1/16
1/256

Figure 1.



SAND LAYERS IN TILL.

(in pocket)

Figure 1. - Frequency curves of till (exclusive of fragments greater than 2 mm.) and of sand from a layer in till.

2J. Till from cut along highway 7 miles west of Knik River highway bridge.
2I. Till from road cut on Hornung farm, about 2 miles west of Matanuska.
2A. Till from railroad cut along Matanuska River about 1 mile north of Palmer.
S39. Sand from layer in till, exposed in the east bluff of Matanuska River about one-half mile north of the highway bridge.
S40. Sand, as in S39.

sand, or silt than the underlying and overlying till may be observed in some exposures. These zones are commonly a few feet thick and may extend laterally a hundred feet or more in well-exposed sections. The zones are interpreted as fabric developed during déposition of the till.

Fractures cutting till may be traced a few tens of feet in some exposures. In the bluff above the river one mile north of Palmer such fractures have an apparent dip of approximately 40° up-valley; the walls of these fractures are separated by 3 to 5 inches of sand and silt laminated parallel to the walls. The orientation of the fractures suggests that they are thrust faults, but this interpretation is difficult to reconcile with the fact that laminated sand and silt occur between the walls of the fractures. They are more reasonably explained as tension fractures filled with sorted sediment by percolating water.

The fractures and the fabric zones consisting of sandy till may be recognized in dry weather because they remain more damp at the surface than adjacent silty till. Exposures of till are too limited to permit conclusions regarding the occurrence of these fabric zones and fr ctures in the agricultural area as a whole.

In some exposures layers of sand or gravel, commonly a few inches to a foot or two thick, occur within massive till. Most of these layers the writer has seen are composed of medium to rse sand or sandy pebble-gravel; they appear to constitute relatively narrow stringers inclosed in compact till. Some of the layers show sharp changes in grain-size and thickness over short distances, but at any one spot the material is well sorted. Frequency curves of samples from one layer, given by figure 1 (p. 16), display better sorting than that of most other sediments studied by the writer.

Sandy and gravelly streaks in till also have been encountered in many wells in the agricultural area. These layers of sorted sediment appear to be similar to lenses and stringers of imperfectly sorted material found in till in the United States (Meinzer, 1923, p. 285). The writer believes that these deposits were laid down by small subglacial streams that flowed temporarily upon till beneath the ice before being covered by additional till from the overlying ice. The good sorting of the material may be due to deposition from confined water flowing under hydrostatic pressure. Evidence from outcrops and wells suggests that these layers are narrow and of limited and irregular areal extent.

In a few exposures slightly sorted material which resembles till may be observed resting upon massive till. The till-like material shows neither the bedding nor the sorting of outwash gravel. The best exposure seen by the writer is in a gravel pit on the lower slope of Lazy Mountain, about half a mile northeast of the Matanuska River highway bridge. There the slightly sorted material rests upon the underlying massive till along an irregular but distinct surface. This slightly sorted material is best explained as superglacial till: it probably is composed of debris that lay upon the surface of the ice and became slightly sorted before being let down upon the massive till beneath as the ice melted. Exposures in the agricultural area are not sufficiently numerous or extensive to show the areal importance of superglacial till.

The till of the Matanuska Valley agricultural area is relatively impermeable. Only the layers of sorted material yield water freely, and these in small quantities. Poor surface drainage is characteristic of many tracts underlain by till; marshes are common, even on higher ground. Some lakes, including Lake Wasilla, appear to rest upon till. Contact springs are present along hillsides in localities where saturated gravel lies on till.

Glaciofluvial Gravel and Sand

The outwash deposits in the agricultural area show a wide range in sorting. The mechanical composition of 4 samples is given by figure 2 (p. 20). These samples are probably representative of most of the glaciofluvial deposits of the agricultural area. Some stream-laid deposits are so poorly sorted, however, that they resemble till. The other extreme of sorting is represented by openwork gravel composed of pebbles or cobbles of approximately equal size and without

(in pocket)

Figure 2. - Frequency curves of glaciofluvial sediments.

S27. Fine fraction of gravel (less than 2 mm.) from road cut three-fifths of a mile east of Wasilla.

S29. Sand from pit near junction of Glenn Highway and road to Buffalo Mine, about 5 miles northeast of Palmer.

S1. Sand from floodplain of Matanuska River at the highway bridge, about 2 miles east of Palmer.

2F. Silt, as in S1.

interstitial finer materials.

The stones in the gravel represent all the rock types found in the Matanuska Valley and in the surrounding mountains, although weak sedimentary and metamorphic rocks are less common than massive igneous and metamorphic rocks. The sand consists predominantly of grains of quartz and dark minerals, together with fragments of schist and greenstone.

Bedding is well or moderately well developed in many exposures of sand and gravel, but where exposures are extensive the beds are generally seen to pinch out laterally. Cross-bedding is common, in places associated with channel-and-fill structure. Imbrication of pebbles is conspicuous in some sections. Faults are present in some exposures, particularly in thin beds of sand, and are attributed to slumping of the deposits.

Layers of silt are included in the sand and gravel. Some of these layers probably were due to the settling of silt from standing water in temporary ponds formed in cut-off stream channels. Others were deposited in ponds near the ice. Bedded and faulted sand and silt, associated with dirty gravel that contains silt boulders and is cut by sand and silt veins, are exposed in the Matanuska bluff about one mile east of Moose Creek. The deposit was laid down in a pond and later deformed, perhaps by ice-shove.

Layers of fine, relatively impermeable material occur in the bottoms of depressions (ice-block holes) on the

Holtet property, near the Matanuska bluff about 4 miles north of Palmer. Here the fine-grained material rests on the underlying gravel and in turn underlies eolian silty sand. These layers are absent on hills between the depressions. They are interpreted as being either deposits formed in ponds which occupied the depressions during melting of the ice, or the residue of fine debris left by the melting of the blocks of ice which were buried or partly buried in the gravel.

Layers of till are also present locally in gravel. Such a layer lies beneath part of Wasilla, where it was penetrated by a number of wells. There the till layer has an extent of 1 to 2 acres; it is as much as several feet thick, and lies about 15 feet beneath the land surface.

Gravel exposed in the bluff at Goose Bay contains a bed of peat that is as much as 3 feet thick in some places.

The glaciofluvial materials in the agricultural area are permeable. Where the land surface is underlain by sand and gravel it is generally well drained except where till is at shallow depth. Most of the wells in the agricultural area obtain their water from sand and gravel.

Fluvio-Estuarine Deposits

Along and in Knik Arm glacial silt brought into brackish water by Matanuska and Knik Rivers has been and is being deposited as bars, mudflats, and beaches.

Nonglacial Deposits

Eolian Deposits

Eolian deposits in the Matanuska Valley agricultural area consist chiefly of silt and sandy silt (loess); sand is present locally, generally in dunes. The frequency curves in figure 3 (p. 24) show the excellent sorting characteristic of wind-deposited material.

Samples of eolian sand and silt examined under the microscope consist chiefly of quartz grains which, except for the larger ones, are fresh and angular. Chips of dark rock are included among the sand grains. In many sections the lowermost part of the loess contains pebbles andcobbles apparently derived from the underlying glacial material.

Thin layers of pinkish-white or gray volcanic ash occur in the eolian sand and silt.

Stratification of the eolian deposits is poorly shown except where ash layers, zones of woody debris or of humus, or alternating sandy and silty streaks are present. The dunes are made up of inclined beds. Some of the sand and all the loess is bedded parallel to the land surface. The vertical jointing characteristic of loess in many classic areas is developed here only in thick sections of silty sand near the Matanuska bluff north of Palmer.

The eolian deposits of the Matanuska Valley agricultural area are relatively permeable.

(in pocket)

Figure 3. - Frequency curves of eolian sand and silt.

S31. Sand from cliff-head dune on the west bluff of Matanuska River about 2 miles north of Palmer.
S2. Sand, as in S31.
S24. Sediment from snow dune beside Matanuska River about 3 miles southwest of Moose Creek (1950).
1J. Volcanic ash from layer in silt, exposed in road cut in terrace at the west end of Bodenburg Butte.
S45. Silty sand from horizontal bed beneath cliff-head dune; locality as in S31.
O. Silt (loess) from road cut along Glenn Highway on Eckert farm, at northern edge of Palmer.

Slope Deposits

In this area slope deposits are unimportant except along the mountain walls of the valley.

A mantle of angular rock fragments and interstitial fine material covers much of the upper part of Lazy Mountain. The material differs from sandy till in the angular and weathered character of its fragments and in its lack of compaction. The fragments are sandstone, which forms the bedrock higher on the mountain. The mantle deposit is attributed to breaking and transport of rock by frost. Similar deposits formed from underlying unconsolidated materials have been recognized at a few localities on the valley floor.

Talus, composed of angular rock fragments of a wide range of sizes, is present beneath rock cliffs along part of the eastern and southern sides of the valley. It is best developed beneath Pioneer Peak.

Both talus and the frost-disturbed material on Lazy Mountain are relatively permeable.

Deposits of poorly sorted material transported by slumping, rainwash, or mudflow are present locally beneath bluffs cut in unconsolidated material. These deposits are generally relatively impermeable.

Alluvial Fans

Several small alluvial fans are present west and south of Lazy Mountain. They are composed of poorly sorted sand and gravel. Irregular bedding, with channel cut-and-fill structure, is exposed at one locality. These deposits are relatively permeable.

Nonglacial Lake and Stream Deposits

Deposits of reworked gravel, sand, and silt occur along the channels of existing nonglacial streams. Many of the lakes on the valley floor are being filled by the deposition of peat in the water near shore. Peat is also being deposited in poorly drained tracts throughout the area. Deposits of calcareous marl, reported (Irwin, D. L., personal communication, 1949) to be formed by the plant _Chara_, are present in many lakes. Isolated clam shells may be seen on the bottoms of some of the lakes.

GEOMORPHOLOGY

Landforms due to Glacial Erosion

Glacial erosion of the valley walls is best shown on Pioneer Peak, just beyond the limit of the area mapped in plate 2; there facets formed by the truncation of preglacial spurs are conspicuous. On two spurs, about one-half and one mile west of the Knik River bridge, facets reach an altitude of about 2,500 feet. The lower parts of the facets, below an altitude of about 1,600 feet, are somewhat more steeply inclined. The upper part of the facet one mile west of the bridge is a series of subparallel, steeply inclined surfaces rising one above and behind another (fig. 4, p. 28). The higher, steplike facets cannot be explained by simple glacial erosion. All the facets strike about N60°E. Of nine joints observed in an outcrop at the bridge, six strike northeast, five of them between N45°E and N75°E. The writer believes that glacial erosion of this mountain wall was in part joint-controlled; the truncated spurs that stood higher than the upper surface of the ice during the last glaciation (and which may have been inherited from an older glaciation) were eroded back by joint-controlled frost-wedging. According to this interpretation the steplike facets are not due directly to glacial erosion. Because their lowest extent is difficult to estimate neither they nor the lower facets give reliable evidence of the thickness of the last ice that occupied the valley.

The small bedrock hills on the valley floor (pl. 2) are smooth and rounded, and undoubtedly were shaped by glacial erosion. On Bodenburg Butte, which rises nearly 800 feet above the valley floor southeast of Palmer, polished and striated rock surfaces are exposed near the summit. The striae trend westward.

Figure 4. - Truncated spurs on Pioneer Peak; view toward south, from Bodenburg Butte.

Figure 5. - Till-cored crevasse filling 1-1/2 miles west of Pittman.

Landforms due to Glacial Deposition

Ground Moraine

Ground moraine forms the land surface in much of the western half of the Matanuska Valley agricultural area; it is predominantly till but sand and gravel mantle its surface locally. West of the Wasilla-Fishhook road and north of the Wasilla-Knik road the ground moraine is interrupted only by outwash drainage channels and restricted areas of other glacial features. Farther to the east and south comparable ground moraine is presumably represented by the till that is exposed in a few localities or that is known to lie beneath the gravel deposits which form the land surface. In general the topography of the ground moraine consists of rolling hills and valleys having a relief of 100 feet or less. However, two contrasting types of topography are present. The first of these is characterized by a systematic orientation of its features; the second shows little regularity in the pattern of its surface.

In the ground moraine west of Pittman and Railroad Lake and north of a line between Pittman and Big Lake, elongate subparallel hills and valleys trend south-southwest (pl. 2). This orientation is made more conspicuous by the presence of elongate lakes or marshes in most of the valleys. Local relief within this tract may be as much as 100 feet but is commonly 50 feet or less. Each large elongate hill consists of alternating low knolls and saddles; adjacent lakes or marshes within a single elongate valley are separated by slightly higher ground.

The elongate hills are composed of till which is locally mantled by gravel. The elongate valleys are underlain by gravel. Low gaps cut in some of the saddles on the hills are also floored by gravel; these gaps lie at higher levels than the adjacent valleys. Bedded deposits flank some of the hillsides. Such a deposit is exposed in a gravel pit beside the railroad about 4-1/2 miles southeast of Houston, or two-fifths of a mile west of BM 253 (pl. 2). Here, on the southeast side of a hill, horizontal beds of gravel containing numerous striated boulders end abruptly in the hillside overlooking the valley to the east.

Within this tract west and northwest of Pittman the ground moraine exhibits a micro-relief formed by many small ridges (fig. 5, p. 28; fig. 6, p. 31) which rise from the surface of the till and locally protrude through any surficial gravel which may be present. They commonly are 5 to 10 feet high. They may be straight in plan or sinuous; they may branch, bend, or intersect. Some of them are interrupted by gaps, beyond which they continue in the same direction or at an angle. They commonly trend across the direction of glacial movement. The crests of the ridges are rounded and, along their strike, gently rolling.

(in pocket)

Figure 6. Maps of till crevasse fillings.

Figure 7. - Oblique aerial photograph showing hilly belt near Pittman, and ground moraine with oriented lakes to the northwest; view toward the northwest, from an altitude of about 700 feet. The lakes are ice-covered.

Figure 8. - Oblique aerial photograph showing ground moraine with oriented lakes and marshes west of Pittman; view looking southeast, toward Knik Arm and the Chugach Range, from an altitude of about 700 feet.

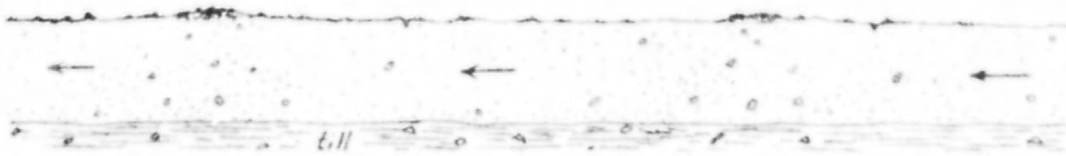
Where exposures are available the larger ridges may be seen to have a core of till and a mantle of sandy gravel. Such a section is well shown in the railroad cut (fig. 5, p. 28) and gravel pit about 1-1/2 miles west of Pittman. The core of this ridge consists of massive silty till with subordinate, discontinuous sandy and pebbly streaks of irregular attitude. Many of the smaller ridges consist of till without a cover of washed material.

Some of the ridges not only are mantled by gravel but are surrounded and even in part covered by gravel fill. At the gravel pit 1-1/2 miles west of Pittman ridges at least 20 feet high are completely buried by horizontally bedded cobble-and boulder-gravel. At locality B (fig. 6, p. 31) some of the small ridges are partly buried by gravel. Here some of the ridges trend more or less parallel to the contour of a gently sloping hillside; locally the inter-ridge fill is just sufficient to give the hillside a steplike form. Some of the fill here consists of openwork cobble-gravel.

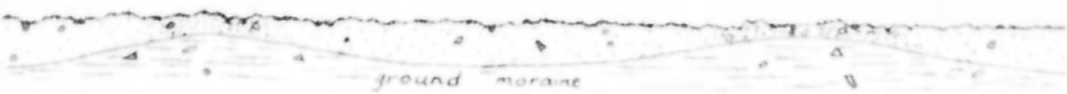
At the lake north of the railroad 3 miles southeast of Houston (pl. 2) till ridges extend down a hillside and across a peat-filled former part of the lake to end abruptly at the present shore (fig. 6, locality A, p. 31). A pavement of lag cobbles on the lake bottom at the end of each ridge shows that it once extended farther into the lake.

The writer saw no evidence that these ridges are other than depositional; he believes they are most plausibly explained as crevasse fillings. He visualizes their formation by a sequence such as follows. Glacial stagnation in the Pittman-Houston area was accompanied by the formation of crevasses that extended through the brittle ice to the underlying surface. Debris accumulated in the crevasses by slumping from the upper edges of the walls and by the melting of debris-laden blocks of ice that fell from the walls. Some of the crevasses remained relatively short. Others, though longer, did not contain through-flowing streams until after considerable material had accumulated in them. With continued melting of the ice mass some of the crevasses joined and were occupied by meltwater streams. Further melting left the crevasse fillings standing as ridges. Meltwater drainage shifted to newly-exposed ground moraine, but was confined by the ridges and by decaying ice blocks. Gravel fill was deposited between and even over some of the ridges. Locally the meltwater streams were sufficiently competent to leave openwork gravel in their channels. This suggested sequence of events is illustrated by figure 9, A-D (p. 35).

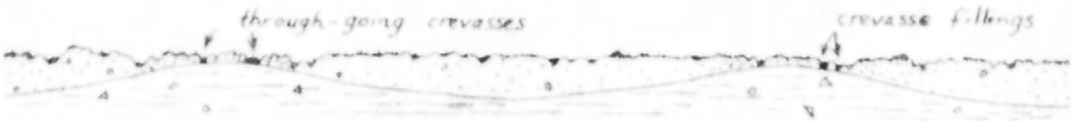
The elongate valleys in the ground moraine are most reasonably explained as the depressions left by melting of the last remaining blocks of ice. Till ridges extending into a lake basin (p. 33), and horizontally bedded gravel



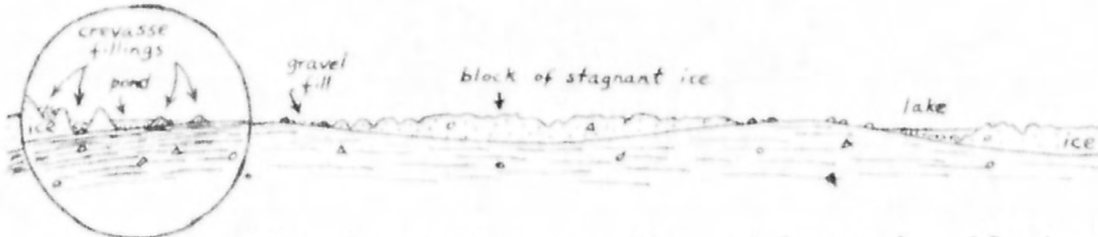
A. Active ice in which debris is concentrated largely in parallel zones extending across the direction of ice movement.



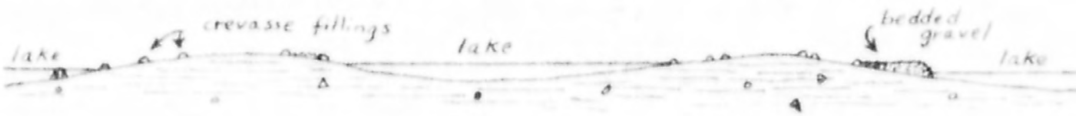
B. Stagnation of the ice, and formation of the major topography on the ground moraine.



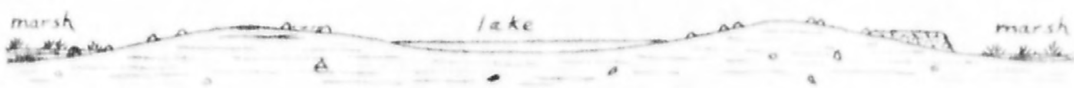
C. Formation of through-going crevasses in the wasting ice, and of crevasse fillings.



D. Complete separation of large ice blocks; formation of stream and lake deposits.between crevasse fillings and along edges of large ice block^-.



E. Complete deglaciation.



F. Present-day landscape.

Figure 9. - Suggested sequence of development of ground moraine west and northwest of Pittman.

terminating beside and above another valley (p. 30), substantiate this conclusion. The separation of the ice blocks, as part of the hypothesis already described, is illustrated by figure 9, C-D (p. 35).

The topography of the ground moraine in this tract west and northwest of Pittman has been described as consisting of elongate, alternating, subparallel hills and valleys whose trend is at a high angle to the direction of glacial movement. Small ridges on the hills are readily explained by the influence of stagnant ice upon deposition, but no such explanation can account for the larger features, the hills and valleys. The writer believes that the major topography here was formed after advance of the ice had ceased but before the formation of through-going crevasses; and that the topography was formed by the deposition of debris beneath melting stagnant ice in which the load had been concentrated in subparallel zones. The suggested sequence of development is shown by figure 9. The debris-rich zones in the ice may have been folded medial moraines such as may be seen on the Malaspina (Washburn, 1935) and Bering Glaciers along the Gulf of Alaska. In summary, the writer concluded that the manner in which the stagnant ice melted was due in large part to the form of the underlying depositional topography, which in turn had been determined by the distribution of rock debris in the stagnant ice.

Accretion of till beneath moving ice, a process accepted as commonplace in the study of glacial deposits, requires the melting of ice at the base of the glacier. Such melting may be explained by the pressure of the overlying ice or by the heat of friction caused by its movement (Holmes, 1952, p. 1004). It seems likely that two factors may affect melting of the basal ice of a stagnant glacier: the transmittal downward of atmospheric heat by meltwater descending through the ice (Thwaites, 1950, p. 17), and the upward flow of earth heat from beneath the glacier. The glacier which lay in the Matanuska Valley probably was a temperate glacier, in the terminology of Ahlmann (1948, p. 66; older references not seen); that is, throughout the glacier the temperature was that of the melting point of the ice, except for a relatively thin layer at the surface in winter. Under such temperature conditions heat introduced into the glacier would be available for melting ice, rather than being transmitted through it. It is difficult to assess the relative importance of the two sources of heat suggested with regard to the basal ice. It seems likely, however, that percolation of water from the surface of the glacier would have been important only during later stages of stagnation, after openings had been formed. Earth heat may therefore have been of greater relative importance during earlier stages of stagnation.

Although earth heat escaping at the ground surface is sufficient to melt only a fraction of an inch of ice per year, its effect on overlying ice might be appreciable over a long time. Included rock debris would be in temperature equilibrium with the surrounding ice, and heat received by ice-and-debris at 32°F. would be expended in melting ice rather than in changing the temperature of the debris. It would seem, therefore, that under conditions of uniform heat flow debris-laden ice would undergo more rapid melting per unit volume than relatively clean ice. This assumption has been made in figure 9, B (p. 35), which presents the writer's explanation of the differential topography formed beneath the stagnant ice.

Ground moraine which lacks this conspicuous orientation of relief features is exposed in several areas extending southwestward from the vicinity of Wasilla to Goose Bay (pl. 2).

This ground moraine is composed of broad irregular hills separated by a few flat-floored outwash channels and many smaller valleys and irregular depressions. The larger features have a general southwestward trend; the smaller features are not conspicuously oriented.

The moraine consists of till but in many places its surface is mantled by gravel deposits; most of these were probably laid down by meltwater streams, although some may have been let down from melting ice. It is possible that thin estuarine deposits occupy some of the depressions in the ground moraine near Goose Bay. Many erratic boulders lie upon the surface of the moraine. Locally there are sinuous ridges up to about 1 mile long and 30 feet high. Several such ridges 1 to 1-1/2 miles northwest of Wasilla, and two smaller ones near the highway about 3 miles west of Wasilla, appear to be eskers. One ridge, three-fifths of a mile west of the road about 5 miles northeast of Wasilla is composed, at least in part, of till. Inconspicuous gravel ridges up to 5 feet high and several hundred feet long lie on ground moraine north of the highway about 5 miles northeast of Wasilla. These ridges are parallel and trend northwest. All of the ridges were probably formed in tunnels or crevasses in the ice; the single till ridge must have been formed in a crevasse, in the manner already postulated for ridges near Pittman.

Along the edges of some of the valleys in the ground moraine the moraine is indented by terraces that are underlain by gravel. About three-quarters of a mile northwest of Wasilla there is a series of channel scrolls cut into the edge of the moraine above Lake Lucile. Some of the channel scrolls may have been cut by subglacial streams, but one, a well developed loop (pl. 2), was more probably cut by a stream from the south or east, flowing over what is now the valley.

The larger valleys extending across the ground moraine are floored by gravel deposits that are described in the next section of this thesis. Till is known to be at or near the surface beside some of these valleys, as, for example, on the shores of Lake Wasilla (fig. 10, p. 41); till probably underlies the valleys at shallow depth. One of the eskers 3 miles west of Wasilla crosses a low hill that stands only slightly higher than the valley floor at Lucile Creek. Three-fifths of a mile east of Wasilla horizontally bedded sand and gravel is exposed 40 feet above the shore (summer, 1951) of Lake Wasilla. It is evident that the valley whose axis passes through Wasilla was formed by the uncovering of a depression beneath the ice rather than by erosion, and that the lake basins in it were occupied by the last remaining blocks of decaying ice. Meltwater streams flowing along the edges of these ice masses laid down kame-terrace deposits. The ice-block origin of the [redacted] basins is substantiated not only by the bedded deposits and channel scrolls already described but by the pattern of spits in Lake Wasilla and other lakes to the east (pl. 2).

The other large lake basins north and northeast of Wasilla are also most reasonably explained as ice-block holes. Many smaller depressions in the ground moraine are probably also of this origin. Some of these smaller depressions are floored by openwork cobble-gravel which

Figure 10. - Sketch map and section in glacial drift at and near Lake Wasilla.

must have been deposited by meltwater streams of considerable volume.

It is possible that the form of the land surface in the area described in the preceding paragraphs may be explained by an extension of the hypothesis used in explaining the ground moraine near Pittman. The hilly areas near Wasilla trend in the direction of glacial movement, however, and with lack of additional evidence they are as readily explained by deposition beneath moving ice.

End Moraine

Hills of till south of Big Lake are continuous to the west with an arcuate band of hills that extends from the vicinity of Willow and Nancy, northwest of Houston, to Knik Arm near Goose Bay (pl. 2). On the basis of aerial photographs, Thor N. V. Karlstrom of the U. S. Geological Survey (personal communication, 1949) interprets this belt of hills as the end moraine of the last glacier which lay over the agricultural area. The writer believes this interpretation to be correct. The arcuate hilly belt is offset to the east, south of Big Lake, and it is possible that two end moraines of slightly different age are present north and south of the lake.

Medial Moraine

Hills of till near Bladgett Lake, southwest of Pittman, rise as much as 150 feet above the surrounding country. These hills are part of the narrow hilly belt that extends southwestward toward Big Lake. Other hills in this belt are of gravel, at least near the surface, and associated with them are pitted and ice-channel deposits. The hills of till may have been continuous with hills on ground moraine northwest of Jacobsen Lake (pl. 2). The hilly belt extending southwest of Pittman may in part represent a medial moraine which grades into ground moraine to the east.

Lateral Moraine

A bench on the slope of Lazy Mountain is interpreted as a lateral moraine deposited along the contact between glacier and valley wall. Gullies cutting the bench expose till resting on bedrock. This bench lies between 1,700 and 2,100 feet above sea level. Two miles north of Palmer the upper surface of the till deposited beneath the same glacier is at an altitude of about 300 to 400 feet. The thickness of the ice over this part of the valley may therefore have been of the order of 1,600 feet. A discontinuous bench (not mapped in pl. 2) which appears essentially similar to that on Lazy Mountain extends along the slope of the Talkeetna Mountains westward from Moose Creek and beyond the canyon of Little Susitna River. Over a distance of 6 miles it slopes westward from an altitude of about 2,500 feet to about 2,000 feet, or about 80 feet per mile.

Glaciofluvial Landforms

Glaciofluvial gravel and sand cover a large part of the valley floor. Meltwater streams have been the principal agents responsible for the formation of all these deposits; where the deposits were associated with ice, however, melting of the ice so modified them that in some localities their fluviatile nature is obscured.

The distinction between proglacial and ice-contact features (Flint, 1947, p. 33) may be applied to many of the deposits described in this thesis. The younger deposits, laid down some distance in front of the ice after deglaciation in the agricultural area, are truly proglacial. Older deposits formed before deglaciation was complete range from those profoundly modified by the melting of buried ice to those not modified at all; some individual features are pitted in one locality and not in another. The distinction between proglacial and ice-contact deposits is followed in the paragraphs below as an aid in description, and it is mentioned in the legend of the geologic map (pl. 2). The difficulty of classifying some of the features, however, makes advisable the use of glaciofluvial map units chosen on another basis.

Proglacial Deposits

The modern proglacial deposits are being formed downstream from the existing Matanuska and Knik Glaciers. Water and sediment in these streams are derived chiefly from the glaciers except during the period of snow melt in the spring. Stream flow decreases markedly in winter, and very little suspended sediment is then carried.

The alluvial plain of Matanuska River is about 55 miles long; over this distance its gradient is about 29 feet per mile. Within the agricultural area the plain is up to 1-1/4 miles wide in places where its valley walls are of unconsolidated material; the gradient there is 21 feet per mile. The alluvial plain of Knik River is about 25 miles long and up to 2-1/2 miles wide; its gradient is about 10 feet per mile.

The surface of such an alluvial plain is nearly flat; during low-water stages its local relief is commonly 5 to 10 feet or less. It consists of many braided channels separated by low, flat-topped bars of interbedded sandy gravel and sand. Silt is generally subordinate except in abandoned channels where it has settled from standing water after flooding.

The thickness of the alluvial-plain deposits of the modern streams is not known. Channel measurements made by the Geological Survey show the depth of scour at the Matanuska River highway bridge during high water to be at least 23 feet. Three telephone poles were driven 19 to 21 feet into gravel beside the approach to the Knik River bridge without encountering bedrock.

Low tree-covered terraces along Matanuska River, and alluvial fans of many streams flowing into it, appear to be slightly older than the active alluvial plain. The terraces stand a few feet above the highest modern alluvial deposits; in many places they are covered by cottonwoods which may be about 100 years old. Alluvial fans such as those of Moose and Eska Creeks, also a few feet higher than the active alluvial plain, have been eroded by the river and trenched by their own streams. It is reasonable to conclude that since deposition of these low terrace and fan deposits Matanuska River has eroded its alluvial plain; it may be doing so under present conditions.

Gravel deposits in other terraces, higher than those already described but lower than the terrace on which Palmer is situated, are the remains of older proglacial alluvial plains. Such terraces include those west of Matanuska River at the highway bridge, and others east of the river between the bridge and Knik River.

The terrace upon which Palmer stands is part of a conspicuous alluvial plain that was here much more extensive than the modern Matanuska plain. The Palmer terrace is nearly flat; over most of its surface the local relief is not more than a few feet. Near Palmer several low bedrock hills rise above its surface. Immediately south and southeast of Palmer the terrace surface is nearly smooth, being marked only by shallow swales and a few low terraces that are inconspicuous on the ground. Beginning about 2 miles to the south it grades southward into pitted topography formed from the terrace by the melting of buried or partly-buried blocks of ice. Where the terrace element is dominant over the pitting the surface has been mapped as alluvial-plain deposits (pl. 2).

At the river north of Palmer the terrace is underlain by till covered by at most a few feet of gravel. Here the terrace plainly is due to erosion. A well about 1-1/4 miles south-southwest of Palmer penetrates 65 feet of gravel resting on till that appears to be the same as the till near the surface farther north. Other wells about 1-3/4 miles southeast of Palmer penetrate as much as 100 feet (one well, possibly 200 feet) of gravel. The writer believes that the presence of till near the surface north of Palmer can in part be attributed to deposition by lodgment behind hills on the bedrock floor of the valley. It is possible, in addition, that the stream, flowing through the narrow gap in the bedrock near the present highway bridge, eroded the tract south of Palmer to a level lower than that of the present terrace, that this valley was later built up by alluviation, and that the present Palmer terrace, including the part underlain at shallow depth by till, was then cut. The writer thinks this hypothesis unlikely, however.

The greater part of the Palmer terrace is free of pits and may be considered proglacial. To the south, however, it is pitted. At the time the alluvial plain south of Palmer was formed, the adjacent deposits to the west and southwest still contained stagnant ice. The presence of pits along only part of the outer edge of the terrace suggests that there they are due to encroachment of the stream upon the adjacent gravel deposits that still contained stagnant ice. The stream may have filled many of the pits in the new part of the plain as they formed, but after the plain was terraced melting of the last remaining ice left the present pits.

The alluvial plain along Wasilla Creek and that above Little Susitna River (pl. 2) are unpitted and are therefore considered proglacial. The meltwater that formed them came in large part from the northern edge of ice that lay near Moose Creek.

Alluvial-plain deposits in many of the meltwater drainage channels crossing ground moraine in the western part of the agricultural area also are largely proglacial. The deposits are pitted locally, however.

Along and in Knik Arm, glacial silt brought into brackish water by Knik and Matanuska Rivers is being deposited as beaches and bars. North of Knik Arm and west of Matanuska is a flat surface that stands 20 to 30 feet above mean sea level. This flat is underlain by tough, relatively impermeable gray silt. Streams crossing it are nearly bankfull at the average high tide (the tide range at Anchorage, farther west on Knik Arm, is of the order of 30 feet), and probably the flat is partly covered by very high tides. Farther east, near Reedy Lake, are fresh-water bogs underlain by gray silt which resembles the estuarine silt seen farther west. Stream-laid sand forms the surface of the flat at Matanuska and near the point at which Wasilla Creek enters the flat. The boundary between fluvial and fluvio-estuarine deposits is thus established only within broad limits (pl. 2).

On a similar flat at the Eklutna CAA station, south of Knik Arm, the silt ranges from 4 to more than 11 feet thick; a well about 20 feet deep passes through the silt and obtains water from underlying gravel. It is possible that the silt deposits north of the estuary are of similar thickness, but no information is available.

Bars in the modern estuary reach a level somewhat lower than that of high tide. It seems likely that this relation existed during formation of the flat north of Knik Arm, and that the flat was formed during a stand of the sea several feet higher, relative to the land surface, than that of the present. Later deposition by flooding during very high tides probably has built up the flat somewhat and smoothed irregularities in its surface. It is possible that estuarine material was deposited in some of the lower depressions in the ground moraine near Goose Bay at this time.

Ice-contact Deposits

The higher terraces, north and west of Palmer, unlike that on which the city is situated, are of dominantly ice-contact nature. Near the Matanuska bluff these terraces are fairly well preserved. Toward the west and southwest they grade into pitted topography over short distances. Over much of the country within a mile or two of Palmer the original fluviatile form of the topography can be seen in areas between pits. Farther away the topography is much less regular, although the accordance of hilltops and the presence of small, flat-topped gravel deposits show its fluviatile origin in some localities. The surficial geology map (pl. 2) shows the deposits near Matanuska River as alluvial-plain deposits; those to the west that have been modified by the melting of buried ice are mapped as pitted deposits.

Terraces near Eska Creek, and west of Lazy Mountain and south of Wolverine Creek, also show both proglacial and ice-contact features, but the proglacial features are dominant and the gravel is mapped as alluvial-plain deposits.

Some of the gravel deposits in terraces are relatively thin and rest upon till. A well on the highest of the terraces west of Lazy Mountain reached till 10 feet beneath the land surface. In several wells on the higher terraces north of Palmer, till was encountered at depths of 20 feet or less. The presence of till beneath a few feet of gravel on the Palmer terrace north of the city has been mentioned. The form of the alluvial plains that may be restored on the basis of these terraces resembles that of the valley trains figured in textbooks. It is evident, however, that the older Matanuska features, with the possible exception of part of the Palmer terrace, differ from valley trains in being due dominantly to erosion rather than to alluviation. The thin gravel deposit covering each terrace represents merely the load being shifted along the alluvial plain at the time it was trenched and abandoned by the stream.

Most of the remainder of the gravel mapped as alluvial-plain deposits (pl. 2) probably was laid down near or in association with stagnant ice.

Small kame terraces such as that south of Lake Wasilla (p. 40), and similar features north of the lake and beside Lake Lucile, are mapped as alluvial-plain deposits; they are, of course, ice-contact features. No attempt is made

(in pocket)

Figure 11. Pitted terraces near Palmer

Figure 12. - Oblique aerial photograph of terrace on which Palmer is situated. Palmer and Matanuska River are in the middle distance, Lazy Mountain in the right distance, and the Talkeetna Mountains in the distance. Note pit in lower left corner. View looking north-northeast. (Photograph used by courtesy of Alaska Agricultural Experiment Station, U. S. Dept. Agriculture.)

to differentiate them on the geologic map because they grade into other alluvial features over short distances.

In the section dealing with glacial deposits evidence was presented to show that depressions in ground moraine near Pittman, and those containing Lake [redacted] and other lakes near it, are ice-block holes. Other separate depressions and areas of irregular topography found throughout much of the agricultural area also are considered to be due to the melting of stagnant ice upon and about which gravel and sand had been deposited. Exposures in road cuts (1951) between Palmer and Four Corners show that on many hilltops horizontally bedded gravel is truncated by the sides of the adjacent closed depressions. One-half to 1 mile west of Palmer these depressions indent the level surface of one of the terraces extending southwestward from the river bluff north of Palmer. Most of the depressions west and southwest of Palmer have fairly steep sides, as do the pits on the Palmer terrace; the ice blocks to which they are due probably extended almost to the land surface or protruded above it. 1-1/2 to 3 miles north and northwest of Palmer, as well as in other parts of the agricultural area, there are extensive tracts of gently rolling and moderately irregular topography attributed to the melting of more deeply buried ice (cf. Flint, 1947, fig. 41B, p. 149).

Along the southern and southwestern edge of the tract

Figure 13. - Vertical aerial photograph of the area surrounding the Matanuska Agricultural Experiment Station; note crevasse fillings (right center), terraces (left center, lower left), and pitted deposits (lower right, upper left). (Photograph used by courtesy of Soil Conservation Service, U. S. Dept. of Agriculture.)

Figure 14. - Oblique aerial photograph showing crevasse fillings and terraces at the Matanuska Agricultural Experiment Station.

between Palmer and the Agricultural Experiment Station the ice-block holes are steep-sided, elongate, and oriented in subparallel fashion. Accordance of the tops of the hills and ridges between the depressions is conspicuous. Near the Experiment Station and northeast of it the ridges and intervening depressions are narrow, sinuous, and parallel (figs. 13, 14, p. 55). To the north and south this topography grades into the less regular, pitted topography; to the west the ridge-tops pass into level surfaces that are terraced. The local relief is as much as 150 feet. Several levels of ridges and terraces stand one below another from north to south. A quarter of a mile north of the Experiment Station a gravel pit in a ridge exposes horizontally bedded gravel and clean sand; interbedded clean sand and sandy gravel were exposed (1951) in a building excavation on the terrace just below the gravel pit. Rockie (1942, p. 365) has interpreted the parallel sinuous ridges as crevasse fillings, deposits formed in crevasses between narrow ridges of ice that later melted away. The writer believes this interpretation to be correct. The deposits in the ridges and associated terraces were probably laid down in part in standing water, in the manner described by Flint (1928).

Deposits that may be crevasse fillings lie in a small tract 3-1/4 miles northwest of Palmer. In another area about 1/3 mile northwest of Pittman, crevasse fillings are associated with pitted deposits and eskers.

Isolated ridges that probably are eskers lie on ground moraine near Wasilla (p. 39). Other ridges, composed of water-laid gravel and sand, also are mapped as eskers (pl. 2); they are in the hilly belt near Pittman, in a tract lying just east and west of Moose Creek, and in smaller tracts elsewhere in the agricultural area. Near Moose Creek they are associated with pitted deposits. In a gravel pit north of the highway 1-1/4 miles west of the stream, gravel and sand rest on poorly sorted material; the gravel and sand are well bedded but faulted and cut by sand veins, and locally dip at high angles.

Some glaciofluvial deposits were not differentiated during mapping. Most of these are in the tract north and west of Pittman, where relief is slight and there are few exposures. The writer believes it safer not to attempt differentiation of these deposits until additional field work has been done. Most of the deposits here probably are ice-contact features, however. They appear to consist chiefly of alluvial-plain deposits and fillings around ice blocks; these two types of deposits are gradational in many places here.

The wide distribution throughout the agricultural area of ice-contact features, with great numbers of pits, shows that stagnation of ice was important during deglaciation.

The features formed range from those in which gravel was deposited against blocks of ice protruding above it to those due to complete covering of the ice. Where protruding ice melted, sliding of the adjacent material occurred and slopes were formed at about the angle of repose of the material. Melting of buried ice resulted in collapse of the overlying material and the formation of depressions with gentler slopes, and of tracts of gently rolling country. Gradations between these forms are common. In special situations crevasse fillings and eskers were formed.

Together with glacial deposition, and erosion by melt-water streams, stagnation is one of the dominant morphogenic processes that have shaped the surface of the valley floor.

Stream Terraces and the Development of Drainage

The development of drainage on the valley floor during and after deglaciation was studied by reconstruction of the courses of outwash streams. The altitudes of terraces, generally determined by altimeter with bench-mark control but in a few localities from topographic maps*, were

*The maps used are the USGS Anchorage C-6, C-7, and C-8 quadrangles (1951, 1952) rather than the less accurate Corps of Engineers maps used as the base for the geologic map, plate 2 (the USGS maps could not be used for plate 2 because they cover only part of the agricultural area). The estuarine flat north of Knik Arm may be cited as an example of the difference in topography shown by the two sets of maps: the CE Matanuska quadrangle shows several hills marked by the 50-foot contour on the flat west of Matanuska; on the USGS C-7 quadrangle the highest contour here is 25 feet above sea level; field examination shows that the flat is nearly featureless and nowhere approaches an altitude of 50 feet.

---

plotted against distance downstream. The terraces and their altitudes are shown by plate 3, the corresponding profiles by plate 4.

In order to minimize errors in determining the altitudes most measurements were checked by repeating each altimeter traverse in reverse. Measurements were made only where the form of the terraces appeared not to have been modified by later erosion, pitting, or deposition. Correction for the thickness of the eolian mantle, which conforms with the topography, was not made except at a few localities where altitudes were measured upon the Matanuska bluff; elsewhere in the agricultural area the difference in thickness of the loess between localities even several miles apart is generally not more than a few feet, and is within the limits of measurement error. Nor was any correction of altitude attempted because of the distance of a terrace from the center line of its alluvial plain. Such correction could not be determined from the data at hand; moreover, the form of the active alluvial plains suggests that the older plains may have been nearly flat, and that any correction would be small.

The terraces north, west, and southwest of Palmer suggested the working hypothesis that Matanuska River once flowed southwestward past what is now Palmer, and that its course has gradually shifted southward to its present position. The stream now flows between rock walls at the highway bridge near Palmer, and between points of rock downstream, so that much of its course is relatively fixed. This present course is several miles longer than some of the older ones, however, and several miles away from some of the older terraces. It therefore seemed desirable to use two different lines of profile to which the terraces could be related. The profile lines chosen coincide from Eska Creek to a point north of Palmer (see pl. 3). Southwest of this point the idealized older course is drawn as a smooth curve that extends southwestward to and along Knik Arm; the younger course is drawn as a smooth curve along the active alluvial plain of Matanuska River. Matanuska terraces higher than that on which Palmer is situated are related to the higher line of profile; the Palmer terrace and the lower terraces downstream from the highway bridge are related to the lower, longer line of profile.

From each terrace (pl. 3) a perpendicular was drawn to the line of profile; the point of intersection was taken as the position of the terrace on the line of profile, and its distance downstream from Eska Creek, at the northeast edge of the agricultural area, was measured. Established and suggested correlations of terraces are shown on plate 4. The resulting profiles are believed to represent several of the older grade lines of Matanuska River.

Many other profiles that might be constructed from combinations of terraces in the tract north of Knik Arm and the estuarine flat would not represent old grade lines. It is evident from the terrace map (pl. 3) that many of the apparently-correlatable terraces represent different stream courses and should not be correlated. In addition there are terraces formed in association with wasting ice that do not represent extensive alluvial plains. Several hills of till, truncated by stream erosion and covered by thin gravel deposits, are indicated on the terrace map, and two are shown in figure 10 (p. 41). These terraces, and no doubt many others on hilltops and hillsides, were formed by melt-water streams that flowed across or swung against high parts of the ground moraine as they protruded through the wasting ice during deglaciation. Lower-lying till west of one hill (fig. 10) is not covered by gravel. This till appears not to have been eroded by running water; it evidently was protected by the overlying ice while the hilltop was being eroded.

Most of the large, well preserved terraces in the agricultural area are in the tract bordering Matanuska

River and Knik Arm on the north. It appears from field observations (not yet supported by altitude determinations) that small terraces in much of the remainder of the agricultural area will permit reconstruction of meltwater drainage courses. It seems likely that the most important outwash drainage was along the courses marked by conspicuous terraces along and north of Matanuska River and Knik Arm. (The remainder of the meltwater from the northern part of the valley floor probably drained southward from Big Lake to Goose Bay, inside the end moraine, and passed through the moraine along the present course of Little Susitna River.)

Old grade lines (pl. 4) have nearly the same gradient, about 19 to 22 feet per mile; it is interesting to note that the profile of the active Matanuska alluvial plain is very nearly parallel with the older, higher profiles. If the reconstruction of grade lines in plate 4 is valid, the older of these meltwater courses received much of their drainage from ice near or beyond the northeastern edge of the agricultural area. The reason for the trenching of the successive alluvial plains is not clear. Of several hypotheses advanced by Thwaites (1950, p. 50) to account for the trenching of glaciofluvialldeposits, that which seems most reasonable with reference to this area is "...change of streams from depositing to eroding due to recession of their source to a greater distance from the locality in question thus changing its position on the normal outwash stream profile" (steeper near the ice front, due to excessive alluviation; more gentle downstream, possibly with erosion of the alluvial plain which cannot be maintained at its former gradient now that the ice is no longer present to provide a high-level source of water and sediment). Use of this explanation here requires that sea level did not rise significantly during trenching. The fact that most of the terraces are pitted suggests that they were formed over a relatively short period (although the time required for the ice blocks in gravel deposits to melt is not known), perhaps short enough for sea-level rise to have been slight. A second requirement is that the chief source of the major stream was far enough up-valley that a slight decrease in the gradients of successively lower alluvial plains would not be detectable in the reconstructed profiles. Such a location of the source is considered reasonable, particularly as deglaciation may have been well advanced here at the time of formation of the higher terraces.

During deglaciation in the central part of the valley floor, wasting ice lay over much of the area near Wasilla; the last blocks of ice occupied the depressions which now hold the conspicuous lakes there. Drainage from this ice was in large part to the southwest, along its edges and beyond it. Part of the meltwater spilled over to the south at a point just east of Wasilla, joining the main Matanuska drainage. The last meltwater drainage from the Lake Lucile depression flowed west and southwest beyond the ice; the wide outwash drainage course is now occupied by small Lucile Creek. Drainage from the Lake Wasilla depression followed the southward course of what is now Cottonwood Creek.

Outwash drainage from the northern part of the Matanuska ice, and probably including water from the canyons of Moose Creek and Little Susitna River, flowed along the present course of Little Susitna River.

The writer originally considered the alluvial plain along Wasilla Creek to have been due to superposition of an outwash stream upon ice and debris, but found difficulty in explaining how a stream would have become established across the main trend of the ice and presumably across the main trend of the superglacial topography of ice and debris. Clyde Wahrhaftig (personal communication, 1952) has suggested that the course of Wasilla Creek might reasonably be explained by integration of drainage during deglaciation, possibly by the overspilling of divides as wasting ice melted away. The writer believes this interpretation correct. He lacks field data to support the hypothesis, however, and the inferred sequence of development in figure 15 (p. 65) is offered only tentatively. It appears reason-

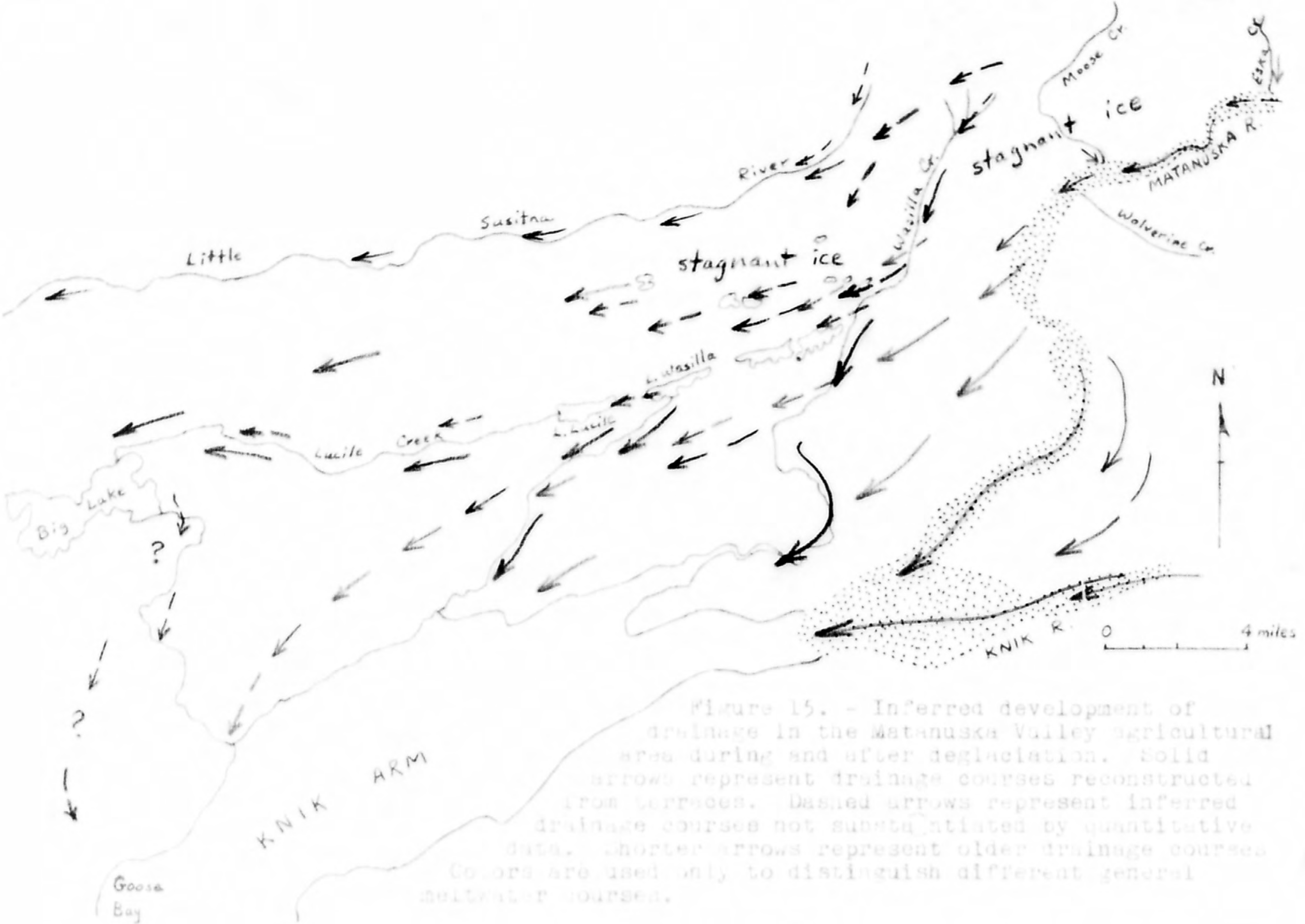


Figure 15. - Inferred development of drainage in the Matanuska Valley agricultural area during and after deglaciation. Solid arrows represent drainage courses reconstructed from terraces. Dashed arrows represent inferred drainage courses not substantiated by quantitative data. Shorter arrows represent older drainage courses. Colors are used only to distinguish different general meltwater courses.

able to conclude, nonetheless, that southward shifting of drainage, such as that at Lake Wasilla and that inferred in the development of the Wasilla Creek plain, was an important factor in the development of drainage during deglaciation.

The end moraine that lies west of the agricultural area is breached near Anchorage, southwest of Goose Bay (see pl. 1), and the gap is occupied by Knik Arm. It appears likely that this gap has existed since an early stage in the deglaciation. Certainly it was present during later stages, when wide alluvial plains were formed along what is now Knik Arm, and much of the meltwater from wasting ice on the valley floor passed through it.

A well on the beach at Anchorage, just west of the gap in the end moraine, passed through about 100 feet of estuarine silt and clay without reaching the base of the formation. A second well, outside the moraine and at an altitude of 60 feet, reached the base of the estuarine material 145 feet below the present sea level. It is evident that sea level here has stood considerably below its present position, relative to the land surface, in the recent past; this change in sea level was probably eustatic. High-level estuarine deposits near Anchorage suggest that uplift of the land surface has also occurred, probably since the last glaciation. It thus seems likely that changes of level in this immediate region have been not only eustatic but in part isostatic following removal of the load of glacial ice. If warping of the land surface occurred, however, it is not evident in stream profiles in the agricultural area (pl. 4); the older profiles and the active alluvial plain of Matanuska River show very nearly the same gradient. It is possible that warping, if it occurred, affected only the westernmost part of the agricultural area, beyond the terraces in plate 4, or that it occurred chiefly during the early stages of deglaciation and was nearly complete by the time these terraces were formed. Further consideration of this problem must await additional data.

The present estuary, Knik Arm, was formed by drowning of the lowermost part of the Knik-Matanuska Valley by the postglacial rise of sea level. The flat north of Knik Arm is reasonably explained by slight uplift of the land, elevating the estuarine deposits; by a slight drop in sea level; or by a combination of these factors. Inasmuch as evidence of uplift was not found in the agricultural area a slight eustatic change in sea level is considered the more reasonable explanation of the basis of available information.

A recent slightly higher level of the Matanuska alluvial plain, suggested by low terraces and alluvial fans, has been discussed (p. 46). The writer believes that this postulated higher plain is too low to be correlated with the estuarine flat, and that the plain is somewhat younger.

The Forms of Eolian Deposits

Eolian deposits mantle the land surface of the whole of the Matanuska Valley agricultural area with the exception of the active alluvial plains of existing streams, some recent terraces, flats subject to tidal flooding, and a few steep slopes in bedrock. Over the greater part of the agricultural area this mantle consists of loess, but sand is present in several local areas, generally in dunes. These wind-blown deposits have been discussed by Tuck (1938), Rockie (1946), and Black (1951).

Dunes occur in four general tracts within the agricultural area (fig. 16, p. 69): between Fish Creek and Goose Bay, on the bluff west of Moose Creek, near Jim Creek, and along the Matanuska bluff north of Palmer.

Between Fish Creek and Goose Bay, dunes are most conspicuously developed within 1 to 2 miles of Fish Creek. They are elongate in plan and trend southwest; poorly exposed foreset beds dip southwestward. The dunes are 5 to 10 feet or more high and up to several hundred feet long. They lie upon ground moraine, and the dune field is truncated to the northeast by the bluff overlooking Knik Arm. The dune-building winds blew from the northeast, and the sand probably was derived from bare alluvial plains extending over what is now the estuary and the flat beside it.

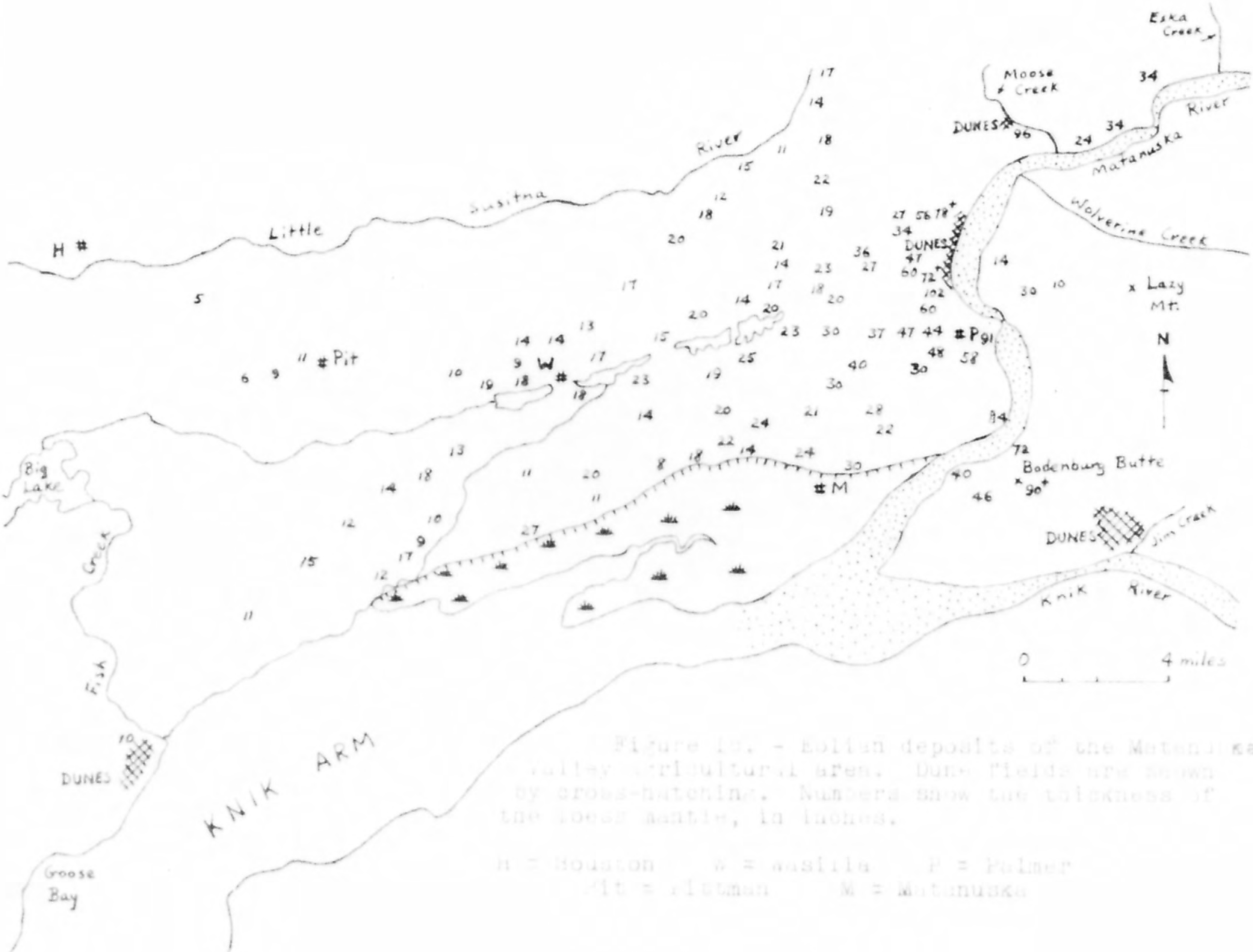


Figure 1[illegible]. - Eolian deposits of the Matanuska Valley agricultural area. Dune fields are shown by cross-hatching. Numbers show the thickness of the loess mantle, in inches.

H = Houston W = Wasilla P = Palmer
Pit = Pittman M = Matanuska

The northeastward extensions of several such alluvial plains are present as terraces northeast of Knik. The dunes are covered by weathered sand and silt which suggests an age consistent with such a history.

A few dunes lie upon glaciofluvial gravel on the west bluff of Moose Creek about 2 miles upstream from its mouth. The dunes are oval in plan, 5 to 10 feet high, and up to about 100 feet wide and 250 feet long. They trend westward. Six layers of silt, 1/2 to 1-1/2 inches thick, are interbedded with sand in one of the dunes; associated with some of the silt layers are thin dark bands rich in organic matter. An exposure of sandy loess nearby shows two thin bands of volcanic ash, but no ash layers were found in the dunes. A weathered layer at the surface of the dunes shows that they are not modern. It is unlikely that they were formed as cliff-head dunes above Moose Creek, which flows in a direction normal to the trend of the dunes and of the Matanuska Valley; they probably were formed before the canyon was cut. The interbedded silt layers may represent periods of decreased wind strength; the dark bands are incipient soils.

A dune field north of Knik River near Jim Creek extends for a mile across a low terrace toward Bodenburg Butte. The dunes are elongate and trend northwest. They are 10 to 15 feet high and up to several hundred feet long. Near the river they are partly covered by vegetation; beyond a distance of about a quarter of a mile from the river they are completely stabilized by vegetation, including trees. Stumps of 9 trees, white spruce cut during the period 1949-51, have ages ranging from 70 to 126 years. Sand in the dunes shows only slight iron-staining near the surface. These dunes are modern and have been built by winds blowing down the Knik Valley; the sand is derived from its bare alluvial flat. The dune field has attained its maximum area under existing conditions, for dunes have been built back to the edge of the active alluvial plain.

A ridge of eolian sand capped by cliff-head dunes extends along the edge of the west bluff of Matanuska River for 2 miles, beginning about 1-1/2 miles northwest of the highway bridge near Palmer. This ridge is several hundred feet wide and locally rises 20 to 30 feet above the ground surface to the west. The dunes are oval or irregular in plan and up to 30 feet high. They are made up of fine to coarse sand, together with some granules and pebbles which probably were carried by gusts accompanying winter storms. Exposures in several dunes cut by the highway show that the bedding dips toward both their windward and lee sides. All the dunes were stabilized by vegetation; on several there are cottonwoods 18 inches in diameter or larger that are partly buried by sand. Many of the dunes have been partly destroyed during retreat of the bluff. They are modern, and are built of material carried from the bare Matanuska plain.

At several localities along the Matanuska bluff the sand composing the ridge beneath the dunes is exposed. Erosion of a dune a few hundred yards south of the junction of the Glenn Highway and the Palmer-Fishhook road has uncovered this older sand, which rests on glacial deposits. Five 1/4- to 1/2-inch bands of volcanic ash and several layers of silt and silty sand are interbedded with this older sand. By their outcrop pattern (fig. 17, p. 73) they show the bedding in the sand beneath the dune to be essentially horizontal. This sand is here about 40 feet thick; the dune resting upon it is about 30 feet high.

An excellent description of the loess is given by Tuck (1938), who shows clearly that it is of eolian origin. He cites modern wind transport of dust, with measurable accumulation in recent years; buried plant material and volcanic ash; and the manner in which the surface of the loess parallels that of the underlying material. To these arguments may be added the mechanical composition of the loess (fig. 3, p. 24) and the presence of buried snail shells and weathering zones.

Tuck (1938, p. 649) finds that the thickness of the loess is greatest near Palmer and decreases toward Wasilla, the Talkeetna Mountains, and Moose Creek; he believes (p.653)

(in pocket)

Figure 17. Map of dune and horizontally bedded sand

that the greater part of the dust has come from the Knik floodplain. Aside from a belt along Matanuska River, where horizontally bedded sand and sandy loess are known to reach a thickness of at least 40 feet, the thickest eolian deposits are near Bodenburg Butte and in a belt extending parallel to Matanuska River north of Palmer; in these two general areas loess is commonly 5 to 8 feet or more thick. Figure 16 (p. 69) shows the thickness of loess sections measured on level ground (on flat hilltops of some extent, where possible) at many localities in the agricultural area. The thicknesses suggest that the Matanuska plain has been as important assource of dust as the floodplain of Knik River. The westward decrease in the thickness of the eolian deposits is in agreement with the conclusion that the source of the material lay to the east, but it is not necessary to conclude that all of it was derived from alluvial plains along the present courses of Knik and Matanuska Rivers. Some of the loess in the western part of the agricultural area probably came from older alluvial plains over what is now Knik Arm, or to the north (cf. the discussion of dunes near Fish Creek, p. 68). Volcanic ash found in one locality west of Wasilla suggests, however, that much of the loess west of Wasilla is equivalent in age to loess near Palmer, and hence probably came from sources located essentially as those of the present.

Many exposures of loess and horizontally bedded sand near Palmer show bands of volcanic ash whose attitude conforms with that of the surface topography. The bands range from very thin to about 1/2 inch in thickness. Where the ash is best developed, in thick eolian deposits near Matanuska River, there are five bands: two, within a few inches of each other, are near the bottom of the section; two, also together, are farther up; and one is by itself in the upper part of the section. In thinner sections of loess, farther west, the closely-spaced pairs appear as single bands, and only three are present. Few exposures more than about 2 miles west of the river show all three bands, and west of Wasilla ash was recognized in only one locality. This distribution of the ash is discussed in a later paragraph of this chapter. The source of the ash is not known but it may be Mt. Spurr, about 100 miles to the west, or one of several other volcanoes farther away (see P. S. Smith, 1939, pp. 81-82, pl. 16).

Tuck (1938, p. 649) also describes the decrease in grain size of the loess with increase of distance from Matanuska River. In speaking of loess, however, he includes both silt, such as covers the greater part of the agricultural area, and the sand along the west bluff of Matanuska River. The matter of terminology is relatively unimportant. The significant point Tuck makes is that the eolian deposits are a single unit. Additional data that support this argument are now available.

The number and sequence of ash bands in the eolian sections near Matanuska River permits their correlation. Sand and loess lying on gravel about 2 miles north of Palmer and on terraces to the south, down to and including that on which Palmer is situated, are thus shown to be equivalent. The eolian mantle here is one continuous deposit that extends down over the scarps between terraces. Loess is the remainder of the agricultural area to the west is part of this same continuous deposit overlying the youngest glacial materials. The writor believes this continuity sufficient basis for considering the loess and horizontally bedded sand of the agricultural area a single deposit.

The transition from sand on the Matanuska bluff to loess a short distance away, evident from correlation by the ash bands, is an interesting featuresthat is perhaps to be expected in such an area of eolian deposition near the source of the material. Similar instances of such transition seem to have been described relatively rarely, however. One example in the literature is a locality along the Elbe River (reference by Poser, 1951, p. 51, to Grahmann, 1930/31; original reference not seen).

In many sections the lowermost part of the loess contains pebbles and cobbles derived from the underlying glacial material. At a few localities the basal loess and the till immediately beneath it have been mixed by frost action; stones in this frost-disturbed layer, unlike those in the till, are split, and the material composing the layer is more permeable than the till. At most other localities where stones were found in the basal loess, however, no evidence of frost action or other slope movement was observed. In these localities the stones are generally not more than about a foot above the base of the loess. Mixing of gravel with the overlying loess as a result of the falling of trees and the tearing up of their roots (Lutz and Griswold, 1939) is considered the best explanation of the occurrence of stones in the basal loess. This mixing process is common in the modern forest here in localities where the loess is thin enough to be completely penetrated by large roots.

Deformation of the older part of the loess in many localities, shown by slight folding of the lowers and middle ash bands and weathering zones, is attributed to frost action; the deformation has occurred on flat tracts as well as on slopes. Lateral movement of material was locally sufficient to rotate stones in the loess, but there was little mixing of loess with the underlying gravel. It is difficult to date this slight deformation relative to the formation of the frost-disturbed layer described in the preceding paragraph; where it is exposed that layer is overlain by loess that lacks distinguishable ash bands or other horizons which might show deformation.

Chemical weathering of the loess is evident in most exposures; where thick the material is usually brown or grayish-brown (the freshly-deposited silt is gray). Dark bands in the lighter-colored material represent periods of more effective weathering, possibly because of temporarily decreased deposition of dust. Some of these dark bands contain considerable organic matter which shows that soil-formation had proceeded appreciably before being interrupted. In the western part of the agricultural area, where the loess mantle is generally less than a foot thick, and in some localities to the east where it is also thin (as, for example, on the lower slope of Lazy Mountain east-northeast of the highway bridge), podsolization is well advanced; the soil shows the bleached zone, the underlying humus layer, and the reddish-brown zone of sesqui-oxide accumulation beneath, that are characteristic of podsols. Where these characters are well developed, ash bands and other horizons, if present in the loess, are masked by iron-staining. Over much of the area of ground moraine west of Wasilla soil-formation has affected not only the loess but also the upper part of the till beneath; in some places where oxidation is deep and the till not stony, the boundary between till and loess cannot be determined in the field.

The loess is the parent material of most of the agricultural soil on the valley floor. Rockie (1946) and Kellogg and Nygard (1951) have described the soil in detail. Kellogg and Nygard (1951, p. 72) believe that podsolization is the dominant soil-forming process in this area but that characteristic podsols have developed only where deposition of wind-blown material has been slow enough to permit podsolization to keep pace with the addition of new material.

The high permeability of the eolian material and the presence of the vegetative cover (and perhaps the low rainfall intensity) make surface runoff negligible. Water erosion of the eolian mantle is unimportant and the surface form of the deposits is therefore in general well preserved. Wind erosion of these deposits was insignificant before the introduction of agriculture. At present wind erosion is a serious problem on some cleared land, particularly in the path of winter storms moving down the Matanuska Valley. Both wind and rainwash appear to be effective in the erosion of loess on Bodenburg Butte. Tunnels have formed locally in the loess on this hill, possibly by the falling of the basal loess into cavities in underlying talus. Collapse of the roofs of the tunnels has begun in recent years, and this process may prove important in the future within this small area.

Few exposures of loess show evidence of erosion after deposition. Nonetheless the loess mantle is commonly thicker in valleys than on adjacent hilltops. Excavations across a small valley and upon the adjacent hill, one-third of a mile south of the railroad about 2 miles east of Pittman (fig. 19, p. 81), showed that here the thickness of the loess ranges from 10 inches on the hilltop to at least 68 inches on the valley floor. Upon the hill the loess and the till immediately beneath it are heavily iron-stained. The thick loess in the valley is light to dark brown and has distinct weathering zones and one ash band of very irregular thickness. The loess on the valley floor probably has been derived in part from the adjacent hillside by erosion of newly-fallen dust. The reworking of the dust may have been by rainwash, by meltwater from snow, or, in dry weather, by the wind.

Dust may be deposited on or in snow, either by falling upon it or by being blown with it during a storm. The snow dune illustrated by figure 20 (p. 82) is an example of the amount of dust that snow may contain under favorable conditions. This dune was built on a low bar beside Matanuska River 3 miles southwest of Moose Creek. The snow lasted well through the summer (1950) beneath a protective cover of wind-blown sand. The following season the writer found a 1/2-inch band of silty sand and plant debris on the former ground surface beneath the thick layer of sand. The importance of the deposition of wind-blown dust upon snow in the agricultural area cannot be estimated until winter observations have been made. Observations during the autumn of

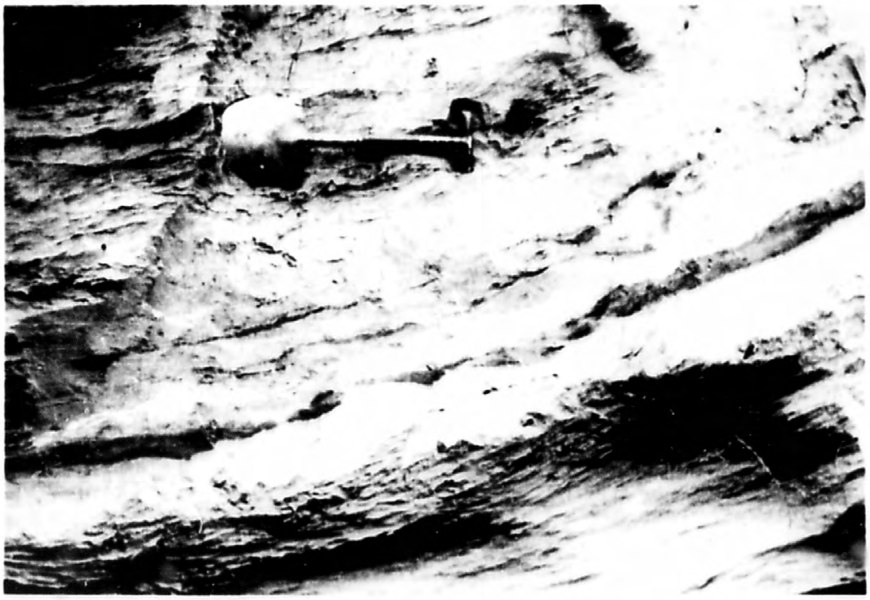


Figure 18. - Layers of volcanic ash and a buried soil layer in sandy loess on the west bluff of Matanuska River about 3 miles north of Palmer.

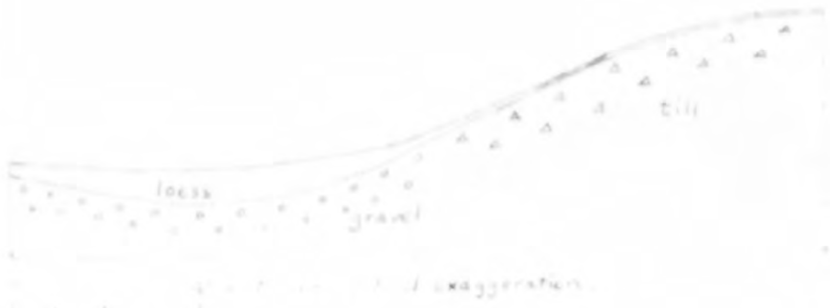


Figure 19. - Section showing the thickness of loess on a hill and in the adjacent valley, about 1/3 mile south of the railroad 2 miles east of Pittman.

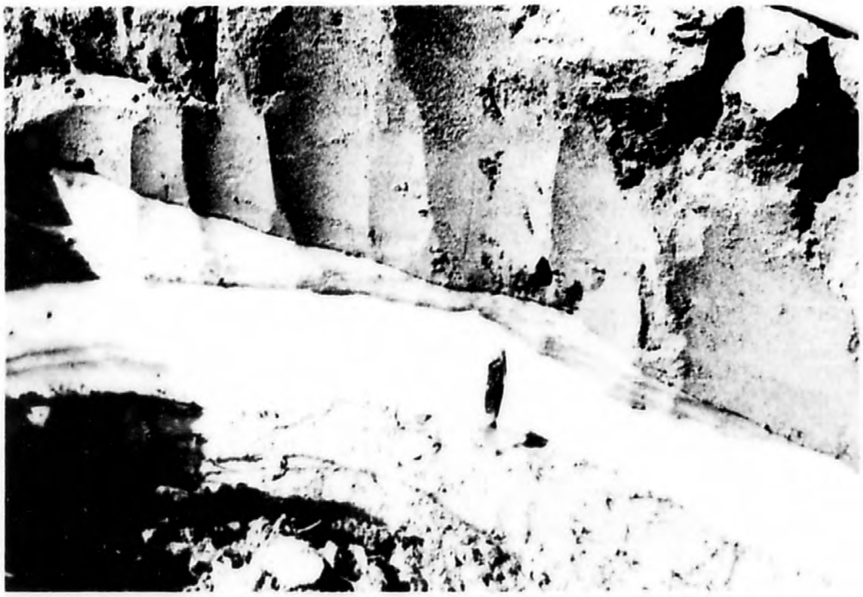


Figure 20. - Section in snow dune, beside Matanuska River about 3 miles southwest of Moose Creek; July, 1950. The snow dune is overlain by a protective layer of sand.

1952 suggest that dust, once deposited on snow, is likely to remain there while the snow lasts. The dust particles become embedded in the snow crust, probably in the same way that rock fragments melt their way into the surface of glacial ice by absorbing heat from sunlight. The snow cover may thus be significant in its effect on the even distribution of eolian dust. Moreover, the most important dust deposition probably has been during winter storms when a snow cover was present.

In some parts of the agricultural area the rate of accumulation of eolian material has been significant during recent years. Tuck (1938, p. 649) cites the burial of section corners under several inches of soil between 1913 and 1935. These localities are near Matanuska River, however, where the most rapid deposition may be expected. Deposition probably is now very slow in the western part of the agricultural area.

The Forms of Other Deposits

Slope Deposits

Frost-disturbed debris, mantling the underlying materials from which it is formed, tends to soften the appearance of the land surface. The upper slopes of Lazy Mountain are nearly everywhere rounded; except locally the bedrock is covered by a layer of frost-broken debris. Some of the upper slopes exhibit a micro-relief due to poorly developed turf-banked terraces. Upon much of the mountain the debris is stabilized by a moss cover. Gentle slopes along the ridge leading to the summit are bare, however, and here orientation of tabular rock fragments in tightly packed bands extending downslope is conspicuous. At an altitude of 2,800 feet on the southwest slope of the mountain the frost-disturbed mantle contains rounded granitic boulders unlike the bedrock exposed on the mountain. These boulders may represent an older glaciation during which the ice extended higher on Lazy Mountain than during the last glaciation.

Frost-disturbed material mantling till has been recognized at a few localities on the valley floor. Here it is predominantly fine-grained, but unlike the underlying till it contains many split stones. It appears to grade upward into the overlying loess.

The frost-diturbed layer mantling till is postglacial; its formation seems to have continued only during the early part of the period of loess deposition. Slight disturbance of the older loess, observed in a few places, may have occurred at the same time. The frost-disturbed material on Lazy Mountain was formed over a period of time whose older limit cannot be fixed on the basis of available data.

Talus is present as irregular heaps of debris beneath rock cliffs below the summit of Lazy Mountain and along the mountain front to the south. The most conspicuous deposits are along the base of Pioneer Peak just beyond the southern limit of the area described this thesis. Here the talus occurs not only beneath cliffs but in conical piles beneath ravines, where it has accumulated by rock fall, rock slide, and avalanche. All the talus deposits are postglacial; the most important are still being formed.

Alluvial Fans

The alluvial fans on the west slopes of Lazy Mountain extend westward from gullies cutting the lateral moraine. They slope at angles of 20° and less. The existing streams that cross the Lazy Mountain fans are small and carry little sediment except during the period of snow melt in the spring. Building of these fans proceeds very slowly probably the greater part of their growth took place shortly after deglaciation.

Formation of the fans along the mountain front to the south has also continued to the present. The fan beneath the notch in the hanging valley south of Lazy Mountain is growing most actively. It has no soil cover, as the Lazy Mountain fans have in places, and in exposures the writer has seen it contains cobble-gravel just beneath the ground surface.

Low fans at the mouths of Moose and Eska Creeks (p. 46) have been included with the alluvial-plain deposits on plate 2.

Lake Ramparts

Lake ramparts, ridges of sand and gravel built by ice push, are present along the shores of many of the larger lakes in the agricultural area. An easily accessible example may be seen at the south shore of Lake Wasilla about a mile east of Wasilla. The most conspicuous ramparts border several of the lakes northwest of Pittman. Of the two processes that commonly form lake ramparts — lateral expansion of ice due to temperature changes, and wind-drift of broken ice — lateral expansion is the more satisfactory explanation of the most conspicuous ridges because they occur on all sides of the lakes. Some of the smaller ridges, along the south and southwest sides of the lakes, may have been formed by the push of wind-drifted ice during spring storms, however. The writer saw no evidence that lake ramparts are being formed at present in the agricultural area. All the ramparts he saw are covered by trees.

Beaver Dams

Beaver dams may be seen along many streams and at the ends of many lakes in the agricultural area. Most of the dams the writer has seen are abandoned, breached, and tree-covered. Those at lakes are not likely to be confused with lake ramparts because they are of local occurrence, commonly on water bodies too small to form ramparts.

PERENNIALLY FROZEN GROUND

Perennially frozen ground (permafrost) was found in three bogs. These are located as follows (see pl. 2): 2-1/2 miles southeast of Wasilla; 2-3/4 miles east-southeast of Wasilla; and 2-1/4 miles west of the Experiment Station. A fourth locality, in a bog three-quarters of a mile south of Palmer, is described by Dachnowski-Stokes (1941). No doubt there are many additional localities in the agricultural area in which small poorly drained areas are underlain by thin bodies of perennially frozen ground.

A pit dug nearthe southern edge of the bog 2-1/2 miles southeast of Wasilla exposed frozen peat underlain by frozen loess 21 inches thick, in turn underlain by nonfrozen saturated gravel. The frozen loess contains crystals, veinlets, and small irregular masses of ice, together with many well-preserved twigs and other bits of wood. The same loess, where it overlies the gravel on the adjacent hilltop, is 18 to 20 inches thick; in some sections it contains poorly preserved woody material. The writer believes the presence of many wood fragments was characteristic of the loess in general during its deposition, rather than a peculiarity of the loess now found beneath the frozen peat. It seems likely that wood in the loess beneath the bog was preserved by being frozen at some time subsequent to its deposition, and that wood in nearby unfrozen loess was largely destroyed by weathering.

The perennially frozen ground in this bog is postglacial. It probably was not formed until the loess mantle had reached approximately its total thickness in this part of the agricultural area; if it had been present through much of the period of loess deposition silty peat would have been deposited in the bog. It has remained frozen for all or the greater part of the time since its formation; if it had been thawed for long intervals weathering of the loess and its organic contents should have become well advanced. The evidence obtained does not permit more detailed dating of the frozen ground.

The writer saw no evidence suggesting that postglacial perennially frozen ground has been widespread in the agricultural area, or that in bogs such as those cited it has extended very far beyond the present borders of the bogs.

QUATERNARY STRATIGRAPHY AND HISTORY

Older Glacial Deposits

The till deposits described in earlier sections of this thesis appear to form a single, more or less continuous sedimentary unit deposited during one glaciation. Covering this till in many parts of the agricultural area are contemporaneous or younger gravel deposits. The other suficial deposits described are also younger than the till. Several natural exposures and about 35 wells show older glacial deposits lying beneath this till. These older deposits are mainly glaciofluvial but one well penetrates what may be an older till.

In the bluff along Knik Arm east of Goose Bay the surface till rests upon gravel (table 2). In several exposures along Matanuska River north of Palmer the till lies beneath surficial gravel but rests upon older gravel (table 3). Most of the wells that pass through the near-surface till into older deposits are in an area lying within a few miles west, northwest, or north of Palmer, but others are near the Agricultural Experiment Station and about 3 miles east of Wasilla. Table 4 presents logs of three such wells. The second of these is about three-eighths of a mile west of the Matanuska bluff and 2-1/2 miles north of Palmer; the "blue mud and gravel" lying 63 to 101 feet beneath the surface is correlated with the buried till in the Matanuska bluff (table 3).

Gravel at Goose Bay locally has been cemented by iron oxide (table 2), some of it so firmly that masses which fall from the bluff remain as boulders on the beach. Red and brown gravel, in which the color is probably due to iron-

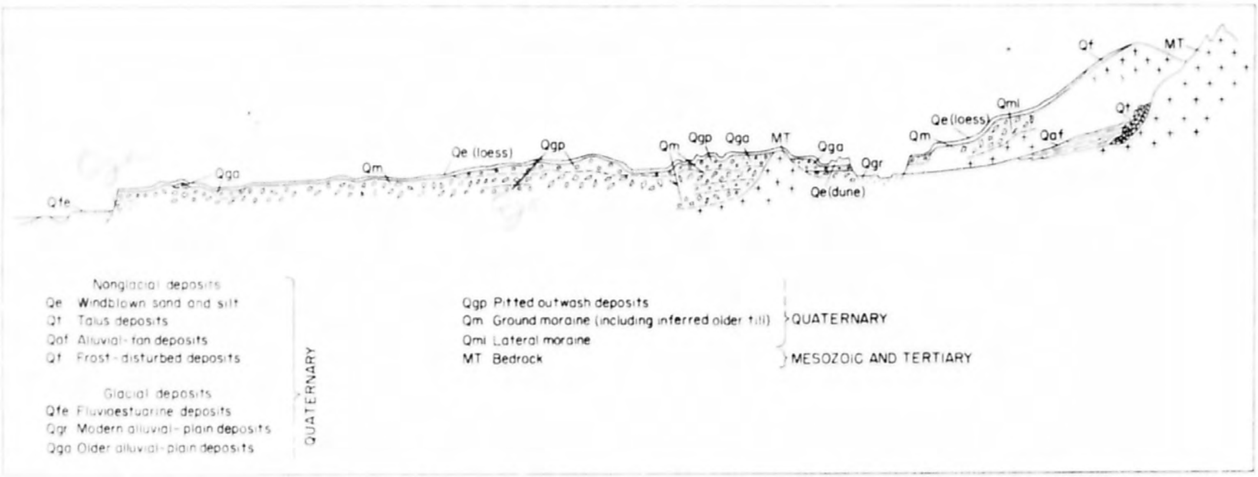


Figure 21. Generalized section of the Matanuska Valley agricultural area showing stratigraphic units.

staining, as well as layers of slightly consolidated gravel that may not be cemented by iron, are shown by some of the logs. The lower gravel in the Matanuska bluff is locally consolidated slightly, but here the consolidation may be due to binding by silt; the same effect is shown by heaps of silty gravel, formed by slumping and rainwash, at the base of the bluff.

The older gravel may represent the advance outwash of the glacier which deposited the overlying till, the outwash associated with the retreat of an earlier glacier, or both. The evidence of weathering of the gravel suggests strongly that part of it, at least, was exposed for some time after its deposition but before being covered by the overlying till, and that this gravel represents an earlier glaciation. The "blue mud" from 198 feet to bedrock at about 226 feet, in the second log in table 4, may be till deposited during this presumed earlier glaciation. It is possible that the granitic boulders in the frost-disturbed mantle on Lazy Mountain (p. 84) also represent this glaciation.

The surficial gravel is locally 100 feet or more thick; in general it seems to thin toward the west. The thickness of the near-surface till, in wells that pass through it, commonly ranges from 10 to 60 feet. The thickest section of till in the agricultural area, known to the writer, is in an unfinished well about 3 miles northeast of the mouth of

Table 2. - Section in bluff north of Knik Arm about one-quarter mile east of Goose Bay (thicknesses estimated).

	Thickness (feet)
Eolian sand	3
Till, gray-brown, silty; includes a few layers of poorly sorted gravel	15
Sandy pebble- and cobble-gravel; interbedded horizontal sand lenses as much as one foot thick and 40 feet long show cross bedding	20
Peat, brown-black, slabby, containing compressed twigs and stems of wood	2-1/2
Silt, gray	1
Sand, silty, somewhat iron-stained	3
Sandy pebble- and cobble-gravel, conspicuously iron-stained; locally consolidated	1
Covered interval beginning at beach	5
Total	50-1/2

Table 3. - Section in bluff west of Matanuska River about 3 miles northwest of Matanuska River highway bridge (thicknesses estimated).

	Thickness (feet)
Eolian sand	20
Sandy pebble- and cobble-gravel; horizontally bedded	40
Till, gray, silty	40
Sandy and silty pebble- and cobble-gravel; slightly consolidated; locally deformed beneath overlying till	60
Covered interval beginning at river	70
Total	230

Table 4. - Selected drillers' logs showing the presence of older glacial deposits in the Matanuska Valley agricultural area (logs through courtesy of Alaska Rural Rehabilitation Corporation).

ARRC tract no. 14 (3 miles southeast of Wasilla)

Log (in feet below land surface)		Interpretation
Topsoil	0 - 5	
Sand and gravel	5 - 75	
Coarse sand	75 - 90	
Gravel, mud, and sand, water blue and mucky, will bail out	90 - 110	
Glacier mud and gravel, blue and thick; water seeping	110 - 128	Till 90-174
Glacier mud and sand	128 - 139	
Blue mud	139 - 174	
Water; gravel; water stands to 75 feet; red gravel	174 - 177	Oxidized gravel 174-177
Water; gravel	177 - 180	

Table 4. - Selected drillers' logs showing the presence of older glacial deposits in the Matanuska Valley agricultural area (continued).

ARRC tract no. 132 (2-1/2 miles north of Palmer)

Log (in feet below land surface)		Interpretation
Topsoil..................	0 - 15	
Gravel...................	15 - 63	
Blue mud and gravel.....	63 - 101	Till 63-101
Gravel, loose-running...	101 - 116	
Gravel...................	116 - 155	Slightly consolidated gravel
Cemented gravel..........	155 - 178	
Pea gravel...............	178 - 181	
Cemented gravel..........	181 - 187	155-178 and 181-187
Gravel...................	187 - 198	
Blue mud.................	198 - 215	
Blue mud and shale rock; pipe stopped at 226 feet on 2-foot ledge of hard shale.................	215 - 226	Till 198-226 (?)
Shale, open hole from 226 on...........	226 - 510	
Well abandoned - dry hole		

Table 4. - Selected drillers' logs showing the presence of older glacial deposits in the Matanuska Valley agricultural area (continued).

ARRC tract no. 95 (1 mile northwest of Palmer)

Log (in feet below land surface)	Interpretation
Topsoil.................. 0 - 5	
Gravel.....................5 - 28	
Blue mud..................28 - 40	
Granite wash..............40 - 45	Till 28-86
Blue lime shell...........45 - 55	
Water, gravel, sand.......55 - 59	Layers of sorted material at
Gravel and mud............59 - 64	
Sand and gravel; some water..............64 - 65	55-59, 64-65,
Blue mud and gravel.......65 - 73	
Gravel and sand...........73 - 77	and 73-77
Blue mud..................77 - 86	
Water gravel; 60 feet of water in pipe........86 - 88	Older gravel 86-88

Moose Creek; here till extends from 10 feet beneath the surface to a depth of about 150 feet, and it is not completely penetrated. The thickness of the older gravel is known at only one locality (table 4, second log); there it is 97 feet.

The lateral extent of these older glacial deposits is not known, but the wide distribution of the three general areas where their presence is established (near Palmer, between the Experiment Station and Wasilla, and at Goose Bay) suggests that they may underlie a large part of the agricultural area. The form of the buried gravel deposits also is not known; they may be outwash plains (of relatively wide extent) or a series of narrow alluvial plains.

The age of wood from the peat at Goose Bay (table 2) has been determined by radio-carbon dating to be 19,100±900 years (Kulp et al, 1952, pp. 412-413). A peat sample collected by Ernest Dobrovolny, of the Geological Survey, from beneath till on the south bank of Eagle River has been dated at 14,300±600 years (Kulp, 1952, p. 263). Correlation of surficial till deposits at Goose Bay, and at Eagle River across Knik Arm to the south, is justified by their proximity in the same valley. If the average values for the radio-carbon dates are used, therefore, it is necessary to postulate that the ice-free period preceding the advance of the ice which laid down the younger till must here have lasted at least 4,800 years.

On the basis of previously determined radio-carbon dates Flint and Deevey (1951, p. 263) conclude that the time of the maximum Mankato ice advance in the State of Wisconsin was about 11,000 years ago. Samples of wood from till of the Cary (?) substage and of the Cary (?) or Tazewell (?) substage are older than 17,000 and 15,000 years, repectively (Flint and Deevey, 1951, p. 286).

The writer concludes tentatively that the glacial episode during which the surficial and near-surface till in the Matanuska Valley agricultural area was deposited corresponds approximately in time to the Mankato, although it may have begun sooner and lasted longer than the Mankato in the Midwest; and that the peat at Goose Bay and Eagle River dates from the preceding warmer interval. The postulated older till cannot be dated on the basis of vailable evidence, but it probably was deposited during the glacial episode preceding the last.

Quaternary History

There is little evidence of the form of the preglacial topography in this region, but the mountains must have presented a different appearance before the glacial steepening of slopes. This steepening is most conspicuous along the front of the Chugach Range, where several prominent spurs were truncated. Bodenburg Butte and the other bedrock hills between Matanuska and Knik Rivers probably are the remnants of the preglacial divide separating these streams.

The writer has found evidence for at most two glacial episodes in this area. The older of these has no expression in the topography of the valley floor. The deposits of the younger ice form the surface over the greater part of the agricultural area. A brief summary of the development of the topography of the valley floor is given in the paragraphs below.

The last ice tongue that lay over the agricultural area, a large glacier formed by the merging of the Matanuska and Knik Glaciers of that time (and possibly including ice from farther up the Matanuska Valley), extended a few miles west of what is now Big Lake; there its end moraine is preserved as an arcuate band of hills, convex toward the west. Deglaciation over the greater part of the Matanuska side of the large valley was by stagnation. The behavior of the Knik ice at that time is not known.

As the ground moraine became exposed by melting of the ice, meltwater streams began to cut shallow valleys across it. With continued melting lower ground was uncovered and the drainage courses shifted. In the western part of the agricultural area much of the ground moraine was only slightly modified by erosion, or by local deposition of thin deposits of gravel, in areas between the drainage channels. To the east thicker gravel deposits were laid down between and over blocks of stagnant ice, and the drainage channels shifted frequently. While thick ice lay over much of the valley floor west of Palmer, a large part of the drainage from the middle and northern parts of the Matanuska ice was westward toward Big Lake and along the Little Susitna. As the ice thinned this drainage shifted southward to join the main Matanuska drainage and that from the Knik ice. Final melting of the ice left the land surface irregular in most of the agricultural area.

The gap in the end moraine at Anchorage probably was open from the beginning of the deglaciation. It appears that during the early part of the deglaciation sea level was considerably below its present position. Alluvial plains along what are now Matanuska River and Knik Arm were trenched repeatedly. The available evidence is not sufficient to permit conclusions regarding depression of the valley floor beneath the load of ice and its recovery during and after deglaciation. Knik Arm was formed by the postglacial rise of sea level. The estuary appears to have reached a slightly higher level than that of the present, relative to the land surface, at least once during postglacial time. Activity of the streams continues; Matanuska River appears to have been eroding its alluvial plain within recent time.

Glaciation on the valley floor was, of course, accompanied by glaciation in the surrounding mountains. The larger mountain valleys held tributary glaciers which joined the main ice stream. In many of the smaller mountain valleys there were small glaciers that did not join larger glaciers; their moraines may be seen in valleys above Eklutna Lake, up the Little Susitna Canyon, and up the valleys of Moose and Wolverine Creeks. Many valleys and mountain slopes that were not glaciated were affected by frost action due to the same cold climate which produced the glaciers, and these were covered by a mantle of frost-disturbed debris. Rock glaciers now preserved in some of the mountain valleys may have been formed at this time.

During and after deglaciation on the valley floor wind-blown dust was laid down as a mantle over the greater part of the agricultural area; deposition continues slowly at the present day. Unconsolidated deposits were disturbed locally by frost action, and local bodies of perennially frozen ground were formed in bogs. Postglacial alluvial fans and talus deposits are still being built along the valley walls.

GROUND WATER

The Matanuska Valley agricultural area is the most thickly settled rural area in Alaska. More than 300 wells have been dug or drilled here, and they give, in addition to data on the distribution and thickness of the materials penetrated, valuable information on the occurrence of ground water in glacial deposits. Most of these wells, and most of the exposures also, are in the eastern part of the agricultural area. Information regarding ground water is therefore most detailed for this part of the valley floor.

Water-bearing Materials

Till

Till is important in the ground-water hydrology of the agricultural area because of its relative impermeability and its wide distribution at or near the land surface. About 25 wells obtain water from till in this area; many other wells pass into or through it and derive their water from gravel lying above or beneath it. The development of ground-water supplies from till, even in limited amounts, must be considered because of the current need for water supplies in areas of till that are already settled and because of possible future need in large areas of potential agricultural land, as yet unsettled, which are underlain by till.

Field tests by means of a variable-head permeameter (table 5) suggest that the permeability of typical till in the agricultural area is of the order of 1/10,000 that of

Table 5. - Permeability coefficients[a] of undisturbed samples of water-bearing materials, determined with a variable-head permeameter[b,c].

Sample[d]:

1	2	3	4	5	6	7	8	9
0.021	505	3381	2813	2105	161	168	52	187
.027	511	3081	2677	2081	169	151	57	189
.035	420	3116	2602	2105	166	166	54	188
.029	410	3081	2531	2123	162	169	55	180
.052	337	3051	2445	2101	157	165	54	182
.031	319		2558	2071			55	183
.029	425		2335	2057			55	173
.021	419		2370	2001			52	175
0.024			2297	2046				176

a/ Expressed in Meinzer's units as the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a [redacted]ature of 60° F. (Wenzel, 1942, p. 7).

b/ Wenzel, 1942, pp. 64-65.

c/ These determinations were made in the order in which the figures appear, from top to bottom, in the columns above. The apparent decrease in permeability with time in most samples is attributed to the release of air within them from the water used in the tests. If this is true the range in permeability determined for a given sample is a function of the length of the test, and the best values for most samples are the first ones determined. The permeability of these samples probably can be compared on the basis of these tests, but comparison [redacted] determinations with published determinations on other samples is not justified because of the range in conditions under which the different sets of tests were made.

d/ 1. Compact till from bluff of Matanuska River about 1 mile north of Palmer.

2. Sand from layer in till; excavation on Ferrin property, about 1/4 mile southeast of Matanuska River highway bridge.

3. Glaciofluvial sand from gravel pit on Palmer-Fishhook road about 200 yards south of Wasilla Creek.

(continued)

Table 5. - Permeability coefficients of undisturbed samples of water-bearing materials, determined with a variable-head permeameter (continued).

d/ 4. Glaciofluvial sand from gravel pit on Palmer-Fishhook road about 200 yards south of Wasilla Creek.
5. As in sample 4.
6. Sand from stream bank 1/2 mile south of Matanuska.
7. As in sample 6.
8. Sand from bar in Matanuska River at highway bridge.
9. Sand from dune on bluff of Matanuska River about 2 miles north of Palmer.

---

glaciofluvial sand. The permeability of thin sand layers in the till, on the other hand, is comparable with that of surficial sand.

In almost all wells that obtain water from till the water occurs in sand or gravel layers within the till. These permeable layers are commonly a foot or less in thickness, but thicker water-bearing zones are penetrated by some wells. A Geological Survey test hole started in till, about 2 miles north-northeast of the Matanuska River highway bridge, penetrated 1 foot of coarse sand, 2 feet of gravel, and 1 foot of fine and medium sand before passing into till again at a depth of 26 feet. A well on the Withey property, about 2-1/2 milesnnortheast of Wasilla, obtains water from a 2-1/2 foot zone of sandy material. In a third well, about 2 miles northeast of the Matanuska River highway bridge, water seeps occur at several levels; here, however, the water-bearing material may be superglacial till rather than a layer of sorted sand and gravel.

The importance of fractures cutting till and of sandy or stony fabric zones, in the movement of ground water through the till, cannot be estimated because of the inadequncy of exposures.

Springs issuing from till are unimportant. Seepage from thin sand or gravel layers in till may be observed in some exposures, as in the east bluff of Matanuska River about half a mile north of the highway bridge. The flow of water from seeps the writer has observed is not sufficient for more than a small supply, but the water may present a drainage problem if the till is to be excavated.

The yields of these wells are small at best, but a well penetrating one or more water-bearing layers in till may provide a modest water supply for a household or for a small number of livestock. Most of these wells probably yield not more than 100 to 150 gallons per day. The Geological Survey test well 2 miles north-northeast of the Matanuska River highway bridge was pumped steadily at 30 gallons per hour over a 3-hour period, with a drawdown of 19 feet. The recovery of water levels in wells in till after pumping may be slow; an extreme example is a dug well on the Bradley property, 2-1/2 miles southeast of Wasilla, in which the water level required 7 days to recover after 250 gallons had been pumped in 45 minutes.

Water obtained from near-surface (supraglacial?) till probably is derived from precipitation which percolated into the material. The writer believes that water obtained from included sand or gravel layers is derived from the till itself by downward percolation, and that the quantity of water obtainable depends not only upon the permeability of the till and the size of the well which collects the water but also on the roof area of the sand or gravel layer.

The hydrologic effect of the till, aside from the occurrence of small quantities of water in sandy layers it may contain, is two-fold. First, where till lies at or near the land surface, bodies of surface water, or bodies of ground water in thin gravel, may be held above it; where it lies at or immediately below the water table, water in reasonable quantity cannot be obtained from the upper part of the saturated zone. Second, where till overlies older gravel deposits it may form a confining layer beneath which the water is under artesian pressure. These effedts are considered in the section which follows.

Glaciofluvial Gravel and Sand

In the Matanuska Valley agricultural area sandy gravel and subordinate sand and clean gravel are of such permeability as to be good water-bearing material wherever they occur below the water table. They are widely distributed throughout the area, and most of the recoverable ground water occurs in them.

The data in table 5 illustrate the range in permeability of samples of glaciofluvial sand, and show the striking difference in the permeability of till and sand from this area. Attempts to extend these tests to include undisturbed samples of gravel were unsuccessful. The writer believes, however, that the permeability of most gravel here is comparable with that of the sand. On the other hand, silty gravel or sandy gravel containing much fine sand or silt is probably much less permeable than the sand tested, whereas the well sorted gravel seen in some exposures is undoubtedly many times more permeable than any of these samples.

Over a large part of the agricultural area, ground water is present in gravel under water-table conditions. Perched water bodies, however, cause apparent local irregularities in the level of the water table. On ground moraine in the western part of the area, lakes, marshes, and bodies of ground water in gravel are held up by till. In some horizontally bedded deposits of gravel perched ground-water bodies may be above silty layers. Three wells a few hundred feet east of the east end of Bodenburg Butte obtain water at a depth of 28 to 35 feet. In a fourth well here the static water level is 53 feet below the land surface (September, 1951). Perched water, in bodies up to a few feet thick, was encountered at several levels in this fourth well; one of the perched bodies was at about 34 feet (Frey, J. D., personal communication, 1951). It is likely that in all these wells the same body of perched water was encountered; the impervious layer beneath it may be a buried channel floored with silt.

Many of the small streams flowing across gravel deposits that appear to be relatively permeable may be perched. In a well on the Carson property, about 3-1/4 miles east-southeast of Wasilla, the water stands 33 feet below the land surface; a creek a few hundred feet away is only about 6 feet lower than the ground surface at the well. The water level in a well on the Kirchner and Menk property, 1-1/2 miles north of Four Corners, is about 7 feet below the level of the bed of Wasilla Creek, 20 feet away. In a Geological Survey test well about 2 miles north of the Knik River bridge the water level is about 30 feet below the bed of Bodenburg Creek, 50 feet away. It seems likely that the beds of these streams have been rendered relatively impermeable by a "seal" of silt (Cederstrom, 1952, p. 3) in the gravel over which they flow, although they probably feed the ground-water body to a slight degree.

The presence in the area of perched water bodies, and of streams flowing at levels above those of the water table in the adjacent deposits, cause apparent irregularities in the water table. Other apparent irregularities may be due to the presence of relatively impermeable material at and below the level of the water table. A layer of till in gravel beneath part of Was'lla lies at about the level of the water table over an area of at least 1 to 2 acres. The till is as much as a few feet thick. In several wells the water rose above the base of the till when the layer was penetrated.

With the exception of seeps from sand layers in till, all the springs seen by the writer derive their water from gravel. The springs occur in three general situations: (a) in saturated gravel below the water table, exposed by recent stream erosion, as at springs along the Matanuska bluff south of Palmer and near Matanuska; (b) in topographic depressions where the water table intersects the land surface, as probably is the case at Brazil Springs northwest of Palmer; and (c) at the contact of saturated gravel and underlying till, as occurs on the hillside above (east of) the mouth of Fish Creek.

In the chapter on Quaternary stratigraphy the presence of older glacial gravel beneath the surficial or near-surface till in three general areas is described. Most of the wells that reach such gravel are in the area immediately west and north of Palmer, and more information on the hydrology of the buried gravel is therefore available here than elsewhere in the agricultural area. In many wells that pass through the buried stratum of till and into the underlying gravel, the water rises to a level higher than the base of the till; in several the static water level is higher than the upper surface of the till. In a well on a hilltop about 1 mile west-northwest of Palmer the water rises within 20 feet of the surface, although the hilltop stands 30 to 40 feet above the adjacent surrounding land surface. Figure 22 (p. 111) summarizes the available information on the depth and thickness of the stratum of till and on the water level in wells along a section west and northwest of Palmer. It is evident that artesian conditions are developed where the buried stratum of till is present; the confined water is probably connected hydrologically with unconfined water in places where the till is absent.

Only one well in the agricultural area has been pumped at a rate greater than 100 gallons per minute (gpm). This well, about a mile west-northwest of Palmer, is reported (Bourne, 1952) to have yielded 118 gpm with a drawdown of 35 feet, after 16 hours' pumping. Its specific capacity was thus about 3.4 gpm per foot of drawdown. This well was finished with a screen. It obtains water from sand and sandy gravel beneath the buried stratum of till already mentioned. A well beside the highway about 4 miles north of the Knik River bridge yielded 44 gpm with a drawdown of 5.6

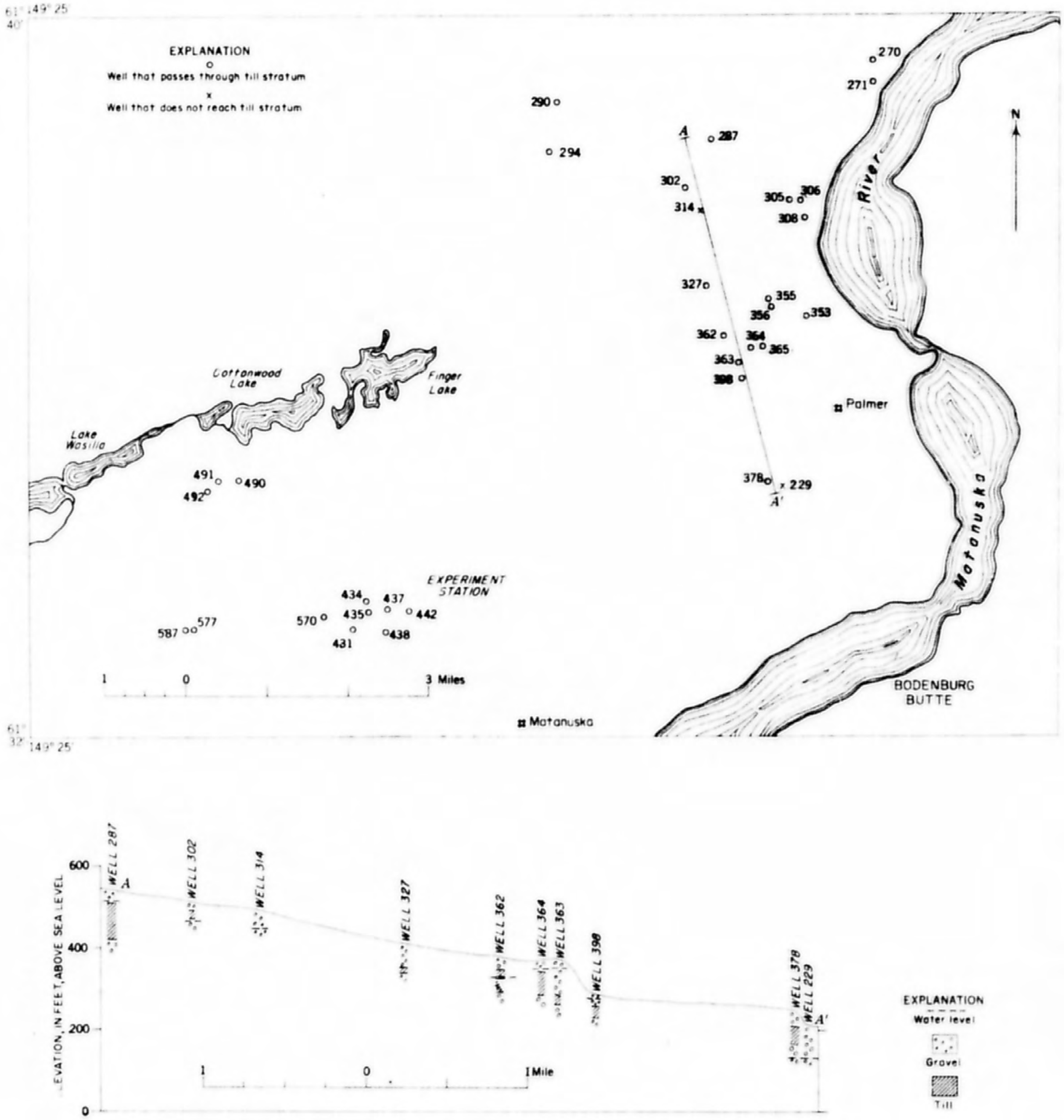


Figure 22. Map and section showing distribution of older glacial deposits known from well logs.

feet after 4-1/2 hours' pumping. It is a 3-inch open-end well. In view of its small size, lack of a screen, and higher specific capacity, it must penetrate material more productive than did the other well. No other wells in the agricultural area have been pumped at rates comparable with these. Farm wells are usually pumped at rates of a few gpm, and for only short periods. A well about one mile west of Palmer is reported (Rivers, 1950) to have yielded 5.65 gpm with a drawdown of 7 feet, in a 24-hour test.

While there are no additional data available to permit estimation of possible yields of wells in this area, it is reasonable to assume that under favorable conditions yields comparable with those of the first two wells mentioned in the preceding paragraph could be obtained from saturated gravel in many parts of the area, particularly with the use of screens and proper well-development.

With respect to the quantity of water available and the cost of its acquisition the deposits between Matanuska and Knik Rivers probably are the most favorable in the agricultural area. The water table is closer to the surface here than in many other parts of the area, and the gravel and sand are well sorted. The ground water in this tract is derived from precipitation on the land surface and from runoff from the mountains to the east.

Available information on the occurrence of ground water in the terraces west of Lazy Mountain is meager. Till is known to lie beneath the uppermost terrace at shallow depth in one locality, and bedrock underlies the lower terrades in the valley wall of Wolverine Creek. Little is known also of the potential ground-water resources in the hilly tract between Eska and Moose Creeks, and west of Moose Creek. Gravel is present in the pitted deposits and in the terraces near Eska Creek, but most of the few wells in this tract end in till.

Almost all the [redacted]ful wells on the Palmer terrace are south or southeast of Palmer. They obtain water from gravel. The water table is generally 60 feet or more beneath the land surface. Many wells in and north of Palmer encountered till, bedrock, or both. Some wells in Palmer obtained salt water from bedrock.

The surficial gravel deposits that underlie most of the area as far west as Wasilla contain unconfined ground water in many places. Some wells have encountered till above the level of the water table, however, and have been either unsuccessful or of small yield. Water probably is readily obtainable from many of the gravel deposits in drainage channels and depressions in the ground moraine west of Wasilla, and in the terraces south and southwest of Wasilla. Most of these gravel deposits appear to be relatively thin, however, and to rest on till, so that the quantities of water obtainable from shallow wells may in general be small.

The presence of gravel beneath the surficial or near-surface till is known in three general areas within the agricultural area (p. 89). It is possible that gravel underlies the till over a large part of the valley floor, and that water supplies could be obtained from deeper wells in many parts of the agricultural area where only shallow wells of low yield are now used.

Eolian Sand and Silt

The wind-blown sand and silt that mantle glacial deposits in the Matanuska Valley agricultural area lie above the water table and generally are not saturated. They are important in the hydrologic cycle, however, because they are permeable and permit rapid infiltration of water that reaches the land surface. Information obtained during irrigation experiments (Wilson, C. W., personal communication, 1951) shows that on two farms, one at Palmer and the other near Matanuska, infiltration of water into agricultural soil may take place at the rate of at least one-third of an inch per hour for several hours without perceptible runoff.

Small perched bodies of ground water occur in eolian sand and silt near the Matanuska bluff about 4 miles north of Palmer. The sand and silt ranges from 9 to 14 feet in thickness; it lies upon pitted gravel deposits. The water bodies, which are from 3 to 7 feet thick, are found only beneath the pits (ice-block holes). The impermeable layer that retains the water beneath each pit is thought to be either the residue of unsorted glacial debris left upon melting of the block of ice or a deposit formed in a pond which occupied the pit during melting of the ice beneath. Most individual pits here cover a few acres or less. It is evident that the water in any perched body is derived only from precipitation received within the pit itself, and that the quantity of water present beneath a pit is small. Perched water in eolian deposits has not been reported elsewhere in the agricultural area, and it probably is present only in restricted areas near Matanuska River where the eolian material is thick and in situations where it is underlain locally by impermeable material.

Other Unconsolidated Deposits

Alluvial-fan and talus deposits here are water-bearing but have not been exploited because of their unfavorable location. Water probably could be obtained from the alluvial-fan deposits without difficulty if they were settled. Nothing is known of the possible occurrence of ground water in the estuarine flat north of Knik Arm. The silt deposits probably are not water-bearing unless the contain sandy layers. A well at the CAA station near Eklutna, south of Knik Arm, obtains water from the underlying gravel. It is possible that water also is present beneath the flat north of the estuary.

Bedrock

Although several wells in the agricultural area have penetrated bedrock, particularly in the vicinity of Palmer, only a few have obtained water from it.

A well about three-quarters of a mile north of Bodenburg Butte is in rock from 36 feet beneath the surface to its total depth of 110 feet. The rock probably is greenstone. The driller's log reportes water at several levels, chiefly below 65 feet; it probably is derived from fractures in the rock.

Two wells, and possibly four, in or near Palmer obtained salt water from bedrock (see section on quality of water).

Water-Level Fluctuations

Reports of well owners indicate that the fluctuation of ground-water levels between wet and dry years is of the order of several feet. Seasonal fluctuations, the water levels being lower in winter and early spring, have also been reported in several wells. Periodic observation of selected wells has been carried on by the Geological Survey since 1949.

Climatological data for 1949-51 are incomplete. 1949 and 1951 probably approached the average in precipitation. 1950 was abnormally dry. Because the ground usually is frozen during the melting of all or most of the snow in this area, and because wind usually removes much of the snow cover, recharge of ground water appears to be chiefly from rainfall.

Figure 23 shows graphically the fluctuations in water level observed in four wells. Each well shows a decline in water level during 1950, interpreted as reflecting lack of recharge from rainfall. The fluctuation is least and the recovery greatest in the Woods well, where the water level is controlled by Matanuska River. Each well shows at least partial recovery during the summer of 1951.

If recovery of ground-water levels continues until the average position of the water table is regained, the declines shown by the graphs probably can be taken as representative of those to be expected after an unusually dry year.

The rapid decline and slow recovery of ground-water levels, as shown by these data, suggest that annual additions to the ground-water body represent only a small proportion of the annual precipitation received in the agricultural area.

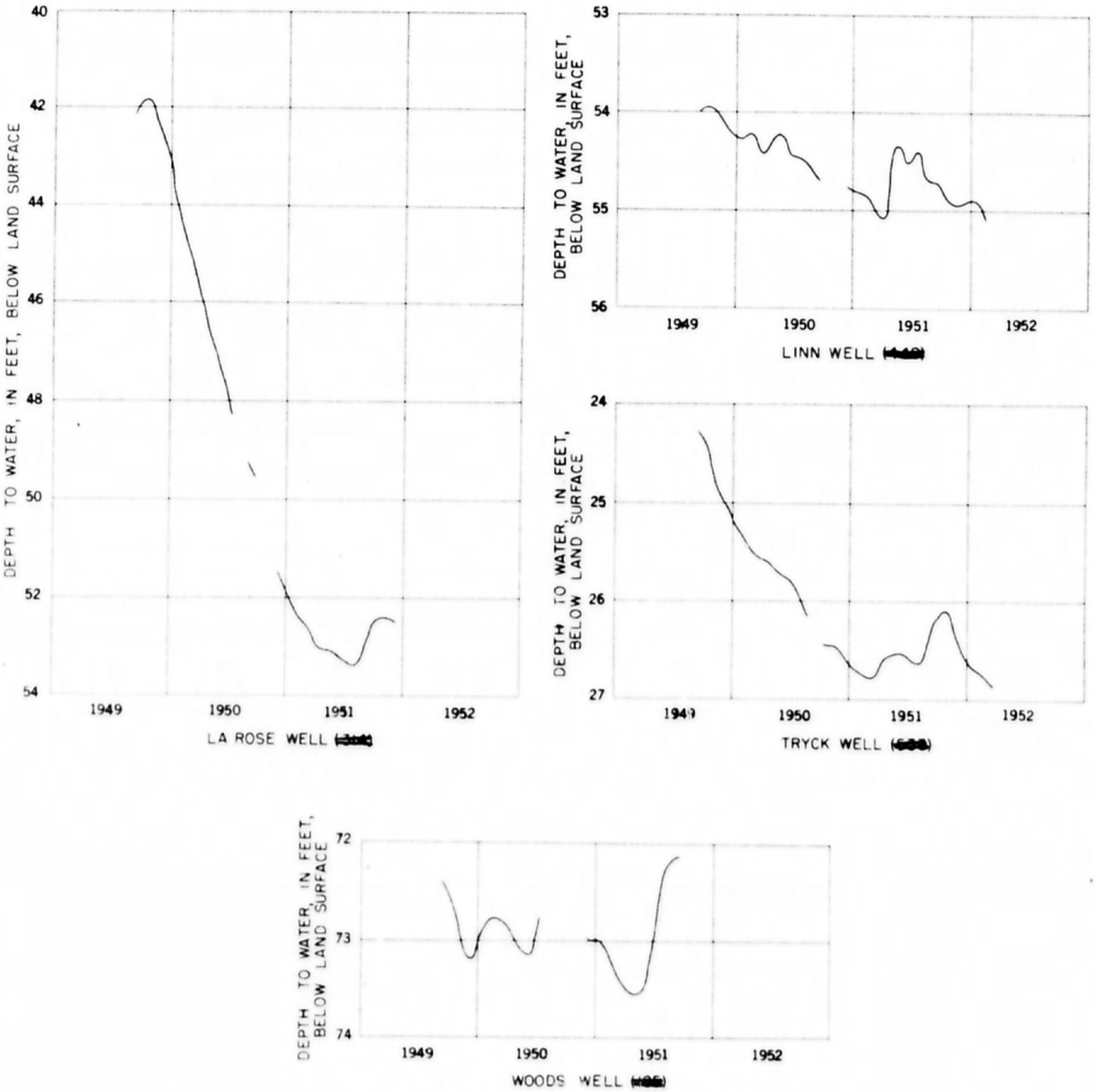


Figure 23. Graphs showing water-level fluctuations in wells.

Quality of Water

The samples whose analyses are presented in table 6 are representative of the chemical character of ground water in the Matanuska Valley agricultural area. These analyses and others in the files of the Geological Survey show that ground water here generally is chemically suitable for human consumption. It commonly contains less than 300 parts per million (ppm) of dissolved solids. The hardness is generally from 100 to 200 ppm and is due largely to calcium and magnesium [redacted]. A few wells (not represented in table 6) obtain very hard water (about 500 ppm or more); artificial softening of such water is desirable. Some wells yield water containing objectionable amounts of iron; the iron content of samples 2025 and 157 (table 6), for example, is sufficient to cause staining of clothing laundered in the water. The nitrate content, a possible indicator of organic pollution, is high in a few samples (for example, no. 157); most of these samples are from shallow dug wells, which are particularly susceptible to pollution.

Water from gravel beneath the buried stratum of till northwest of Palmer appears not to differ significantly from water obtained from gravel above the till (compare samples 1071 and 155). The writer believes that water beneath the till is connected laterally with unconfined

Table 6. - Chemical analyses of ground water[a] by the Geological Survey, United States Department of the Interior (parts per million).

Alaska Lab. No	1060	214	1071	155	158	2025[b]	157
Silica (SiO_2)	15	18	13	13	8.2	10	16
Iron (Fe), total	0.02	0.02	0.04	0.02	0.02	0.08	0.06
Calcium (Ca)	14	18	37	46	51	76	75
Magnesium (Mg)	2.5	5.5	9.4	5.9	5.6	9.4	20
Sodium (Na) Potassium (K)	3.2	1.6	5.7	2.5	5.5	9.2	34
Bicarbonate (HCO_3)	55	76	[illegible]	160	143	236	266
Sulfate (SO_4)	5.9	3.8	9.6	8.7	36	38	35
Chloride (Cl)	0.8	2.0	1.3	1.8	4.5	4.8	42
Fluoride (F)		0.2	0.0	0.1	0.1	0.1	0.1
Nitrate (NO_3)	0.8	1.3	0.2	2.3	0.8	9.4	35
Dissolved solids (sum)	69	88	155	159	182	273	338
Hardness as $CaCO_3$	45	68	131	140	150	228	269
pH	6.9	6.5	7.6	7.3	7.7		6.8

a/ Sources of samples:

1060. Well in eolian sand; Holtet property, 4 miles north of Palmer.
214. Spring issuing from gravel; Dinkle farm, 3 miles south of Wasilla.
1071. Well penetrating gravel beneath till; Palmer city test well about 1 mile northwest of Palmer.
155. Well in gravel; LaRose farm, about 3 miles northwest of Palmer.
158. Well in gravel; King property, 1/2 mile north of Bodenburg Butte.
2025. Well in gravel; Hurley farm, 1/4 mile south of Bodenburg Butte.
157. Well in till and bedrock; Lester property, Palmer.

b/ Salt Lake City Laboratory Number.

ground water where the stratum of till is absent.

Water in small perched bodies in eolian material (sample 1060) is less concentrated in most constituents than most other ground-water samples analyzed. The perched water probably is discharged fairly rapidly by plants and by leakage through the floors of the small basins; it is renewed by local precipitation. The presumed short distance and time the water has travelled in the eolian sediment is thought to explain its slight degree of mineralization.

The cause of the relatively high mineralization of some ground-water samples here (such as the very hard water mentioned) is not known. Bedrock in this area appears to yield somewhat harder water than the unconsolidated sediments, but some of the hardest water is obtained from gravel.

Analyses of different water samples, and the relative importance of the constituents in a single analysis, are difficult to compare when the results are expressed in parts per million. Conversion of the data to equivalents per million permits direct comparison. In table 7 some of the constituents of the samples analyzed are presented as equivalents per million (epm). These same constituents are also plotted on triangular diagrams (fig. 24, p. 123). It is evident from the diagrams that the samples, while of a fairly wide range in concentration, are of essentially the same chemical character or composition; they may be

Table 7. - Chemical analyses of ground water (from table 6), expressed in equivalents per million (epm) and percentage reacting values of ions.

No. in fig. 24:	A		B		C		D		E		F		G	
Lab. No.:	1060		214		1071		155		158		2025		157	
	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%
Ca........	0.70	67	0.90	63	1.85	64	2.30	80	2.55	77	3.79	76	3.74	54
Mg........	.21	20	.45	32	.77	27	.48	17	.50	15	.77	16	1.65	24
Na, K.....	.14	13	.07	5	.25	9	.11	3	.24	8	.40	8	1.48	22
Totals	1.05	100	1.42	100	2.87	100	2.89	100	3.29	100	4.96	100	6.87	100
HCO_3......	0.90	86	1.25	88	2.61	91	2.62	90	2.34	72	3.87	78	4.36	64
SO_4.......	.12	11	.08	6	.20	7	.18	6	.75	23	.79	16	.73	11
Cl, F, NO_3..	.03	3	.09	6	.05	2	.10	4	.15	5	.30	6	1.76	25
	1.05	100	1.42	100	2.86	100	2.90	100	3.24	100	4.96	100	6.85	100

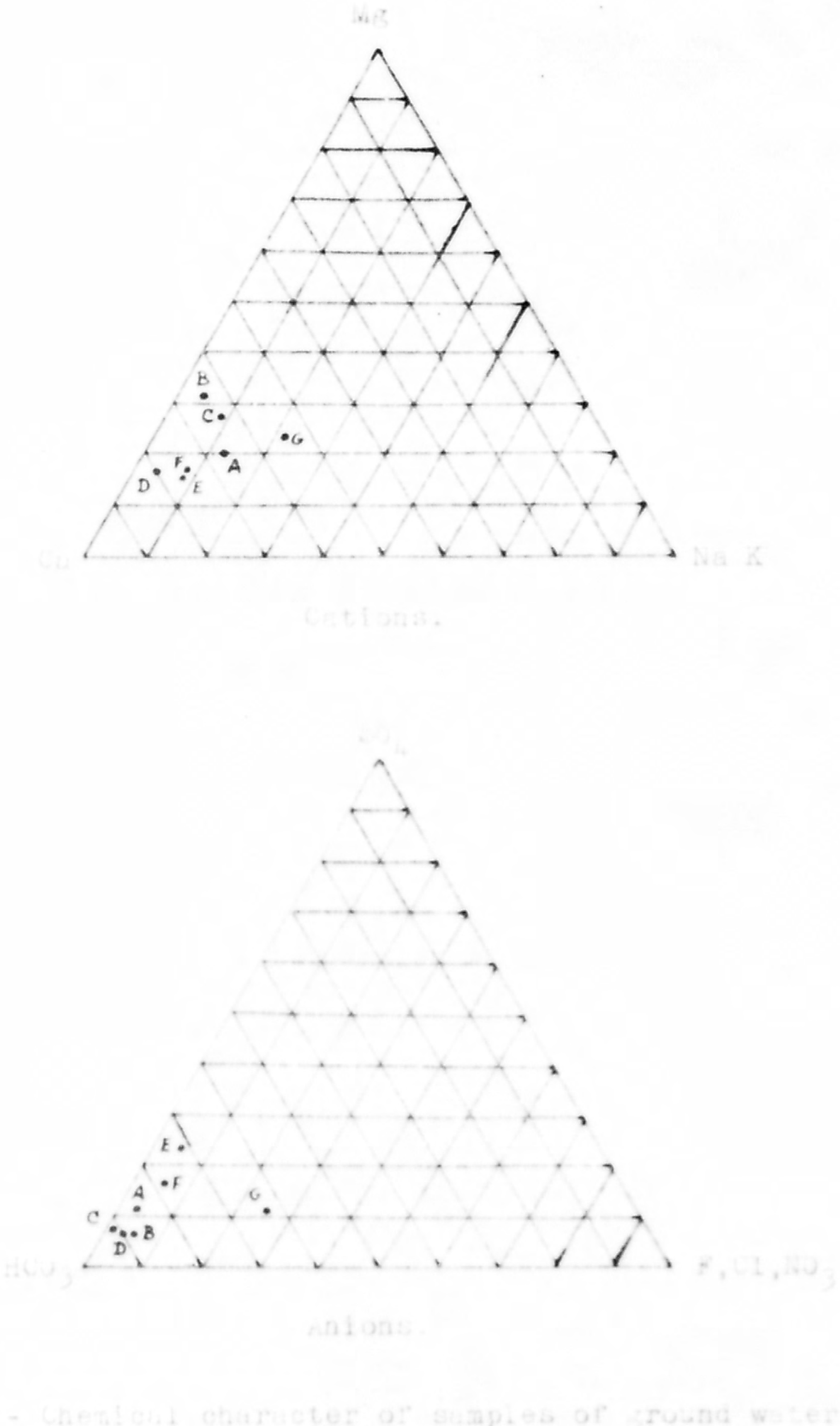


Figure 24. - Chemical character of samples of ground water from the Matanuska Valley agricultural area.

described as moderately hard to hard calcium bicarbonate waters.

During the early days of the agricultural colony several wells encountered highly mineralized water in bedrock in or near Palmer. The files of the Alaska Rural Rehabilitation Corporation list several wells, now abandoned, that obtained salt water, and one that obtained "sulphur water". One sample is reported to have had a carbonate hardness of 4,300 ppm and a chloride content of 3,520 ppm. Reported differences in the chemical character of these mineralized waters suggest that the salt water is of local occurrence. It probably has been trapped in the rock since this area was covered by marine or estuarine water at some time in the past; it is not modern salt water from Knik Arm.

Utilization of Ground Water

Palmer is the only community in the Matanuska Valley agricultural area which has a public water supply. Initial drilling in the town site was, for the most part, unsuccessful. For many years the Matanuska Valley Farmers Cooperating Association piped water for its creamery from Brazil Springs, about 3 miles northwest of Palmer, and excess water was sold to individuals. The spring flow was insufficient to meet the needs after the dry season of 1950. In 1951 the existing pipeline was extended, and water is now obtained from Carnegie Creek about half a mile northwest of the springs.

A test well was completed for the city of Palmer in January, 1952, and utilization of ground water in the future is anticipated.

A community well was dug in Wasilla several years ago, but it is not in use. At present individual wells supply water for all inhabitants.

Water for the settlement at Matanuska, prior to it abandonment, was obtained from a spring at the base of the bluff about half a mile to the north.

Individual wells are capable of providing sufficient water for domestic and farm use, during most seasons, throughout the greater part of the agricultural area. A large proportion of farmhouses have plumbing and pressure water systems, and the water use includes supplying livestock and cooling milk. Well water has been used for watering gardens on a very small scale.

Notes on the Occurrence of Ground Water in Glacial Drift

Glacial drift, because of its wide distribution at and near the land surface throughout many of the heavily populated parts of the north temperate regions, is among the terrains most important as sources of ground-water supplies. The

Matanuska Valley agricultural area presents many of the geological situations typical of glaciated regions, and hence forms a convenient basis for the consideration of the occurrence of ground water in glacial deposits. Many of the features developed here by valley glaciation are undoubtedly representative of those in regions of continental glaciation, although they are on a smaller scale.

The hydrologic character of drift, like that of other deposits, is dependent upon those factors that influence its permeability. The nature of the material, particularly the sorting of its constituent particles, determines its water-transmitting character; the relative size, shape, position, and composition of adjacent deposits determines their effectiveness as aquifers or confining bodies.

The sediments included under the term drift are till, outwash-stream deposits, and deposits laid down in standing water. Both till and the fine-grained deposits formed in lakes or in bodies of estuarine or marine water are relatively impermeable; their poor permeability may be due to lack of sorting, to a predominance of fine constituents, to compaction, or to a combination of these factors. On the other hand, the relatively well sorted and coarser grained materials forming the deposits of outwash streams and certain lake beds, as deltaic sands and gravels, are commonly much more permeable. This two-fold division of drift on the basis of its permeability is of fundamental importance in the hydrology of glaciated regions.

Glacial deposits commonly are highly variable in composition, size, and shape, or are discontinuous, over short distances. Permeable and impermeable materials are thus likely to be adjacent to one another. Thin, water-bearing sand layers enclosed in till provide an excellent example of such a relation, in this case probably caused by changes in the depositional processes beneath the ice. Other types of stratigraphic relations between till and more permeable deposits, on a larger scale, may be formed by the complex interplay of ice advance and retreat and meltwater activity near the margins of the ice, or by the deposition of outwash material in front of the ice and upon its recently-exposed deposits, or by the deposition of younger drift over that of an earlier glaciation.

Materials of differing permeability also are adjacent to each other at the land surface in glaciated regions. For example, permeable gravel may fill outwash-drainage channels cut into ground moraine (predominantly till) or older valleys cut in bedrock; permeable deposits of gravel and sand may form the land surface for some distance behind and in front of an end moraine; and hills of till representing end moraines of retreatal phases, medial and lateral moraines, and high parts of the ground moraine may protrude through gravel deposits which range from thick to thin within a limited area.

One important consequence of the nature and distribution of glacial deposits is that in large parts of glaciated valleys ground water cannot be obtained, or can be obtained only in limited quantity, from the upper part of the saturated zone. In the Matanuska Valley this is true of large areas underlain by till. Other unconsolidated terrains show this character also, but probably few so strikingly as the glacial deposits.

A second feature of the hydrology of glaciated valleys is the importance of artesian or confined ground water. In some localities there may be little or no recoverable unconfined water above a near-surface layer of relatively impermeable material. In other localities ground water may be unconfined and in free hydrologic connection with artesian water beneath a nearby confining layer that underlies only part of the valley floor. This appears to be the case near Palmer. The situation in other parts of the Matanuska Valley is not known because of lack of data, but the buried till known to be present in each of two other areas west of Palmer probably is also discontinuous laterally because of differences in the glacial deposition or because of later glaciofluvial erosion. It may be expected that in a valley glaciated several times there may be two or more bodies of confined water, one beneath another and separated by relatively impermeable layers.

A third characteristic of the hydrology of glaciated valleys is the common occurrence of bodies of perched water. Layers of silt or of till in outwash-stream deposits hold many small bodies of perched ground water. Moreover, both surface and underground water may be held in depressions on ground moraine. And many streams, even those which flow upon the surface of nonsaturated gravel deposits, may lose little water to the underlying material. Because of this widespread occurrence of perched water in glaciated valleys the levels of lakes and streams may not always be taken as indicative of the general ground-water level beneath the adjacent land surface.

Because of all these differences in the nature and water-transmitting character of the glacial deposits — differences due to changes in the depositional processes at a given locality, to changes in these processes at a given time from one locality to another, to changes from deposition to erosion, and vice versa, during a single glaciation, or to the complex sequence of events accompanying multiple glaciation — the distribution and thickness of water-bearing and nonwater-bearing deposits in a glaciated region may be difficult to define or predict. Study of the geology and ground-water hydrology of a glaciated region requires the use of the methods of field geology together with those peculiar to ground-water investigations. Geomorphology permits interpretation of landforms and of the underlying materials in terms of the processes and materials observed at modern glaciers. Deposits exposed at the surface or penetrated by wells may be studied as stratigraphic units, and the standard methods of correlation used. The geomorphic and stratigraphic methods should be used together wherever possible; indeed, in many instances they cannot strictly be separated. Landforms cannot be used in studying older deposits that have been effaced by erosion or covered by younger materials, however, and in these situations reliance must be placed upon the stratigraphic approach. If sufficient exposures and well logs are available the geologic picture drawn on the basis of these methods may be fairly detailed. The hydrologic character of the deposits is investigated by the study of data from wells. The nature of the hydrologic cycle in the area is described from the study of water-level fluctuations, water-level maps, data on the flow of streams and springs and the flow or pumpage of wells, infiltration at the land surface, and climatological records. These methods, together, permit a qualitative description of the ground-water hydrology of the region. Quantitative methods of ground-water investigation, such as carefully-controlled pumping tests, yield more précise information on the hydrologic charactér of the deposits, and permit prediction of the quantities of water available from the formations studied. It is interesting to note that in some localities where direct observation of the geology is impossible, data obtained by these hydrologic methods may permit inference of the nature of the materials beneath the surface and extension of the conclusions based upon surface geologic studies in other localities.

BIBLIOGRAPHY

Ahlmann, H. W. (1948), Glaciological research on the North Atlantic coasts: Roy. Geog. Soc., Res. Ser., no. 1, 83 pp.

Black, R. F. (1951), Eolian deposits of Alaska: Arctic, vol. 4, pp. 89-111.

Bourne Associates, Inc. (1952), Report on Palmer city test well; typewritten report, 5 pp.

Capps, S. R. (1940), Geology of the Alaska Railroad region: U. S. Geol. Survey Bull. 907.

Cederstrom, D. J. (1952), Summary of ground-water development in Alaska, 1950: U. S. Geol. Survey Cir. 169.

Dachnowski-Stokes, A. P. (1941), Peat resources of Alaska: U. S. Dept. Agr. Tech. Bull. 769.

Flint, R. F. (1947), Glacial geology and the Pleistocene epoch; New York, John Wiley and Sons, Inc., 589 pp.

———— and Deevey, E. S., Jr. (1951), Radiocarbon dating of late-Pleistocene events: Am. Jour. Sci., vol. 249, pp. 257-300.

Grahmann, R. (1931/32), Das Alter der "Hellerterrasse" und der Dünen bei Dresden: Mitt. Ver. Erdkde. Dresden Jahrb. 1931/32, N. F., pp. 85-97.

Holmes, C. D. (1952), Drift dispersion in west-central New York: Geol. Soc. Amer. Bull., vol. 63, pp. 993-1010.

Karlstrom, T. N. V. (1950), Preliminary geologic map of lowlands, Anchorage area, Alaska: U. S. Geol Survey open-file report.

Kellogg, C. E., and Nygard, I. J. (1951), Exploratory study of the principal soil groups of Alaska: U. S. Dept. Agr. Mon. 7.

Kulp, J. L. (1952), The carbon 14 method of age determination: Sci. Monthly, vol. 75, pp. 259-267.

————, Tryon, L. E., Eckelman, W. R., and Snell, W. A. (1952), Lamont natural radiocarbon measurements, II: Science, vol. 116, pp. 409-414.

Landes, K. K. (1927), Geology of the Knik-Matanuska district: U. S. Geol. Survey Bull. 792-B.

Lutz, H. J., and Griswold, F. S. (1939), Influence of tree roots on soil morphology: Am. Jour. Sci., vol. 237, pp. 389-400.

Martin, G. C., and Katz, F. J. (1912), Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500.

Martin, Paul (1942), Surface features of the Matanuska Valley, Alaska: Assoc. Am. Geographers Annals, vol. 37, pp. 127-128.

Meinzer, O. E. (1923), The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489.

Poser, Hans (1951), Die nördliche Lössgrenze in Mitteleuropa und das spätglaziale Klima: Eiszeitalter und Gegenwart, vol. 1, pp. 27-55.

Rivers, V. C. (1950), Report on engineer's investigation and general design for water system, Palmer, Alaska: Engineering Study 13, prepared for Alaska Dept. Health.

Rockie, W. A. (1942), A picture of Matanuska: Geog. Rev., vol. 32, pp. 353-371.

―――――― (1946), Physical land conditions in the Matanuska Valley, Alaska: U. S. Dept. Agr., Soil Cons. Service, Phys. Land Survey 41.

Smith, P. S. (1939), Areal geology of Alaska: U. S. Geol. Survey Prof. Paper 192.

Stone, K. H. (1950), The Matanuska Valley colony: U. S. Dept. Interior, Bur. Land Management, 95 pp.

Thwaites, F. T. (1950), Outline of glacial geology: Ann Arbor, Edwards Bros., Inc., 129 pp.

Tuck, Ralph (1938), The loess of the Matanuska Valley, Alaska: Jour. Geology, vol. 46, pp. 647-653.

U. S. Dept. Agr. (1941), Climate and man: Yearbook of Agriculture.

U. S. Weather Bureau (1936-48), Climatological data, Alaska: Annual Summary.

Washburn, Bradford (1935), Morainic bandings of Malaspina and other Alaskan glaciers: Geol Soc. Amer. Bull., vol. 46, pp. 1879-1890.

Wenzel, L. K. (1942), Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887.