Geology and Ground-Water Resources of the Anchorage Area, Alaska

By D. J. CEDERSTROM, FRANK W. TRAINER, *and* ROGER M. WALLER

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By D. J. Cederstrom, Frank W. Trainer, and Roger M. Waller

ABSTRACT

The Anchorage area, at the head of Cook Inlet in south-central Alaska, occupies 150 square miles of a glaciated lowland and lies between two estuaries and the Chugach Mountains. Two military bases are in the area; Anchorage is the largest city in Alaska and the chief transportation center for this part of the State.

The bedrock in the Anchorage area is chiefly Tertiary shale in the lowland and metamorphic rocks of Mesozoic age beneath the adjacent mountain slopes. Glacial drift which underlies nearly the entire area has an average thickness of several hundred feet and appears to include at least five sheets of deposits, two of which are exposed. The drift consists of till, outwash-stream and lake deposits (sand and gravel), and estuarine (and lake) deposits (clay and silt). The stratigraphy and lateral distribution of the deposits are complex, but data at hand show that the thickest deposits, including all the estuarine and lake sediment and most of the stream-deposited sediment, are beneath the lowland away from the mountain wall, and that the deposits near the mountains are till and subordinate outwash sediments.

Deposits of sand and gravel laid down by outwash streams in channels and on outwash plains are the most important aquifers, and the only ones which yield large quantities of ground water from single beds. Thin layers of sandy or gravelly material in till are also important aquifers although they yield relatively small quantities of water. Bedded sand and silt associated with the estuarine and lake(?) clay commonly becomes unstable during drilling and pumping, and has been successfully developed in only a few wells. Unconfined aquifers are extensive, but permeable saturated material is thin in many places and water supplies available from them are small or undependable in those places. The most important aquifers are confined or artesian. Clay and till form the confining beds; the till is somewhat "leaky" in many places. Near Anchorage the buried water-bearing beds appear to be interconnected and to form a single artesian system. The water table and piezometric surface slope from the mountain wall of the lowland toward the estuaries, and the flow of the ground water is in that direction. The aquifers are recharged by the infiltration of precipitation at the land surface and of surface water through stream beds: near the mountains the artesian aquifers are probably recharged in part by percolation from the water-table aquifer, and far from the mountains the water-table aquifer is probably recharged in part by upward flow from the underlying artesian aquifers. In several valleys and at a few other places, in the lowland, artesian wells flow at the land surface.

The outwash sand and gravel are moderately to very permeable; most of the other water-bearing materials are much less permeable. The co-

efficient of transmissibility for some single beds of sandy gravel is as high as 60,000 to 100,000 gpd per ft (gallons per day per foot); for the entire section of glacial drift at and near Anchorage it is believed to be of the order of 200,000 gpd per ft. Calculations based on this value for the total section and on the slope of the piezometric surface indicate that in the immediate vicinity of Anchorage about 5 million gpd flows through each mile-wide section of the drift (measured in a northeast-southwest direction, perpendicular to the direction of flow), under normal (nonpumping) conditions. Under conditions of continuous heavy pumping the slope of the piezometric surface is steepened, flow is increased, and additional recharge is induced.

The highest yield reported from a well in this area is 2,600 gpm (gallons per minute) with 35 feet of drawdown; the highest reported specific capacity is 180 gpm per ft of drawdown, for a well pumped at 270 gpm. Only a few wells in the area have been developed for high yields. Well screens have been used with notable success in many wells, but in some the screen slot-size used was smaller than the optimum and the increase in well efficiency was much less than might have been obtained with the proper screen. Although many wells were dug in this area before 1950, nearly all the wells constructed since then are drilled wells finished with open-end casing. The dug wells and the drilled wells which tap unconfined aquifers are commonly less than 60 feet deep; most of the artesian wells are deeper than 100 feet, and a few are deeper than 400 feet.

Shallow, very permeable gravel along the upper course of Ship Creek is recharged by infiltration from the stream. The deeper artesian beds here contain water under lower head than the shallow beds, and are recharged by percolation from the shallow beds. A recharge well was constructed through which water flowed by gravity from the shallow aquifer into deeper ones. A maximum of 140 gpm recharge occurred under these conditions, and a total of 20 million gallons of water was added to the deeper artesian system in a 6-month period. Considerable difficulty was experienced in constructing the well with the equipment at hand, but there is no reason why a more efficient recharge well might not be constructed with less difficulty and at reasonable cost if proper equipment were available.

Few wells have been drilled into the bedrock. Small water supplies can be obtained from the metamorphic rocks in some places but probably not from the shale.

The chemical quality of ground water in the Anchorage area is generally good. The water is of the calcium magnesium bicarbonate type and is soft to moderately hard. In some places, particularly in shallow aquifers, it contains objectionable amounts of iron. In most places the ground water contains very little chloride; higher concentrations in water from a few wells are thought to be residual from brackish water which once saturated the sediments. Soft water yielded by several wells has undergone base exchange to some extent.

The temperature of the ground water, 36° to 38° F, is important in helping prevent late-winter freezing of distribution lines.

More than 600 wells had been constructed in the Anchorage area by 1956. Most of these furnish small domestic supplies, but about 50 wells provide public water supplies (mainly for municipal use and for rural housing developments and schools). Geologic and hydrologic conditions favorable for the development of large ground-water supplies are restricted to the lowland part of the area, and largely to the tract between Anchorage and Mountain View on the west and the alluvial fan of Ship Creek on the east. Small ground-water supplies can be obtained in most other parts of the area. West of Anchorage the beds of clay and of till are thicker than at and near Anchorage, and the aquifers are commonly thinner and consist of finer material. In other parts of the area the glacial drift is mostly till or interbedded till and clay that contains only thin aquifers that are probably of restricted lateral extent.

INTRODUCTION

This report summarizes the results of an investigation of the ground-water resources of the Anchorage area by the U.S. Geological Survey. The Anchorage area, at the head of Cook Inlet in south-central Alaska (fig. 1), for the purpose of this report, is defined as the lowland west of the Chugach Mountains and south of Eagle River (fig. 2) that is bounded on the northwest and southwest by Knik

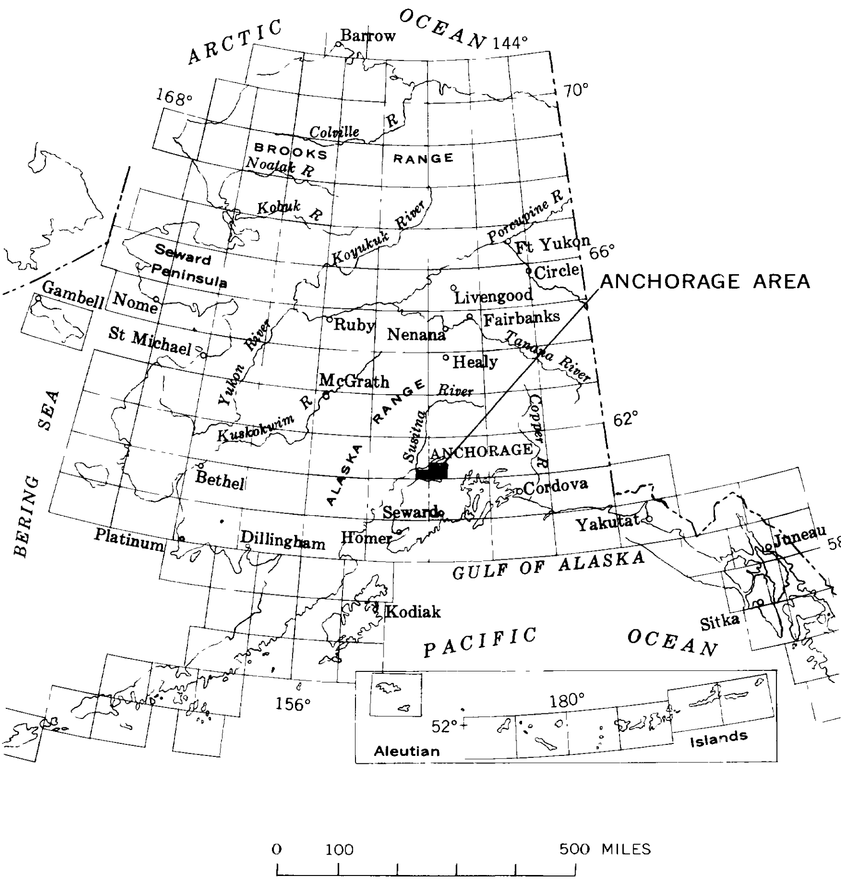

FIGURE 1.—Map of Alaska showing location of Anchorage area.

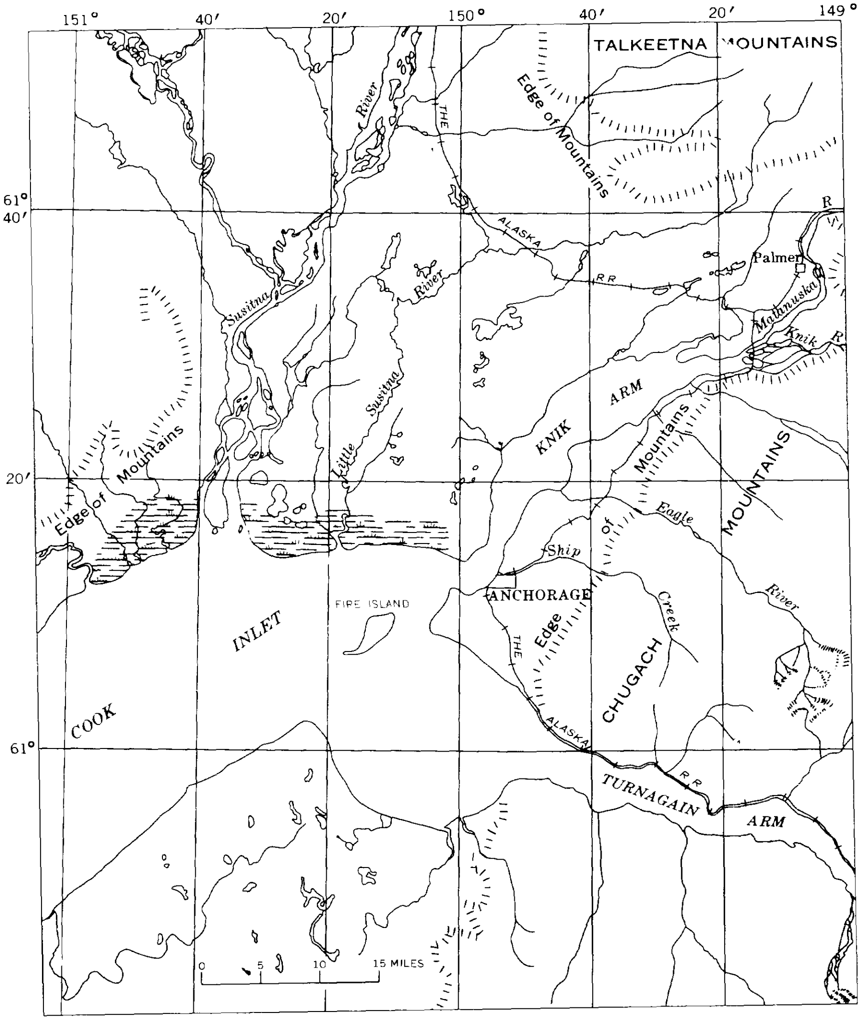

FIGURE 2.—Map showing geographic features in vicinity of Anchorage.

Arm and Turnagain Arm. However, Fire Island, which is separated from the mainland part of the lowland by tidal flats, is included in the area described in this report. As thus defined, the area covers about 150 square miles. It includes the city of Anchorage, several suburban communities, and two military bases, Elmendorf Air Force Base and Fort Richardson.

The purpose of the investigation, for which field studies were made during the period 1949–55, was the determination of the distribution and character of the consolidated rocks and unconsolidated deposits in the area and of the occurrence, availability, and quality of the ground water. The major phases of the work, carried out in large part concurrently, included geologic mapping (pl. 1), well inventory, and test drilling; in addition, fluctuations of water levels were observed in selected wells, several aquifer tests were made, and representative water samples were collected for chemical analysis.

Detailed geological study of the Anchorage area was begun after the Second World War when two aspects of the geology were investigated by the U.S. Geological Survey: a study of the engineering geology of the area (Miller and Dobrovolny, 1959), and the groundwater investigation described in this report. Other works relating to the geology of the Anchorage area include discussions of the upper Cook Inlet region and of the mountains north and south of Anchorage (Capps, 1916, 1940; Park, 1933; Smith, 1939) and discussions of special aspects of the geology, such as peat deposits (Dachnowski-Stokes, 1941), soils (Kellogg and Nygard, 1951), and the Pleistocene geology of the upper Cook Inlet region (Karlstrom, 1955; 1957; 1960).

ACKNOWLEDGMENTS

The investigation on which this report is based could not have been made without the help of many persons who, as individuals or as members of government agencies or of private firms, gave information, permitted access to private or government property, or provided assistance in other ways. To all these persons the writers acknowledge their indebtedness.

The drillers and drilling contractors cited in the well records provided well logs and other information and described their experience with drilling conditions in the Anchorage area. Representatives of the District Engineer (U.S. Army Corps of Engineers), of Alaska Public Works, and of the city of Anchorage provided records of many wells and, with representatives of the Post Engineer (Fort Richardson), of the Alaska Railroad, of the Anchorage Forestry District (Bureau of Land Management), and of the U.S. Public Health Service, facilitated the investigation in many other ways. Particular appreciation is expressed to Mr. A. J. Alter, Chief Sanitary Engineer of the Alaska Department of Health, for his interest and encouragement.

GEOGRAPHY

CLIMATE

The mountain barriers to the north and south prevent the Anchorage area from having the temperature extremes of the interior of Alaska and the heavy precipitation of regions along the Gulf of Alaska.

The average, maximum, and minimum monthly precipitation at Anchorage are shown in table 1. (The values are "normal" values computed by the U.S. Weather Bureau for a standard period, which for the Anchorage station is 1921–50.) In most years the winter and spring are relatively dry; on the average, about 48 percent of the mean annual precipitation falls during the 3-month period July–September and 67 percent during the 5-month period June–October. The maximum precipitation recorded at Anchorage in a 24-hour period was 2.06 inches, in July 1956. The average seasonal snowfall is about 4½ feet, but in 32 years between 1916 and 1955 the seasonal snowfall ranged from 2½ to 11 feet. The deepest snowfall recorded in 24 hours was 17.7 inches, in December 1955.

The spring and autumn at Anchorage are characteristically short, the summer cool, and the winter moderately cold. Table 1 shows the average, maximum, and minimum temperatures by months. The lowest temperature recorded here was −38°F, in February 1947; cold periods during which the temperature reaches −20° to −30°F are usually short. The highest temperature observed was 86°F, in June 1953. Temperatures as high as 80°F are uncommon. The average frost-free season is 112 days. The ground usually begins to thaw in April or May and to freeze in October. During winter the ground commonly freezes to depths of 6 to 8 feet, and deeper where the snow is removed.

TABLE 1.—*Climatological data for Anchorage, Alaska, 1921–50*

[Tr., trace (<0.01 inch). Data from U.S. Weather Bureau]

	Jan.	Feb.	Mar.	Apr.	May	June	July
Precipitation, in inches:							
Normal total	0.76	0.60	0.60	0.40	0.51	0.89	1.55
Maximum monthly	2.13	3.07	1.61	1.50	2.00	2.94	3.28
Minimum monthly	.05	Tr.	Tr.	Tr.	.02	.03	.19
Temperature, in ° F.:							
Normal	13.0	18.6	24.8	35.4	45.7	53.7	57.3
Daily maximum	20.4	26.9	33.8	44.2	55.0	62.8	65.4
Daily minimum	5.5	10.3	15.7	26.6	36.4	44.5	49.1

	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Precipitation, in inches:						
Normal total	2.56	2.71	1.87	1.00	0.84	14.29
Maximum monthly	5.91	5.16	5.13	2.40	2.67	----------
Minimum monthly	.23	.52	.26	.04	.00	----------
Temperature, in ° F.:						
Normal	55.6	48.0	36.0	22.3	13.8	35.3
Daily maximum	63.9	56.3	43.2	29.0	20.4	----------
Daily minimum	47.3	39.6	28.8	15.5	7.1	----------

Cloudy days are common; in an average year there are 205 cloudy days, 86 days which are partly cloudy, and 74 days which are clear. The cloudiness, together with the relatively low summer temperatures, contributes to a low rate of evaporation which in turn favors the growth of forest in this region where the climate is semiarid by middle-latitude standards.

TOPOGRAPHY AND DRAINAGE

The land surface in the Anchorage area slopes north and west from the Chugach Mountains to Knik Arm and Turnagain Arm; its altitude ranges from about 1,200 feet on the mountain slope to sea level along the estuaries. In most of the area the relief, over distances of a mile or two, is less than 200 feet. The most conspicuous topographic feature on the lowland is a wide plain that extends from Eagle River (where that stream leaves its mountain valley) nearly to the westernmost tip of the mainland (fig. 2; pl. 2). This is the plain on which Anchorage, its suburbs, the airports, and most of the military installations are situated. North of the plain a prominent ridge, as much as 150 feet high, runs from Eagle River to Knit Arm at Anchorage. A gently rolling surface extends north of the ridge to Knik Arm, and other tracts of rolling terrain are between the plain and the mountains to the south, between the headlands southwest of Anchorage, and on Fire Island. Tide flats lie between Fire Island and the mainland, border the shore of Turnagain Arm, and extend into the mouths of most of the streams which cross the lowland.

The chief streams in the Anchorage area are Ship Creek, Campbell Creek, and Rabbit Creek, which rise in the mountains, and Chester Creek which rises in the lowland. Eagle River bounds the northeastern edge of the area and drains a small part of it. All these streams flow to tidewater and are tidal near their mouths. The range of tidal fluctuation in the estuaries at Anchorage is commonly 30 feet or more.

The plain that extends from Eagle River toward Point Woronzof and the slopes in hilly terrain are well drained, but many depressions and some flat terrain are marshy. Shallow lakes are common in many of these places, especially southwest of Anchorage.

VEGETATION

Three types of plant cover may be distinguished in the Anchorage area for general descriptive purposes: (1) In well-drained tracts the forest consists of white spruce, cottonwood, aspen, birch, willow, alder, and shrubs and other small plants. Much of the area is wooded, commonly by second growth which followed fires. (2) Tide flats along Turnagain Arm and at the mouths of the tidal streams are practically bare of vegetation where they are subject to ordinary tides, and have a cover of small, salt-tolerant plants where they are flooded infrequently. (3) Poorly drained land above tide level is covered by mosses, sedges, grasses, and other marsh plants. Black spruce, birch, and alder also grow in some marshy places. Peat has formed in most of the bogs. Dachnowski-Stokes (1941) has described typical bogs and peat deposits of the Anchorage area.

CULTURE

Anchorage received its name from its position on Knik Arm at the head of water navigable to ocean-going vessels. Before docks were built, these ships were anchored off shore, and passengers and cargo were unloaded by smaller vessels. Settlement of the Anchorage area began in 1915 during construction of The Alaska Railroad, and the city was incorporated in 1920.

The city grew slowly until the Second World War but rather quickly thereafter. According to the 1960 census (U.S. Dept. Commerce, 1960, p. 9–10), there were 82,833 inhabitants in Election District 10; most of these people live in the Anchorage area as it is defined in this report. Anchorage had a population of 44,237; there were also about 9,000 people in suburban communities and about 29,000 inhabitants of the area who lived outside the city and its suburbs.

Anchorage is linked to Fairbanks by The Alaska Railroad. Since completion of the railroad a highway system has also been constructed; it links Anchorage with Kenai Peninsula communities to the southwest, with parts of interior Alaska, and with Canada and the conterminous United States by way of the Alaska Highway. Much of this highway system has been paved since the Second World War, and it is of growing importance for automobile and truck traffic. Water transportation to Anchorage is important despite the fact that in many years the port has been ice-bound during the winter months, and a considerable volume of freight, including cement, petroleum products, and military supplies, is brought by freighter and by barge. Construction of improved port facilities was completed in 1961. Anchorage is an important center for air travel to Alaska communities, and is also on international air routes.

Most employment in the Anchorage area is related to the activities of government agencies, chiefly the military. In addition, Anchorage serves as the transportation and supply center for much of the surrounding region. These factors, together with the rapid growth of population in the area, have led to the increasing importance of the transportation, construction, and service industries. A small fish cannery is the chief other local industry. Some farming is carried on; the chief crops are potatoes and vegetables.

PURPOSE AND SCOPE OF INVESTIGATION AND HISTORY OF GROUND-WATER DEVELOPMENT

A brief appraisal of the ground-water resources of the Anchorage area was made by the senior author in the autumn of 1949. There were then about 20 drilled wells in and near Anchorage, some of which were rather shallow and not all of which were successful. On the other hand, numerous dug wells were in use. No well in the area, with the exception of a well (No. 51) at Artesian Village which had a reported flow of 100 gpm (gallons per minute), produced more than 10 to 15 gpm. Three other wells on the military reservation had reported yields of 50 to 140 gpm but were pumped only at low rates.

Deep test holes and thorough testing of the strata in them were the greatest and most immediate needs of the investigation. Test drilling on a small scale was begun in 1950. Because the equipment then available in the area was not adequate to carry out such a testing program, a modern well-drilling machine was rented from the Alaska Department of Health. Test drilling with that machine was begun in 1951 and was continued for each season through 1955. Most of the drilling was done for the Geological Survey by Messrs. George and Glenn Ramsey. Several of the more significant findings of the test-drilling program are cited on pages 10–11.

Before and during the test-drilling phase of the investigation, a continuing inventory was carried on to record and preserve data provided by the drilling of water wells. A tabulation of wells, made by J. E. Kerr and Cederstrom, and released early in 1951, showed that about 35 additional wells had been drilled in the Anchorage area since 1949. The rate at which wells were drilled continued to increase rather steadily thereafter. By the end of 1952 there were about 140 drilled wells in the area, and by the end of 1955 more than 600 drilled wells. A second tabulation, prepared by Cederstrom and Trainer and released in 1953, showed that by the end of 1952 deep wells supplied water to 16 trailer camps, 8 restaurants, 4 large schools, and 8 housing projects. Most of the remaining wells provided small domestic supplies. With few exceptions, the rural inhabitants of the area, as well as residents of surburban areas later annexed by the city of Anchorage, relied on ground water for their domestic supplies. Anchorage and the military posts used water from Ship Creek.

The drilling of domestic and other wells of low yield provided considerable subsurface information which is invaluable in the interpretation of the geology of the area. However, most of these wells were drilled only deep enough to obtain the quantity of water needed for one or a few families, and little effort was made to develop large quantities of water. Thus they did not provide detailed information about the quantities of ground water available and about some other hydrologic problems of the area. The test wells drilled by the Geological Survey, and test and production wells drilled by the military authorities and by the city of Anchorage, provided information of this kind.

The following paragraphs present briefly, more or less in chronological order, the more significant results of well drilling in the Anchorage area. Emphasis is placed on the test wells, but a few other wells of particular importance are also mentioned. Wells mentioned by number may be located by reference to plate 2; the logs of many of them are given in table 4. A tabulation of most of the well records collected during this investigation has been published by the Alaska Department of Health and Welfare (Waller, Cederstrom, and Trainer, 1961).

The first deep test well drilled in the area by the Geological Survey (well 177, drilled in 1952) was southeast of Anchorage and about a mile south of Merrill Airport. The well penetrated several thick beds of permeable sand and was the first in the area which indicated, from the results of pumping tests and from other information, that a total yield of a million gallons per day, or more, might be available from a single well.

The second of the Survey's deep test wells (64, at the Ranger Station on Oilwell Road, about half a mile northeast of Artesian Village) was also drilled in 1952. It penetrated several very permeable aquifers of sand and gravel, and tests again demonstrated a potential yield of a million gallons per day or more. In addition, this well was the first in the lowland part of the area to penetrate the entire section of unconsolidated deposits (here 394 feet thick) and to enter the underlying shale bedrock.

The increasing use of water from Ship Creek (which provided the total supplies of Anchorage and the military bases) and the fact that the stream already was barely able to meet demands during the winter season of low flow prompted the military authorities in 1952 to begin a study of possible additional sources of water. A firm of consulting engineers engaged to carry out the study recommended (Black and Veatch, 1952, p. 10) the drilling of a deep test well on Elmendorf Air Force Base. The well (28, about a mile west of Mountain View), drilled for the District Engineer by a private contractor in 1953, reached a total depth of 850 feet; it penetrated the bedrock, and remains the deepest well in the area. It was pumped at a rate of 1,380 gpm, or nearly 2 million gallons per day (mgd). Another test well (35), drilled a short distance away by the Geological Survey, was used as an observation well during the test-pumping of well 28.

All these wells are in the lowland a considerable distance from the wall of the valley. Numerous wells drilled by private drillers showed that similarly favorable ground-water conditions probably prevail in much of the remainder of the lowland near Anchorage. Farther west and south, however, drilling showed the distribution of aquifers to be erratic. One well (282) drilled in 1953 at Turnagain Heights (southwest of Anchorage) did not reach water-bearing sand until a depth of 443 feet, but produced 150 gpm with 16½ feet of drawdown. South of the International Airport, well 606 obtained a yield of 270 gpm with a drawdown of only 1½ feet; it remains the most efficient well in the entire Anchorage area. Wells drilled near Sand Lake and farther south and west showed that geologic and hydrologic conditions in that part of the area are very different over short distances.

Privately drilled wells to the east and south showed that, with local exceptions, ground-water conditions near the valley wall are much less favorable for the development of large water supplies than near Anchorage. Deep wells, such as 505, 509, and 571 in the southern part of the area and wells 195–198 about 3 miles east-southeast of Anchorage, provided good examples of the range in geologic and ground-water conditions near the valley wall.

At the same time the information being provided by both the test drilling and the drilling of water wells began to show more clearly that supplies of ground water sufficient for domestic use can be obtained from the unconsolidated deposits in most parts of the Anchorage area. The bedrock showed little promise as an aquifer.

In 1953 and 1954 the Geological Survey drilled several test wells along Ski Bowl Road, near the valley wall about 5 miles east-northeast of Anchorage. Well 17 was drilled into the shale beneath the unconsolidated deposits (230 feet thick); pumping tests indicated that more than a million gallons per day should be available from layers of sand in the unconsolidated deposits. Ground water was also found to be available in large quantities near Ship Creek at this locality (well 18) from shallow aquifers recharged by infiltration from the stream. A recharge well (19) was constructed to test the practicability of increasing recharge and thus of increasing the underground storage of water which now flows away to the sea.

Some additional developments during 1956, after the completion of this investigation, are noted here and at other places in this report because they answer important questions raised during the investigation.

Officials of the city of Anchorage had been considering for some time the feasibility of using ground water to supplement the existing surface-water supplies. As the results of test drilling and test pumping by the Geological Survey and by the military became available, the decision was made to develop supplemental ground-water supplies. It was considered that the expense involved would be justified by the savings in preventing the freezing of distribution lines throughout the area, as a result of the use of relatively warm ground water during the winter. Test drilling was carried out in 1955 and 1956 at sites near Merrill Airport, in a general locality near existing water mains and near where drilling had shown the presence of favorable ground-water conditions. One well (163) was converted into a production well, and other production wells were also drilled. The results of the drilling are discussed later (p. 84); it may be noted here that several of the wells were even more productive than had seemed likely on the basis of the earlier drilling.

At the same time the Corps of Engineers drilled several wells near Ship Creek, southwest of the Ski Bowl Road test locality. These wells also were highly successful.

The municipal wells and those at Fort Richardson are pumped during the coldest months of the year. During the winter of 1956–57, for the first time, no mains in the city distribution system froze, service calls because of frozen connections decreased sharply, and overall consumption of water decreased by a million gallons per day because residents no longer had to allow taps to run continuously in order to prevent freezing of the lines (Anchorage Daily Times, March 6, 1957, p. 11). More than a third of the daily consumption of 6 mgd was pumped from wells at that time.

GEOLOGY

The Anchorage area is in a wide lowland flanked by rugged mountains (fig. 2). The Chugach Mountains, south and east of the area, are underlain by bedrock which is widely exposed at the land surface. In the lowland, however, the bedrock is nearly everywhere covered by unconsolidated deposits, chiefly glacial drift laid down beneath or in front of the great glaciers which flowed into and along the lowland during the Pleistocene Ice Age. During the period since melting of the glaciers, the deposits on the lowland have been partly eroded away; the Anchorage area represents a remnant of the lowland separated from the remainder of it by Knik Arm and Turnagain Arm.

MESOZOIC AND TERTIARY ROCKS

The consolidated rocks that form the Chugach Mountains are exposed in the Anchorage area at several places along the mountain front and have been found in a few wells there. Several wells in the lowland have also reached bedrock, but there appear to be no exposures of consolidated rock in the lowland part of the area described in this report.

The rocks in the mountains near Anchorage are Mesozoic metamorphic rocks which are largely of igneous and sedimentary origin, such as greenstone, graywacke, slate, argillite, and limestone (Capps, 1940, p. 53–61 and pl. 1). Along the mountain front near Anchorage they are exposed (Miller and Dobrovolny, 1959, pl. 1) in the canyon walls of the larger streams that flow from the mountains—Eagle River, Ship Creek, both forks of Campbell Creek, and Little Rabbit Creek. They crop out on all the mountain peaks and higher slopes, at sea level along Turnagain Arm near the mouth of Little Rabbit Creek, and in the vicinity of Potter near the south edge of the area. These Mesozoic rocks have also been found in several wells along the side of the lowland (wells 532, 539, 587, 588, and probably 197). Cuttings from well 539, examined by the writers, are fine-grained light-brown to gray limestone which may be the same limestone exposed at the southern edge of the area (Waring, 1947, p. 5; Miller and Dobrovolny, 1959, p. 9).

Bedrock is not exposed in the lowland part of the Anchorage area, so far as the writers are aware. Just north of this area Capps (1940, p. 62 and pl. 1) found Tertiary shale containing thin coal beds in the north bank of Eagle River; he also states (1940, p. 62) that Tertiary rocks are present at Point Woronzof. The writers were unable to find bedrock at Point Woronzof, however, and believe that the report may have been based on the presence of transported Tertiary coal in the glacial drift. Five wells in the lowland have penetrated bedrock (wells 1, 17, 28, 64, and 197). The rocks in these wells are interbedded shale and sandstone containing coal beds, and are considered to be the Tertiary rocks that are exposed locally at Eagle River and more extensively in the Matanuska Valley to the northeast and on the Kenai Peninsula to the southwest.

Bedrock has been found at too few localities in the Anchorage area to permit detailed reconstruction of the configuration of its buried surface. The available subsurface information suggests, however, that the bedrock surface slopes away from the mountains toward Knik Arm.

QUATERNARY DEPOSITS

Unconsolidated deposits, chiefly glacial drift, underlie the land surface in most of the Anchorage area. The drift consists of till, outwash-stream deposits, and estuarine and lake(?) sediments. Nearly all the drift was formed when Pleistocene glaciers extended into this area, but modern estuarine deposits, consisting in part of glacial sediment transported long distances by streams, are being formed along the coast. The nonglacial deposits include peat and stream- and wind-laid sediments. Plate 1 shows the surface distribution of all except the wind deposits.

GLACIAL DRIFT

TILL ("HARDPAN")

Till is a fragmental unconsolidated material deposited by or from glacial ice with little or no modification by water. It is characteristically unsorted and consists of rock fragments that range from clay to boulders. However, melt water flows in many places beneath and at the margins of the ice, and till deposited there may contain or grade into bodies of stream and pond sediments. In places glacial drift has been washed just sufficiently to make difficult the distinction between till and poorly sorted sand or gravel. Other till has been formed in part of sorted sediment from older deposits eroded by the ice. For these reasons the origin of many possibly ice-laid deposits is difficult to determine. Till is best considered one end member of a continuous gradational series of materials; the other end member is well-sorted drift such as sand or gravel (Flint, 1947, p. 103).

The till in the Anchorage area is poorly sorted and contains angular to rounded stones (pebbles to boulders) in a matrix of mixed sand, silt, and clay. It is characteristically massive and tough, and is known locally as "hardpan" because it is difficult to excavate. Except where weathered it is gray. Exceptions to the textural character described above were found in morainal deposits exposed along Knik Arm northeast of Anchorage, and on Fire Island. In those places the drift is composed of hard, stony sand that contains little silt and clay. The writers believe that this material was deposited from ice in standing water, perhaps as the glacier moved into an estuary or lake. It differs from till (as strictly defined), which was not washed or sorted during deposition, but the two types of deposits probably grade into one another laterally. Where rich in silt and clay, the till is relatively impermeable and does not yield water to wells. Locally, however, the massive material contains thin layers of sorted sand or irregular streaks of sandy and silty material that transmit water much more readily than the massive till.

Photographs (figs. 3–8) of Castner Glacier and of an unnamed glacier beside it, in the Alaska Range, illustrate some of the conditions under which rock debris is washed by water during the melting of a glacier. Rubble from the surface of the ice is in part eroded by melt-water streams and in part let down upon the underlying surface when the glacier melts. Depending on the degree to which it has been washed, this material left after melting of the ice may be a poorly sorted "ablation till" or a well-sorted gravel. The deposits

FIGURE 3.—Rubble cover on terminal part of a valley glacier, Alaska Range.

FIGURE 4.—Close-up view of rubble on the surface of a glacier, Alaska Range.

left in channels and flood plains of melt-water streams in front of the glacier, if they occupy drainage courses cut into ground moraine and are later covered by younger till deposits, may be similar to some of the buried layers and stringers of sandy or gravelly material found in till in the Anchorage area.

Much of the till in the Anchorage area is best known from subsurface data, and the criteria by which buried till may be recognized are therefore important. Till in wells is best identified by its hardness (which causes the layers of more compact material to stand open ahead of the casing during cable-tool drilling), by its relative impermeability, and by the character of the drill cuttings (clay, silt, sand, and stones, sometimes containing chunks of undisturbed material). Pieces of the undisturbed material recovered in cuttings from several wells are like the compact till observed in some exposures, and their presence thus substantiates interpretations based on the other types of evidence.

Some of the deeper beds of till are particularly difficult to drill because they are harder and more compact than till nearer the surface. For example, during the drilling of well 177 (using the cable-tool method), 8 hours of drilling was required to penetrate 3½

FIGURE 5.—Debris on a glacier surface may slump upon deposits formed beneath the ice.

feet of till, about 382 feet below the surface, whereas shallower tills in this well had been penetrated at rates of about 17 feet in 8 hours. The greater hardness of the deep till is thought to be partly a result of compaction during later glacial episodes, when the deposits were overridden by younger glaciers, and perhaps partly a result of later glacial erosion which may have removed the upper part of the till (which had been deposited during glacial recession and was less compact than the till formed during glacial advance). The shallow till, on the other hand, was not overridden; it is less compact than the deep till (which may have been overridden several times), and its upper part contains recessional deposits which in some places are comparatively soft.

OUTWASH SAND AND GRAVEL

Beds of outwash sediments laid down by melt-water streams and in ponds and lakes are at or near the land surface in much of the Anchorage area, and are also an important part of the buried drift.

FIGURE 6.—Slump material has fallen across a stream flowing on the glacier but has failed to dam the stream. Water flowing through this debris winnows out the clay and fine sand content, and thus creates a fairly permeable till.

They consist chiefly of sand, pebbly sand, and sandy gravel, but deposits of gravel, silty sand, and silt are also common. The structure of the deposits ranges from massive to well bedded, and many layers are crossbedded and show channel-and-fill structure. Exposures and well logs show that interbedding of the more sandy and more gravelly layers is common. Typical structures of some outwash deposits are shown by figures 9 and 10.

Most wells do not completely penetrate the water-bearing sand or gravel, and the full thickness of the material is therefore known at few places. The average thickness of the beds of sand and gravel is probably between 20 and 40 feet. Deposits thicker than 100 feet have been found in several wells (606, 608, and perhaps 10). In bluffs at Point Woronzof and Point Campbell and in well 618 (on the bluff southeast of Point Campbell) the deposits are as much as 150 to 200 feet thick.

The sand and gravel are relatively permeable and are the important aquifers in the Anchorage area.

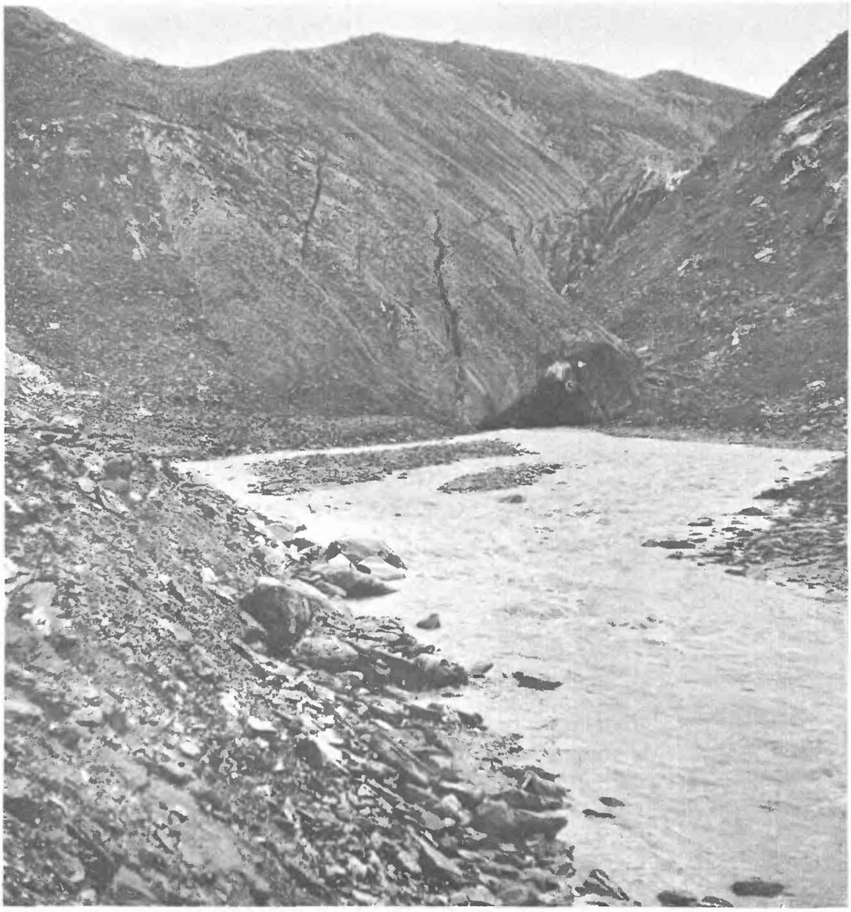

FIGURE 7.—Summer flow in glacial melt-water stream, Alaska Range. Ice face in center background.

CLAY AND SILT

These deposits consist chiefly of clay and silt but in many places contain subordinate sand or stony material. They are well exposed in bluffs along Knik Arm and are recorded by the logs of more than 200 wells.

The commonest material in exposed sections is blue-gray plastic clay. In many places it contains isolated stones and layers or irregular masses of silt, sand, and pebbly sand. All these types of sediment appear to be gradational or closely associated with one another, and in some places they are parts of a single deposit. In subsurface deposits the clay is easily recognized during drilling because of its stickiness. Sandy or silty clay is less sticky, and the

FIGURE 8.—Glacial melt-water channel in early fall. Channel fill material has been somewhat water worked. Such deposits penetrated in wells would probably be termed gravelly till by the driller.

silt and sand are incoherent. Silty fine sand that becomes quicksand during drilling was found in about 25 percent of the wells that penetrated the clay and silt. This sand commonly contains pebbles of coal (which are relatively light particles) but few other large grains. In about 15 percent of the wells that penetrated clay and silt, beds of pebbly clay and clayey or silty gravel were interbedded with, or just above or below, the clay and silt. In many wells the clay, silt, and associated deposits are 100 to 150 feet thick; in a few wells these deposits are more than 300 feet thick.

The clay in these deposits is relatively impermeable and does not transmit water in a practical sense. The sandy and silty beds are slightly to moderately permeable but are difficult or impossible to develop as aquifers.

NONGLACIAL DEPOSITS

A mantle of silt 1 to 2 feet thick covers the land surface in most of the Anchorage area except where modern stream, estuarine, or

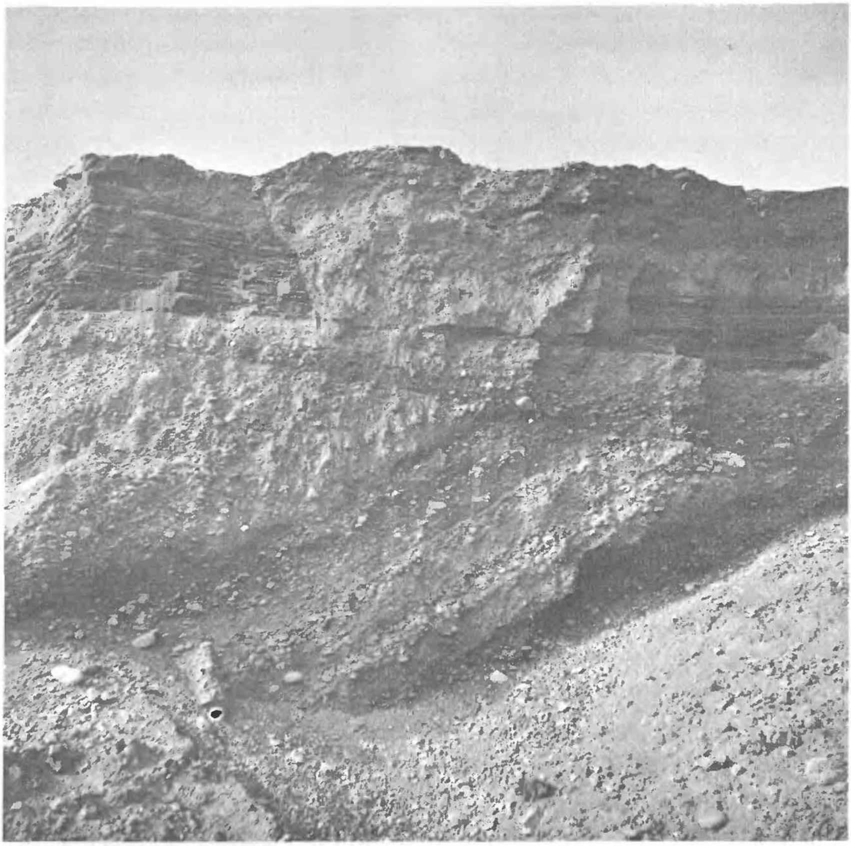

FIGURE 9.—Coarse crossbedded gravel deposits at O'Malley Road and Seward Highway. Width of channel shown in cross section, upper center, is about 7 feet.

bog deposits are being formed. Because of its fine grain size and its wide areal distribution regardless of topography, this material is considered to have been deposited by wind. Dust is occasionally observed being blown into the Anchorage area from along Turnagain Arm or Knik Arm; no doubt dust was more readily available in the past than it is today, both in those source areas and in parts of the Anchorage area. The silt is the parent material of the soil in this area. Kellogg and Nygard (1951) have described typical soils of this area, which are of the podzol type. Dunes are also present at a few places, particularly on bluffs near Point Campbell and near the southwestern end of Fire Island, but are rare in the remainder of the Anchorage area. All these deposits of silt and sand are relatively permeable and favor the infiltration of precipitation.

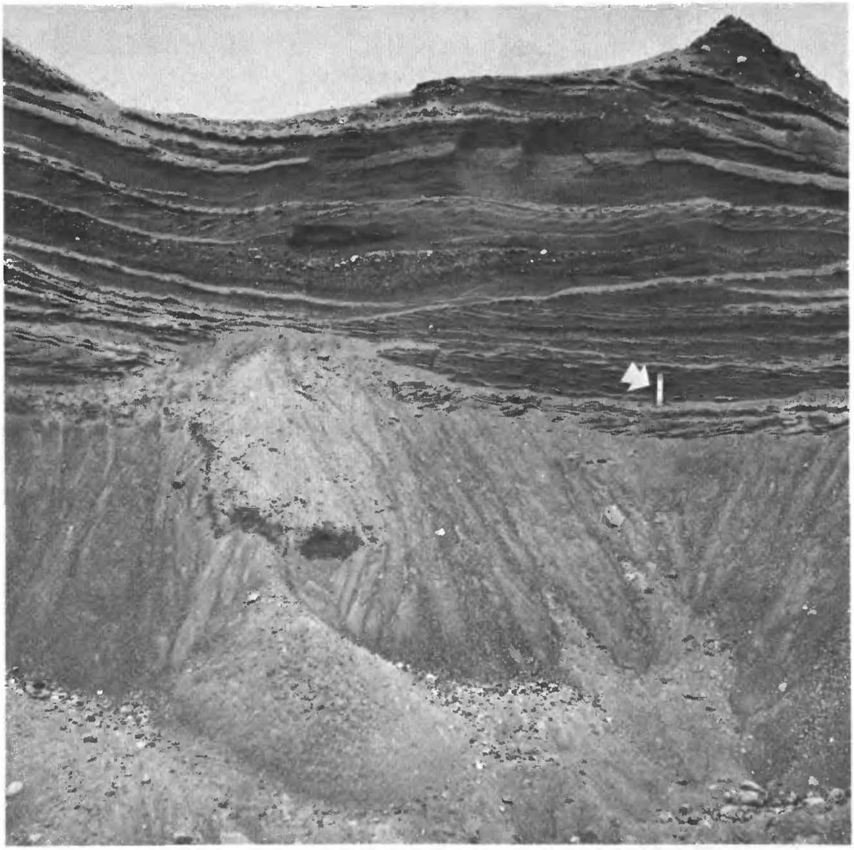

FIGURE 10.—Bedded sand and gravelly sand in pit south of Klatt Road. These deposits are somewhat better sorted than those seen in Fig. 9. Six-inch ruler, right center, shows scale.

All the streams in the Anchorage area except Eagle River are nonglacial. Their deposits are chiefly sand and gravel derived from glacial drift or from low terraces along their courses. The terrace deposits are considered nonglacial because they occupy valleys cut into the youngest outwash deposits in the area and are apparently unrelated to these deposits.

Peat has accumulated in the past, and is forming today, in closed depressions and on flat-floored valleys in the Anchorage area. The largest bogs are in the western part of the area. Dachnowski-Stokes (1941) and Kellogg and Nygard (1951) have described bogs, peat, and bog soils, and Miller and Dobrovolny (1959, pl. 1) have mapped the bog deposits. Peat sections observed during the course of this study range from a few inches to about 12 feet thick. Miller and Dobrovolny (1959, p. 78–79) report similar thicknesses. The writers believe that available subsurface information is sufficient to justify mapping the materials inferred to lie beneath most of the peat deposits. However, the larger peat deposits are indicated on plate 1 by an overprint symbol which shows where such inference has been made.

STRATIGRAPHY OF THE UNCONSOLIDATED DEPOSITS

The wide valley in which Anchorage is situated was glaciated repeatedly during the Pleistocene Epoch. During a given glacial advance the surficial deposits of that time were partly eroded away, and new deposits of till were laid down by the moving ice or were deposited from it as it melted. Melt-water streams carved valleys in the till and formed deposits of sand and gravel. Sand, silt, and clay were deposited in depressions in the newly exposed land surface that were occupied by lakes or estuaries. All these processes of erosion and deposition occurred again during succeeding glaciations, and this sequence of events resulted in a complex series of deposits of varied character and irregular thickness and distribution.

The subsurface data at hand show that the section of glacial drift near the mountain wall is till and local subordinate deposits of sand and gravel. On the other hand, farther out in the valley the section consists of outwash sand and gravel, estuarine or lake clay and silt, and till; in many places the washed or sorted deposits comprise several times the volume of the till. The thickness of the drift ranges from a few tens of feet or less, along the mountain front, to perhaps 700 feet or more (well 28) in the lowland; the average thickness in the lowland is probably several hundred feet.

This pattern in the types of deposits present and in their thicknesses is attributed to the repetition of valley glaciation in this area. During each glacial advance, erosion was concentrated in the deeper part of the valley. During each episode of glacial recession the deposits of washed drift were formed mainly in the deeper part of the valley (1) where the ice had been thicker than near the valley walls, (2) where melt-water streams flowed for longer periods, cut their valleys to deeper levels, and laid down thicker and more extensive deposits, and (3) where depressions were flooded by estuarine or lake waters. The character and thickness of the glacial drift and the stratigraphy of the deposits at a given locality thus depend on the position of the locality in the valley. The occurrence of ground water, which depends on the properties of the deposits in which it is found, is also dependent upon geographic position in the valley.

The deposits of glacial drift in the Anchorage area have been identified and in part correlated by means of several criteria: (1)

lithologic properties such as composition, determined from the examination of exposed material or drill cuttings or inferred from drilling characteristics, (2) hydrologic properties, (3) stratigraphic position, particularly where some of the units occur in a characteristic sequence or have distinctive physiographic form, (4) zones of rust-stained material, or other evidence suggesting unconformities within the deposits, and (5) position relative to a reference horizon such as present sea level. Evidence provided by these criteria must be used with care; it is naturally most conclusive where several criteria are used together and where data have been obtained from several localities near one another.

On the basis of these studies two sheets of glacial drift exposed at the land surface, which represent two glacial advances, have been identified in the Anchorage area. Plate 1 shows the distribution of these exposed drift sheets. Several older sheets of drift are also present but they are buried nearly everywhere. Figure 11 illustrates the writers' interpretation of the stratigraphy of the drift in part of the area. Table 2 presents a composite stratigraphic column for the drift.

Figure 11 is a stratigraphic diagram which shows the sequence of deposits in a series of sections north and east of Anchorage. These sections were chosen for illustration because they show the sequence of deposits in greater detail than sections of similar length in other parts of the area, and because the writers observed the drilling of nearly all the wells on which they are based.

TABLE 2.—*Composite stratigraphic column of the glacial drift in the Anchorage area*

Deposits that are exposed:
- Postglacial estuarine deposits; in part modern glacial drift, in part reworked material.
- Younger drift sheet:
  - Outwash-stream and lake deposits
  - Ground-moraine deposits
  - End-moraine deposits
- Estuarine and lake(?) deposits
- Older drift sheet:
  - Outwash-stream deposits
  - Glacial drift, undifferentiated
  - Ground-moraine deposits
  - Lateral glacier-margin deposits

Deposits that are not exposed:
- Younger deposits:
  - Till, clay and silt, and sand and gravel; believed to represent a single sheet of glacial drift related to a single glaciation.
- Older deposits:
  - Till, clay and silt, and sand and gravel; poorly known but believed to represent at least two glaciations.

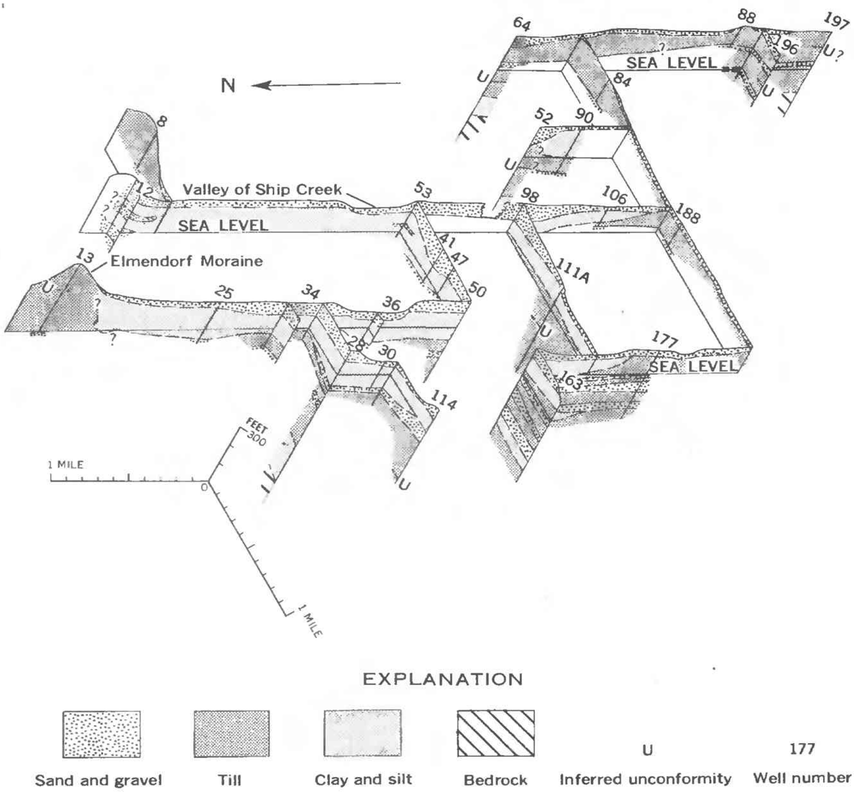

FIGURE 11.—Panel diagram showing geology of the Anchorage area.

The stratigraphic diagram extends across the broad plain on which Anchorage is situated. At the north end of the diagram the land surface is underlain by till; the hill on which well 13 was drilled is part of the end moraine of the last glacier which extended into the area. In the southern part of the tract shown by figure 11 the drift consists chiefly of till and subordinate deposits of sand and gravel. South of well 196, toward the valley wall, till is generally at the land surface, in ground moraine deposited by the next-to-last glacier that invaded the area; this till makes up the bulk of the drift exposed in the southern part of the Anchorage area. The surficial deposit of sand and gravel shown in the central part of figure 11, forms an outwash plain built in front of the last glacier and covers a complex sequence of deposits of clay, till, and sand and gravel. The outwash-plain deposits are piled against the end moraine to the north and overlap the ground moraine to the south. A bed of clay and silt immediately beneath the outwash-plain deposits is exposed along Knik Arm; the older deposits of drift shown in figure 11 are not exposed.

UNEXPOSED DEPOSITS

TILL

The buried beds of till shown in figure 11 were identified on the basis of the criteria cited in the preceding section of this report, and were correlated by means of the sequence of strata. Many of the drillers' logs, together with the writers' interpretations of some of them, are given in table 4. Of particular interest in the logs is the mention of weathered material (brown or yellow till beneath gray or blue till) and of thin zones of "wet" (water-yielding) material in till which otherwise does not yield water. The layers of brown till are thought to mark unconformities where fresh till was deposited upon a land surface underlain by older, weathered till. The wet layers do not necessarily mark unconformities, but where they occur in thick deposits of till, at positions similar to those of the weathered layers found in nearby wells, they are reasonably interpreted as possible unconformities. Study of the drillers' logs suggests that several wells (for example, 50, 64, 111A, 163, and 177) penetrate as many as 3 or 4 layers of till that probably represent as many separate advances of the ice. The uppermost till sheet in each well is reasonably correlated with the older exposed drift sheet, which is at the land surface at and beyond the south end of the area of figure 11.

At other localities in the Anchorage area the buried till also seems to represent several different till layers. Far out in the lowland, as between Anchorage and Lake Spenard to the southwest and between Anchorage and Turnagain to the south, the tills are interbedded with other deposits. Nearer the mountain front, however, the till makes up the bulk of the glacial drift, and only where it shows evidence of unconformities can its probable multiple character be detected. (See, for example, the log of well 516, table 4).

CLAY AND SILT

A layer of clay and silt deposited in standing water lies beneath the outwash-plain deposits in much of the central part of the Anchorage area, and is exposed in bluffs along Knik Arm. Several wells have penetrated older deposits of clay and silt which appear to be similar to the exposed deposits. In the tract represented by figure 11 three wells (28, 64, and 163) penetrated these older deposits. Beds of clay and silt that rest on the bedrock in wells 28 and 64 are reasonably correlated on the basis of subdivision of the overlying tills, but clay in well 163 which appears to be in a similar stratigraphic position is underlain by an older till. A younger unexposed clay which is beneath a layer of till was also found in well 28.

Beyond the region represented by figure 11 unexposed clay and silt was found (1) in wells 1 and 68 to the northeast, (2) in 9 wells south and southwest of Anchorage, near Spenard and the International Airport, (3) in 2 wells (509 and 571) near Turnagain Arm in the southern part of the Anchorage area. Most of the buried clay deposits appear to be equivalent to the younger of the unexposed clay deposits in well 28, and thus to antedate the next-to-last glaciation of this area.

Their grain-size composition shows that all these deposists were probably laid down in standing water. Estuaries and lakes or ponds have probably been present in this area at various times during its glacial history, and both types of environment may be represented by these deposits.

SAND AND GRAVEL

Numerous wells in the Anchorage area tap layers of sand and gravel that underlie buried deposits of clay or till such as those described in the preceding paragraphs. Excellent examples are recorded by the logs of wells 163 (at 188–211 and 268–338 feet), near Merrill Airport, and 177 (173–226 and 317–334 feet), near Anchor Park. The beds are reasonably correlated between these wells on the basis of stratigraphic sequence and relative altitude, and pumping tests in well 163 suggest that the beds are laterally extensive.

Because the wells which tap the buried deposits of sand and gravel do not penetrate them completely, little is known of the range in thickness of these deposits. However, they have been found in many wells and must represent either a few extensive deposits or many small ones. Data from pumping tests suggest that the deposits are interconnected over wide lateral distances. The thickness and apparent wide extent of the sandy deposits in wells 163 and 177 suggest that, in this part of the area at least, the beds are sheetlike deposits, perhaps similar to those in the outwash plain on which Anchorage is situated.

Many thinner layers of sand and gravel found in till, such as some in wells 28 and 196 (see logs), probably represent more local layers formed during deposition of single till sheets. However, data from pumping tests show that many of these thin layers are also effectively interconnected hydraulically.

CORRELATION AND LATERAL EXTENT

Table 2 summarizes the stratigraphy of the glacial drift. Among the deposits that are not exposed are strata of till, of clay and silt, and of sand and gravel that are known from few localities but which seem to represent at least two drift sheets. The best evidence for these deposits is provided by the logs of wells in the tract represented by figure 11, but the deposits cannot be correlated with assurance over more than short distances.

In addition to these deposits known from only a few localities, the buried deposits also include what appears to be an extensive younger sheet of glacial drift that contains deposits of till, of clay and silt, and of sand and gravel. The sequence of deposits has not been established because the deposits cannot be correlated with assurance, but study of the logs of such wells as 28, 163, and 177 suggests the presence of till that is separated from the next younger deposit of till (that is, the older till exposed at the surface) by clay, by sand, or by both these materials. The notes in figure 11 provide examples of the writers' interpretation of the sequence of deposits. This younger sheet of buried drift is best known from the vicinity of Anchorage and Spenard but it is probably present in much of the remainder of the Anchorage area. More than 40 wells in the area penetrate till believed to be part of this drift sheet, and more than 30 wells penetrate a stratum of clay and silt believed to belong to it. On the average, both the till and the clay appear to be about 50 feet thick. The grain-size composition of the clay and silt suggests deposition in standing water; the geographic distribution of the deposit resembles that of a later deposit (table 2 and figure 6) which is at least partly of estuarine origin.

More than 250 wells, widely distributed over the area, have penetrated sand and gravel beneath the tills exposed at the land surface. However, this sand and gravel undoubtedly includes not only deposits associated with the buried till and clay units described above but also deposits formed during advance of the ice during the succeeding glaciation.

EXPOSED DEPOSITS

The exposed deposits consist of two sheets of drift, an older one at the surface in the southern and southeastern parts of the area and a younger one, exposed in the northern and central parts of the area, that overlaps the older deposits to the south. East of the International Airport the younger drift is exposed in about half the area and the older drift is exposed in half the area and underlies the younger deposits in at least a quarter of it. Deposits in the tract west of the International Airport appear to represent the older drift sheet. Deposits exposed on Fire Island are correlated with the younger exposed drift sheet on the mainland.

OLDER DRIFT SHEET

The inclusive term "drift sheet" is used here because the deposits of till and outwash sediments laid down during one glacial episode are readily seen to make up one sheet of glacial drift. The older deposits already discussed were described as layers of till, clay and silt, or sand and gravel because the relations among the individual deposits are not evident.

Deposits which comprise the older drift sheet include glacier-margin, ground-moraine, outwash-stream, and undifferentiated deposits (pl. 1). It is possible that some of these deposits, especially near the valley wall, represent two or more glaciations, but the writers found no evidence for that interpretation; the deposits are therefore attributed to a single glacial episode.

The glacier-margin deposits (table 2 and pl. 1) are present in a narrow tract along the southern and southeastern edge of the area, where they form a prominent bench on the valley wall. They include till, in lateral moraines, and sand, gravel, and poorly sorted material in kame terraces. Well records and exposures show that the sorted material is commonly a few feet thick, although 40 feet of sand and gravel was found in well 537.

The ground-moraine deposits and their extension beneath younger sediments form the most extensive layer of glacial drift in the Anchorage area. The deposits are chiefly till. They are exposed between the glacier-margin deposits (with which they are gradational laterally), on the south, and the outwash-plain sediments which overlap them on the north. Figure 11 illustrates the extension of the ground-moriane deposits beneath the outwash plain; the uppermost till layer in wells 28, 50, and 64, for example, is considered to represent the buried ground-moraine deposits. In 280 wells which completely penetrate these deposits in either their exposed or their buried parts their average thickness is about 60 feet; in 60 of these wells, however, the deposits are more than 100 feet thick. There seems to be no areal pattern of change in thickness. Where existing wells are closely spaced, as in Spenard, fairly accurate estimates of the thickness of the deposits can be made at new localities. In most other places, however, their thickness can be predicted only within broad limits before new wells are drilled.

Sand, gravel, and subordinate silt and clay deposited by melt-water streams during glacial recession lie on the ground moraine and in drainage courses cut into it and into glacier-margin deposits. These stream deposits have been differentiated (pl. 1) as earlier and later deposits on the basis of surface form. Layers of sand and gravel in a few wells may represent these deposits in places where the ground moraine has been buried. The deposits are chiefly clean sand, gravelly sand, and sandy gravel. Neither exposures nor well logs show any conspicuous difference in the character of the materials mapped as earlier and later phases of the deposits. The thickness of the deposits, where penetrated by wells, ranges from a few feet to 80 feet.

The deposits mapped as undifferentiated drift are west of the International Airport and Jewel Lake. Excellent exposures in the bluffs at and near Point Woronzof and Point Campbell and the records of 5 wells provide information about the sediments. The deposits are chiefly sand, silt, and sandy gravel that are deeply rust stained. The material is well sorted within beds (except that pebbles of coal are found in all the beds, including those of sand and silt), and is in large part well bedded. Much of the material is crossbedded. At Point Woronzof and Point Campbell the beds dip gently east or southeast. Material that resembles the till exposed elsewhere in the Anchorage area rests on the sand and gravel at the top of the bluff at Point Campbell; it is covered by dune sand. About three-quarters of a mile southeast of Point Woronzof the sand and silt are overlapped by clay along what appears to be a beach zone; this contact between the deposits is not exposed south of the bluff. Sediments beneath the sand and silt at Point Woronzof, exposed in 1952, are gray clay, brown clay sand, and iron-cemented gravel and sand conspicuously unlike the overlying sand and silt and thought to represent a different deposit. The base of the undifferentiated drift thus appears to be near sea level at Point Woronzof; it appears to be about 20 feet below sea level in well 420 (see log, table 4). Because the top of the deposits is about 200 feet above sea level at Point Campbell, their total thickness appears to be somewhat greater than 200 feet. Miller and Dobrovolny (1959, p. 26) and the writers have independently interpreted these deposits as delta deposits formed by streams flowing east from a glacier thought to have lain west of the position of Point Campbell.

ESTUARINE AND LAKE(?) DEPOSITS

Clay and subordinate silty, sandy, and stony deposits, partly of estuarine origin and perhaps partly of lacustrine origin, underlie at least 40 square miles of the central and southern parts of the Anchorage area. Outside the end moraine of the last glacier (north of Anchorage) these deposits overlap the older ground-moraine deposits to the east and the undifferentiated drift (inferred delta deposits) to the west; near the International Airport and Jewel Lake they extend from Knik Arm to Turnagain Arm. Sediments exposed along Knik Arm north of the end moraine, and found in wells there, probably represent these deposits. This clay has been named the Bootlegger Cove Clay by Miller and Dobrovolny (1959, p. 35).

Figure 11 illustrates the stratigraphic position of the clay, in relation to other deposits, in part of the Anchorage area. The clay forms a continuous or nearly continuous layer which pinches out to the northeast, east, and southeast. North of Anchorage the deposit is interrupted by the end moraine. Interbedded mud and sand in well 12, on the moraine, probably represent sediments laid down at the margin of the ice as the glacier advanced into standing water. None of these deposits were in well 13, also on the moraine. At Cairn Point, in the end moraine where it is cut by the valley occupied by Knik Arm, the clay lies beneath silt, sand, and gravel. Adjacent to the south side of the moraine the silt, sand, and gravel, have been deformed and the beds now dip steeply to vertically; the clay appears to be deformed also. Much of the moraine at Cairn Point is composed of a hard, stony sand thought to be a water-laid "till." All this evidence leads the writers to believe that the last glacier advanced into standing water while the uppermost part of the clay and its associated, near-source deposits were being laid down, and that the moving ice deformed the sediments. Deposits exposed in bluffs along Knik Arm northeast of Cairn Point, and found in wells 3 and 10, are thought to represent the northeastward extension of the clay, overridden by the advancing ice but not completely eroded away.

Outside the tract represented by figure 11, the clay is best known in the vicinity of Spenard, where many wells pass through it into underlying beds of till or sand and gravel. The thickness of the clay ranges from a few feet to more than 300 feet; thicknesses of 100 to 150 feet are common. In a few wells the clay is much thicker than in nearby wells; in well 281, for example, the clay is more than 300 feet thick while in several wells nearby it is less than 150 feet thick. The writers believe that some of these wells may tap two layers of clay (the older one being one of the layers of clay that are not exposed) at places where the intervening layer of till is absent. At a few other places the clay covers buried hills of till which have no expression at the land surface, and there (for example, at wells 333, 350, 381, and 422, in and near Spenard) the clay is thinner than at surrounding localities.

About 180 wells in the Anchorage area pass through the clay. In 60 percent of the wells till was found beneath the clay; sand or gravel was found beneath it in most of the other wells, although in many the sand and gravel are only a few feet thick and rest on till.

The commonest material in exposed sections and in the subsurface is blue-gray plastic clay. Interbedded clay, silt, and sand, thought to be parts of a single deposit, have been differentiated in many wells. (See, for example, the log of well 606.) The sand is fine and silty and contains few larger grains except pebbles of coal; it commonly becomes quicksand when penetrated by the drill. In many places, pebbly clay or clayey gravel has been found interbedded with the clay, silt, and sand; it is thought to consist of slumped or ice-rafted material.

The clay in these deposits is relatively impermeable, and its chief hydrologic significance is in forming artesian confining beds. The sandy and silty materials are slightly to moderately permeable but are difficult or impossible to develop as aquifers.

Fossil clams occur sparsely in clay exposed in the bluff near Turnagain Heights, west of Anchorage. They have been identified by F. S. MacNeil of the U.S. Geological Survey (Miller and Dobrovolny, 1959, p. 45) as species which live in marine or estuarine water today. The writers found shells in place in undisturbed clay, and hence regard the clay which contains them as an estuarine deposit. Miller and Dobrovolny (1959, p. 44–48) consider the origin of the deposit in detail and conclude tentatively that it was probably formed in a glacial lake. The writers have no conclusive evidence bearing on the possible lacustrine origin of any of the material, although they believe that the beds of well-sorted sand associated with the clay are more reasonably explained as lacustrine deposits than as deposits formed in brackish or salt water because they contain little clay; presumably clay would have flocculated and been deposited with the sand in a salt-water environment. It is conceivable that the entire deposit is estuarine and that the sand was laid down in freshened water near the margin of a tidal glacier, but this origin is unlikely because the sand beds have been found in the entire area of occurrence of the clay rather than near one margin of the deposit. Satisfactory explanation of the origin of the deposit probably will have to await detailed studies over a larger area than that described in this report. On the basis of the evidence available at Anchorage, the writers consider the Bootlegger Cove Clay of Miller and Dobrovolny (1959) to be in part an estuarine deposit and perhaps in part a lake deposit. The age of the deposit is considered in the discussion of Quaternary history; the writers believe that the clay was deposited during the period which separated the times of maximum extent of the next-to-last and last glaciers which invaded the Anchorage area.

YOUNGER DRIFT SHEET

Deposits formed during the last glaciation of the Anchorage area comprise a single sheet of glacial drift on the mainland. They include end-moraine deposits north of Anchorage, outwash stream and lake deposits formed outside (south of) the moraine during advance and recession of the ice, outwash-stream deposits laid down inside the moraine during the recession, and ground-moraine deposits inside the end moraine. End-moraine deposits in Fire Island probably were formed during this glacial episode.

The deposits in the end moraine north of Anchorage (the Elmendorf Moraine of Miller and Dobrovolny, 1959, p. 25) are exposed along Knik Arm near Cairn Point and in a few excavations in the ridge to the east; several wells provide subsurface information. In a ravine about a quarter of a mile south of Cairn Point, Bootlegger Cove Clay extends from the beach to a level 126 feet above it (Miller and Dobrovolny, 1959, p. 39); the horizontally bedded clay is overlain by hard, stony sand interpreted by the writers as water-laid "till." Between this exposure and another, about a quarter of a mile farther south, where clay reaches a level about 150 feet above the beach and dips 10° north, folded beds of silt, silty sand, and fine gravel extend down nearly to beach level. These beds dip at angles between 70° south and the vertical; their stratigraphic relation to the clay in nearby exposures is not evident. The hard, stony sand is also well exposed in bluffs farther northeast; in some places it is overlain by clean sand and gravel. Excavations in the ridge to the east expose drift which ranges from compact clayey till (evidently deposited on land rather than in water) to clean sand and gravel; these various deposits are in part interbedded, and in places have been deformed.

The exposure near Cairn Point and to the east, together with the logs of wells 8, 12, and 13, suggest glacial, estuarine or lake, and outwash-stream deposition, including deposition of material from ice standing in water; at some places two or more of these modes of deposition occurred in succession or repeatedly. According to the writers' interpretation the clay and silt are sediments of glacial origin deposited in standing water some distance from the ice; the interbedded silt, silty sand, and fine gravel were deposited near the ice; and the stony sand is water-sorted drift deposited beneath or at the edge of the ice. The folding of the deposits is attributed to the weight of the ice and to shoving by the glacier as it moved forward.

The end-moraine deposits in Fire Island are composed chiefly of water-laid "till" like that at Cairn Point and of clean sand and gravel. These two types of deposits are interbedded and in numerous exposures were seen (1954) to have been deformed into complex folds, many of which are recumbent. The interbedded deposits extend from the beach to levels as high as 100 to 150 feet above it. Other deposits exposed in the bluffs include hard, clayey till and poorly sorted gravel. Deposits in wells 449 and 450 (see log of well 450) appear to be the same as those observed in the bluffs, and are thought to represent a single sequence of deposits about as far down in the section as present sea level. Rust-stained (weathered) material about at sea level in well 450 suggests that the underlying deposits represent an older drift sheet. Miller and Dobrovolny (1959, p. 31–32) report the presence beneath till, in one exposure in the bluff, of coal-bearing sand that resembles that near Point Campbell.

The deposits in Fire Island are believed to have been formed while the terminus of a glacier moved back and forth over this locality and advanced into standing water part of the time. Fire Island is interpreted as part of the end moraine of a glacier that lay in Turnagain Arm. This moraine is tentatively correlated with the end moraine north of Anchorage because outwash deposits that dip eastward, and hence were transported from the west across what is now Turnagain Arm, lie upon the Bootlegger Cove Clay near Jewel Lake.

The most extensive outwash-stream deposits formed during the last glaciation of the Anchorage area extend, as an outwash plain, from Eagle River to the vicinity of the International Airport and from Knik Arm to Turnagain Arm (pl. 1). Their eastern and western boundaries are indistinct in many places because of pitting or because adjacent older outwash deposits have similar surface form. Older and younger phases of the outwash-plain deposits were distinguished on the basis of relative altitude, the younger deposits partly filling depressions cut into the older ones. In some places the Bootlegger Cove Clay, believed to be laterally continuous beneath the outwash sand and gravel, is 30 to 50 feet lower beneath deposits of the later phase than beneath those of the earlier phase nearby.

Outwash deposits mapped as the earlier phase are composed of gravel, sand, and silt. In the tract between the International Airport and the mouth of Campbell Creek their thickness ranges from 10 to 60 feet. Exposures and logs suggest a southward increase in grain size. Sandy pebble and cobble gravel in three gravel pits west of Jewel Lake (sections 9 and 10, T. 12 N., R. 4 W.) dips eastward, and therefore is considered to have been transported from the west. In several small tracts south of Spenard the sediment of the early-phase deposits is sandy or silty (wells 244, 438, and 446). Farther northeast, in the tract that extends across sections 13, 23, and 27 of T. 13 N., R. 3 W., the material is gravel which in places is bouldery (wells 85, 86, and 216).

The general distribution of the deposits, the dip of the beds, and the sizes of the materials in them are evidence that the deposits of the earlier phase were brought in part from the northeast and in part from the southwest. The abundance of sand and silt or silty sand in the vicinity of Sand Lake and the International Airport suggests that part of the material may have been deposited in lake water. The coarser deposits to the northeast and southwest were stream laid.

The deposits of the later phase form a conspicuous outwash plain in the tract between Eagle River and the International Airport. They range from boulder and cobble gravel near Eagle River to pebbly sand and sand at and west of Spenard. This change in grain size, together with the westward slope of the plain and its position relative to the end moraine, shows that the source of the sediment was to the northeast. In the eastern part of the outwash plain the deposits are commonly as thick as 50 to 60 feet, but north of the International Airport they are as thin as 10 to 15 feet. The thin sandy deposits at Spenard and farther west may have been deposited in lake water. The deposits of the later phase of the outwash plain are known to be absent locally. A ditch between the International Airport and Knik Arm exposed (in 1952) clay immediately beneath the surficial peat in several places. Cuttings from auger holes for electric-power poles, about half a mile east of the west end of klatt Road, showed (in 1953) that clay there is covered only by peat. Several wells near the mouth of Campbell Creek (635, 639, 642, 644, and 645) penetrated clay at the surface or just beneath the soil, although other wells nearby (468, 637, 638, and 646) penetrated sand and gravel just beneath the surface that is at least 10 to 23 feet thick.

These outwash-plain deposits were formed during the glacial advance and the early part of the recession. Erosion of the earlier phase deposits, before or during deposition of the later phase sediments, is thought to have been related to a lowering of base level (a lake level?) during glacial recession. All the deposits were laid down while the Knik-Matanuska ice extended to its end moraine and forced Eagle River to flow southwestward across the lowland (although much of the material in the outwash plain probably came from the Knik-Matanuska Glacier). These deposits overlie the Bootlegger Cove Clay which may be in part equivalent in age to the end moraine north of Anchorage. After the front of the Knik-Matanuska Glacier had receded sufficiently to permit Eagle River to flow through the end moraine near its present course the outwash plain was abandoned.

The ground-moraine deposits are best exposed in bluffs along Knik Arm northeast of Sixmile Creek (pl. 1). The dominant materials exposed in the bluffs are water-laid "till," clay, and bedded sand and gravel. These deposits are interbedded and folded in some places (as just north of the small stream that breaches the bluff in section 16, T. 14 N., R. 3 W.). The log of well 3, near the bluff south of Sixmile Creek, records 78 feet of outwash gravel underlain by mud and quicksand that probably represent in part the deposits exposed in the bluff. The water-laid "till" deposits, like those near Cairn Point, are thought to have been deposited during the advance of glacial ice into a body of standing water. The bedded sand and gravel unit which underlies the water-laid "till" probably represents outwash deposits laid down near the ice during the advance.

Away from Knik Arm the ground-moraine deposits resemble those elsewhere in the Anchorage area away from the estuaries, and they are considered to have been formed on land; however, there is not sufficient information to permit drawing a boundary between the two types of ground-moraine deposits in this region north of the end moraine. Clayey till is exposed along Eagle River and The Alaska Railroad; well 5 (see log), about a mile west of Otter Lake, penetrates 111 feet of till evidently formed on land. The most extensive of the later outwash-plain deposits that were formed chiefly north of (inside) the end moraine during recession of the last glacier extend down the valleys of Fossil Creek and Eagle River and past Otter Lake to Knik Arm. The materials which compose these deposits are poorly known; where exposed along the railroad they range from clean sand to sandy boulder gravel. In well 3 these deposits are 78 feet thick.

PARTLY OR ENTIRELY POSTGLACIAL DEPOSITS

The most conspicuous alluvial fans in the Anchorage area are along the front of the Chugach Mountains, particularly at Ship Creek and at both forks of Campbell Creek; others are beneath the bluff along Turnagain Arm. The deposits in these fans are poorly known. Where best exposed, at the south fork of Campbell Creek, they consist of sandy pebble gravel containing cobbles and boulders. Several wells in stream deposits along Ship Creek near Ski Bowl Road extend into interbedded clean gravel and silty or clayey gravel that are probably fan deposits. All the fan deposits have been mapped as a single unit although they represent a considerable span of time. Those at Campbell Creek have been formed since the next-to-last glaciation. Outwash deposits in front of the end moraine at Cairn Point and about 3 miles to the east may be in part fan deposits formed during the last glaciation. Deposits in the fan of Ship Creek were formed during or after the last glaciation. Deposits along Turnagain Arm are entirely postglacial.

Deposits of sand and gravel in channels, valley floors, and low terraces have been mapped along the larger streams that cross the lowland. These deposits are in valleys cut into the outwash-plain deposits and are considered to be postglacial. Where penetrated by wells, the deposits along the streams range from 10 to 50 feet thick, but they may include older deposits beneath the nonglacial stream deposits.

Formation of some of the bog deposits in the Anchorage area may have begun during recession of the next-to-last glacier, but many of the most extensive deposits have formed since the last glaciation and are probably in large part postglacial. The more extensive bog deposits are shown by an overprint symbol in plate 1. The thickest peat observed by the writers, 10 to 12 feet thick, is in a bog about a mile east of Point Woronzof; the lower part of this thick peat is perennially frozen. As many as six bands of volcanic ash, all commonly less than an eighth of an inch thick, were observed in several sections of peat in the bluff along Knik Arm north of the International Airport.

Deposits of windblown silt and sand were not mapped because in most places they form only a thin mantle upon the glacial drift. Dune sand at Point Campbell contains six bands of volcanic ash, and therefore is thought to be equivalent in age to the peat exposed along Knik Arm. No weathering features that suggest long interruptions in wind deposition, such as might be expected in deposits covering drift older than that of the last glaciation, were found in the dune sand.

Estuarine deposits, chiefly clay and silt, form beaches along Knik Arm and tidal flats in the mouths of streams and along the shore of Turnagain Arm. The upper parts of beaches at Fire Island, Point Campbell, and Point Woronzof are sandy and gravelly where the bluffs expose extensive deposits of sand and gravel, and small sand spits are present at the south end of Fire Island and at Point Campbell. The absence of large proportions of clay and silt even where sandy beaches are covered by most tides suggests that much of the modern estuarine sediment has been derived from the coastal bluffs rather than brought from modern glaciers by streams that flow into the estuaries. However, the proportions of reworked and fresh sediment cannot be estimated with assurance. The maximum thickness of the postglacial estaurine deposits is not known. A test hole (well 27) south of Cairn Point penetrated 76 feet of silt and clayey silt that rests on till, but the lower part of the hole may have been in the Bootlegger Cove Clay, which extends below sea level farther east. The upper part of the clay and silt in some wells along Ship

Creek (33, 115, 116), a mile from its mouth, probably represents the postglacial deposits. These estuarine deposits are postglacial with respect to the Anchorage area even though they contain some sediment brought by streams from modern glaciers outside the limits of the area.

QUATERNARY HISTORY

The geologic history of the Cook Inlet region has been summarized by Capps (1940) and Payne (1955). The Anchorage area is at the southeastern edge of the Cook Inlet basin, a structural element probably present since early Tertiary time. The basin has been characterized by low relief and has undergone subsidence and both marine and continental deposition. The adjacent regions to the north and south have been subjected to uplift and erosion that left rugged mountains.

The dominant modern topographic features near Anchorage were present in the preglacial landscape although their form has been modified during Quaternary time. Truncated spurs on the valley walls show that all the valleys, including the main one between the Chugach and Talkeetna Mountains, have been widened by glacial erosion. The valleys have been partly filled with unconsolidated deposits and are characteristically flat floored. Differential movement of the land surface has helped modify the topography and may be continuing at present; it is thought to be partly tectonic uplift and partly uplift during postglacial time, after release of the load of glacial ice that filled the valleys and formed extensive ice caps in the high mountains.

THE SEQUENCE OF QUATERNARY EVENTS

The Anchorage area has been glaciated repeatedly, and the interbedded deposits of glacial drift reflect a complex history of glacial advance and recession, outwash-stream activity, and the formation and draining of bodies of standing water. Two sheets of glacial drift are exposed at the surface, and sediments which are known only from subsurface data appear to represent at least three deposits of till and associated sediments. The older buried deposits of drift cannot be correlated with assurance over even moderate distances. A younger buried till and deposits of clay and of outwash sand and gravel associated with it, widely recognized in the Anchorage area, are similar in character to the better known deposits exposed at the surface. The history implied by these older buried deposits is thought to be similar to that recorded by the deposits that are exposed.

The older exposed drift was formed during a glaciation in which the entire Anchorage area was covered by ice that extended beyond the limits of the area. The formation of extensive glacier-margin and ground-moraine deposists beside and beneath the ice was followed by two stages of outwash-stream activity: an earlier stage in which sand and gravel were deposited between remnants of ice, covering the ground moraine in many places, and a later stage in which valleys were cut into the older deposits and younger outwash deposits were laid down.

During melting of the glacier a delta of sand, silt, and subordinate gravel was built in a lake-filled depression on the wasting ice in what is now the region of pitted terrain between Point Campbell, Point Woronzof, and the International Airport. The sediment was carried eastward from a source an undetermined distance west of Point Campbell. Apparently the lake was bounded on the east by ice, for the hills formed on the delta deposits stand 100 feet or more higher than the country for several miles to the east, and in that country there is no evidence that extensive lake deposits were formed and later eroded away. The eastward transport of sediment into the lake, and the presence in the sediment of coal fragments which apparently did not come from the Turnagain Arm region, present a puzzling problem which Miller and Dobrovolny (1959, p. 31–34) discuss in detail. They believe that the sediment may have been derived from an ice lobe which invaded this part of the lowland from the Susitna Valley or from the Alaska Range, north or west of Cook Inlet. The writers believe this suggestion to be a reasonable one. Another possible explanation is that melt water from the composite Turnagain-Knik-Matanuska Glacier flowed up-valley on the ice and deposited sediment derived from the Knik-Matanuska ice in a depression on the glacier.

Continued melting of the glacier freed a depression extending beneath what are now Jewel Lake, the International Airport, Anchorage, and upper Knik Arm, and in it the Bootlegger Cove Clay was deposited. While water still occupied this depression, the last glacier to invade the area advanced down Knik Arm and built the Elmendorf Moraine. Outwash deposits formed during the early part of this glacial advance evidently were laid down upon the Bootlegger Cove Clay before underlying masses of ice had melted completely, for both the clay and the overlying sand and gravel are extensively pitted in the vicinity of Jewel Lake and the International Airport. The early outwash-plain deposits were trenched, perhaps during stillstand and recession of the glacier margin, and younger outwash deposits were formed. The outwash plain was abandoned when the glacier had melted back sufficiently to permit Eagle River to flow directly to Knik Arm. Ship Creek built a fan upon the outwash plain, and farther downstream the creek cut several distributary channels which now indent the outwash plain at Anchorage.

Several different water bodies, or one body with a complex history, may be represented by the deposits mentioned in the preceding paragraphs that were deposited in standing water. Karlstrom (1953, p. 4) believes that during the last extensive glaciation the glaciers in the upper Cook Inlet trough fronted an extensive lake dammed by glacial ice that had advanced across the lower part of Cook Inlet. His hypothesis explains the presence of lake deposits in the Anchorage area, the numerous changes of base level implied by deposits and erosional features, and, if invasion of the depression by salt water during an episode of glacial recession is postulated, the presence of estuarine deposits in at least part of the Bootlegger Cove Clay.

The chief postglacial events shown by deposits in the Anchorage area are the formation of peat bogs, of a mantle of wind-blown silt and local dune sand, and of tide flats along the coast.

AGE OF THE DEPOSITS

Karlstrom (1953; 1955; 1957; 1960) has described Quaternary deposits and their chronology in the Cook Inlet region. He (1960) distinguishes five major Pleistocene glacial advances; these glaciations, and their inferred positions in the standard North American Pleistocene classification, are as follows: Mount Susitna Glaciation (Nebraskan), Caribou Hills Glaciation (Kansan), Eklutna Glaciation (Illinoian), Knik Glaciation (Iowan), and Naptowne Glaciation (Wisconsin).

Miller and Dobrovolny (1959, p. 11–13) have correlated deposits in the lowland near Anchorage with the Eklutna, Knik, and Naptowne Glaciations of Karlstrom. Their Eklutna deposits are till and outwash material along Knik Arm east of Eagle River. Their Knik deposits include the Bootlegger Cove Clay and what the present writers have termed the older exposed drift sheet and may also include deposits higher on the mountain slope than the area described in this report. Their Naptowne deposits include the Elmendorf Moraine and its correlative deposits.

There has been general agreement that the end moraine which crosses Knik Arm at Anchorage is of late Wisconsin age (Karlstrom, 1952; Pewe and others, 1953, p. 12–13; Trainer, 1953, p. 14). Karlstrom (1953, p. 4) correlated this moraine with a moraine of his Naptowne Glaciation on the Kenai Peninsula southwest of Anchorage; he believes (1957) that the Naptowne Glaciation is correlative with the entire Wisconsin glaciation of the standard sequence.

The writers have not attempted correlation of the buried drift deposits of the Anchorage area with Karlstrom's Cook Inlet chronology. Relative dating of the deposits exposed at the surface, by Karlstrom and by Miller and Dobrovolny, is based in part on the depth of weathering of the drift. For example, Miller and Dobrovolny (1959, p. 16) cite depths of rust staining of the drift of 4 to 8 feet in the older exposed ground moraine and 4 to 12 feet in the lateral-moraine deposits, as against 2 to 3 feet in drift of the last (Wisconsin) glacial advance. On the other hand, the writers believe that the delta deposits and the Bootlegger Cove Clay are not greatly older than the Elmendorf Moraine. This interpretation is based on the pitted character of the delta deposits, the clay, and the outwash deposits which overlie the clay in the vicinity of the International Airport and Jewel Lake; this pitting suggests that the interval between recession of the next-to-last glacier in the Anchorage area and the advance of the last glacier was a relatively short one—not an interstadial episode. If this interpretation is valid, the older drift sheet exposes in the Anchorage area may also be of Wisconsin age. Further investigation may be necessary to resolve this apparent discrepancy in interpretation.

The writers believe that further study of the depths of rust staining should be in materials, and at topographic locations, that are as similar as possible. Till or clay near or beneath bogs should preferably not be considered because high concentrations of iron occur in ground water in and near some bogs, and underlying deposits are likely to be heavily rust stained in consequence. The character of the material and its position relative to the water table should also be considered carefully. Thus, the writers believe that deep rust staining of the deposits exposed at Point Campbell and Point Woronzof has no age significance; the relatively high permeability of the material and its position in the zone of aeration are thought to lead to the rust staining of the sediment. Miller and Dobrovolny (1959, p. 33–34) have reached a similar conclusion, although their terminology and ours differ.

GROUND WATER

OCCURRENCE

UNCONFINED GROUND WATER

Ground water is the water which fills openings in the rocks in the saturated zone of the earth's crust. The upper surface of the saturated zone, above which the openings are filled partly by air and partly by water, is known as the water table. Where a water table is present the ground water is not confined; the water table is free to move upward or downward as water is added to or removed from the zone of saturation. In fine-grained material the earth above the water table is moistened by water drawn up from the zone of saturation by capillarity. Small, interconnected openings in the material above the water table form irregular capillary tubes through which water is drawn and in which it is held by molecular attraction; the zone in which this occurs is known as the capillary fringe. In clean gravel the fringe is thin or practically absent, but in silt or clay loam it may be as much as 8 feet thick. At and near the land surface the earth generally contains some water. This zone is known as the zone of soil moisture (fig. 12). Between the capillary fringe and the belt of soil moisture is the zone of aeration which contains only a very little water. Where the zone of saturation lies close to the surface, the zone of aeration may be absent.

Some of the water which falls upon the earth percolates into the ground and reaches the zone of saturation, where it moves toward lower elevations. It may continue to move underground until it reaches the sea, or it may be discharged at the surface through seeps and springs and contribute to the flow of streams, by evaporation, or by transpiration by vegetation (fig. 13).

Surface runoff and ground-water seepage provide the flow of streams in the mountains east of Anchorage. Where they emerge from the mountains onto lower ground, the beds of some streams are higher than the water table nearby, and in such areas water is lost from the streams to the ground (fig. 13). However, most streams which cross the plain between the mountains and the inlet have incised their beds and attain relatively low elevations within rather short distances from the mountains. Along these incised reaches the stream beds are lower than the water table nearby; hence, in the greater parts of their lower courses the streams do not contribute to the ground-water reservoir but receive water from the ground-water reservoir.

Aquifers which contain water under unconfined or water-table conditions supply numerous shallow wells in the Anchorage area. Many dug wells and shallow drilled wells in Mountain View, and along Fireweed Lane west of Seward Highway, obtain water-table water from the outwash-plain deposits. Other shallow dug wells throughout the area also obtain unconfined or water-table water.

ARTESIAN GROUND WATER

Not all ground water is unconfined. Many water-bearing beds, or aquifers, lie between beds of less permeable materials, and in these aquifers the ground water is confined under pressure. Under idealized confined conditions, as ordinarily visualized, ground water

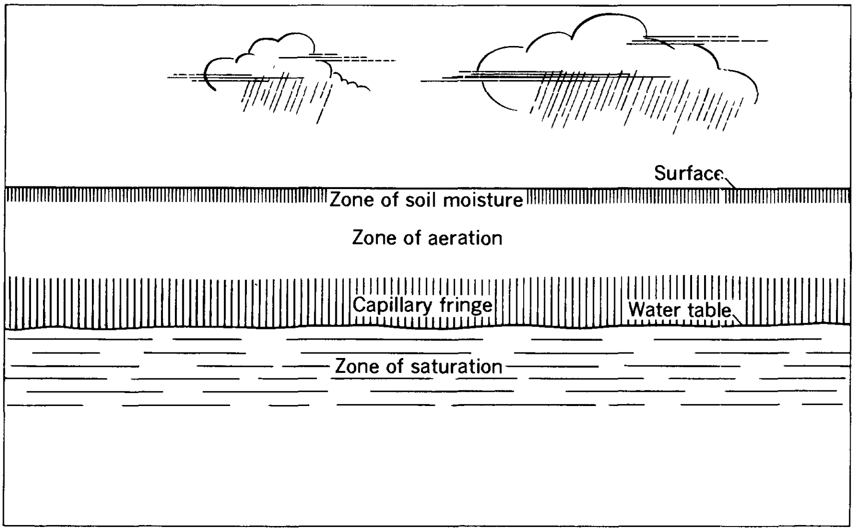

FIGURE 12.—Diagram showing zone of saturation, water table, zone of aeration, and zone of soil moisture.

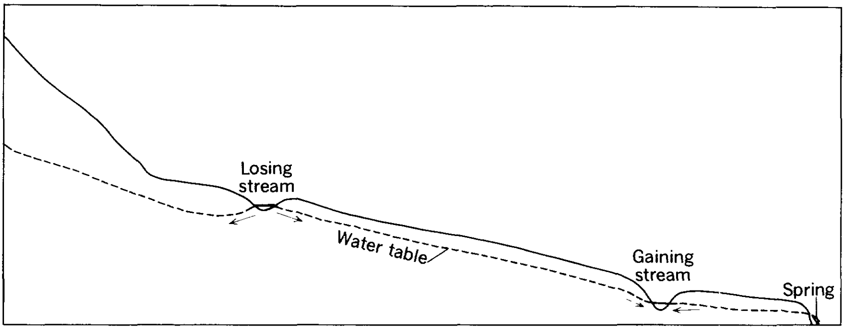

FIGURE 13.—Diagram showing relationship of water table to streams and springs.

occurs in strata separated from the surface by overlying beds of chiefly impermeable material, such as clay. In an intake area on high ground, where the aquifer is at or near the surface, the infiltration of rain, snow water, or stream water tends to fill the permeable stratum beneath the capping bed back to the intake area (fig. 14). The water down slope in the artesian stratum, hydraulically continuous with the water in the higher intake area, is under pressure. On low ground, in some places greatly distant from the intake area, water rises in wells that penetrate the artesian stratum. Where the ground is low enough or the artesian head high enough, the wells flow. It is confusing to speak of a "water level" where, as in a flowing well, water may rise many feet above the surface in a casing extended above the ground. In artesian systems, therefore, the term

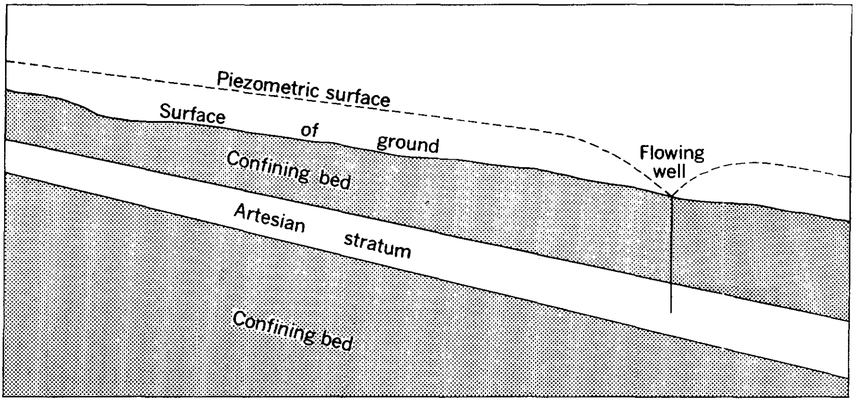

FIGURE 14.—Diagram showing occurrence of artesian water, and the piezometric surface.

"piezometric level" (the pressure-indicating level) or "artesian head" is commonly used instead of "water-level." In all artesian systems the piezometric level is high immediately in and near the intake area and declines progressively with distance from the intake area. In an almost perfect closed system the decline would be very gradual, but where water escapes from the artesian beds by one means or other, the decline is more marked and the piezometric level slopes more steeply.

A degree of imperviousness is a necessary prerequisite for artesian conditions. Where the confining layer has low permeability, water in the confined sediments is under artesian head. This does not mean that the artesian water is perfectly confined; since the water is under pressure it leaks upward, with consequent loss of artesian head (fig. 15). The loss of head tends to progress until the piezometric level is at the level of the overlying unconfined ground water. However, the effect of this upward leakage (that is, loss of artesian head) is offset by the addition of water and restoration of pressure in the intake area. Conversely, in some parts of the artesian system the level of shallow unconfined water may be higher than the head of water in the artesian stratum. In such places unconfined water percolates down through the "impermeable" stratum into the artesian stratum.

Near Ski Bowl Road (well 17) water in the "first" stratum, 90–120 feet below the surface, stood in the well at a level 50 feet below the surface, whereas water in a deeper stratum (at 130–135 feet) stood 60 feet below the surface. Where water levels in shallower artesian strata are higher than those in deeper ones, as in this example, an area of recharge of the water-bearing formations is indicated. This relationship is shown in figure 16.

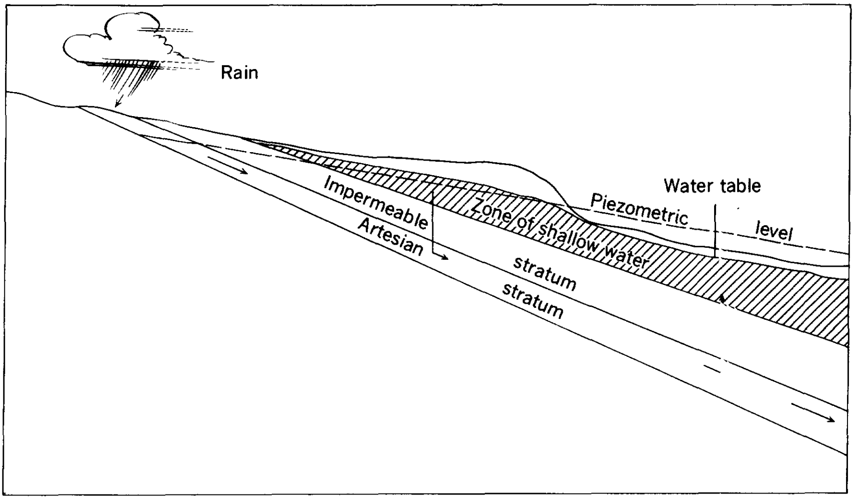

FIGURE 15.—Diagram showing movement of water into and out of artesian beds.

The flow lines in the diagram show the movement of water particles in an idealized situation. The isopotential lines crossing the flow lines show the height above sea level to which water will rise in wells reaching those lines. Thus in the right-hand part of the diagram the shallower well intersects the 280-foot isopotential line whereas the deeper well, at the same place, intersects the 270-foot isopotential line.

The reverse relationship exists in the discharge area of an artesian system: water rises higher in wells tapping the deeper formations than in those which tap shallow aquifers. This difference is very marked in Spenard. In northern Spenard, water in wells less than 200 feet in depth rises 50 to 80 feet above sea level, but in the deeper wells it rises to as much as 128 feet above sea level (well 324, 285 feet deep). Here water is being discharged upward. The left-hand part of figure 16 shows this relationship in the lower (discharge) end of and idealized artesian system. Here a shallow well intersects the 60-foot isopotential line whereas a deeper well at the same location intersects the 70-foot isopotential line.

In this way, and depending on topography (which controls the altitude of the water level in the unconfined aquifer), the amount of recharge water available, the degree of imperviousness of the confining bed, and other factors, there is likely to be a series of gains

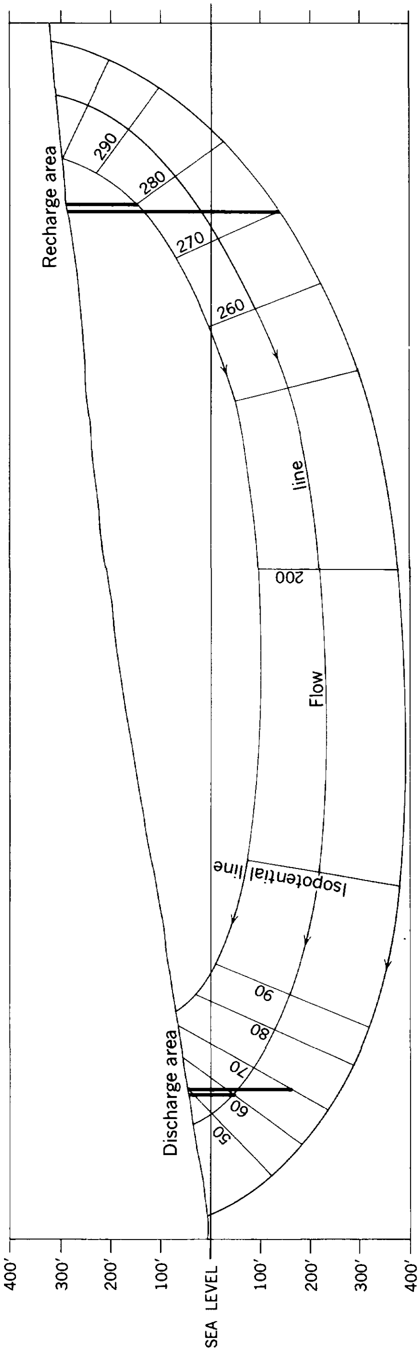

FIGURE 16.—Diagram showing isopotential lines and flow lines in an idealized artesian system.

and losses of artesian head along the entire length and breadth of an artesian aquifer.

SUMMARY OF GROUND-WATER CONDITIONS

The Anchorage area is at one side of a wide valley underlain by deposits formed during several successive episodes of glacial advance and recession. The stratigraphy of the glacial drift—interbedded till, sand and gravel, and clay and silt—is complex. Beds of sand and gravel, and layers of sandy or gravelly material in till, are the most important aquifers; the till and the clay and silt are commonly artesian confining beds. The underlying bedrock is poorly known but the data available suggest that it is not a potential aquifer.

Most of the ground water in the Anchorage area is confined or artesian water. Aquifers in the till, which are usually not more than a few feet thick, appear to be of relatively low to moderate permeability and small lateral extent; however, they are common and in many places probably intersect one another or are closely spaced in the till; they are best visualized as networks enclosed in the till rather than isolated bodies. The thicknesses of the aquifers composed of outwash sand and gravel are known at few places, but they are as much as several tens of feet in some wells. The lateral extent of individual water-bearing beds is not known, but correlation between wells suggests that some beds extend laterally at least several thousand feet. Pumping tests indicate that some beds (or, more probably, interconnected series of beds) extend laterally for distances of several miles. The outwash aquifers appear to include both long, narrow channel deposits and more extensive deposits such as those formed in outwash plains. Near Anchorage, however, all the water-bearing beds appear to be interconnected and to form a single aquifer.

Unconfined or water-table aquifers are present in most of the Anchorage area. The main unconfined aquifer is a sheet of outwash-plain deposits (chiefly sand and gravel) that covers much of the northeastern, central, and western parts of the area. The thickness of the deposits ranges from about 10 to more than 50 feet; the thickness of saturated material ranges from a foot or less to about 40 feet. Unconfined ground water is also present in near-surface deposits of sand, gravel, and till in other parts of the Anchorage area.

The outwash sand and gravel are moderately to very permeable. The coefficient of transmissibility for the entire section of glacial drift at Anchorage is believed to be about 200,000 gpd (gallons per day) per ft. In other parts of the area where the deposits are thinner and contain fewer and thinner aquifers their water-transmitting capacity is much less. Only a few wells in the area have been screened and developed for high yields. The highest yield reported to date is 2,600 gpm with 35 feet of drawdown, produced by a well finished in an artesian aquifer. The highest reported specific capacity of which the writers have record is 180 gpm per foot of drawdown, for an artesian well pumped at 270 gpm. The unconfined sand and gravel are relatively permeable, but few large wells have been constructed in these deposits and their potential yield is poorly known. Unconfined aquifers in the till are relatively impermeable and yield only small (and, in many places, undependable) domestic supplies.

The ground water is replenished by precipitation, directly by percolation from the land surface and indirectly by percolation through the beds of streams and lakes. Much of the unconfined ground water is derived directly from infiltration at the land surface, and much of the artesian water is provided by seepage from streams. However, in some parts of the area much of the recharge of aquifers of both types is probably by flow from other aquifers in which the water is under higher pressure. The fact that the water table and the artesian-pressure (piezometric) surface slope generally westward from the mountains toward the estuaries shows that in general the ground water flows in that direction. Commonly the unconfined ground water is discharged through seeps and springs and by evaporation and transpiration; near the valley wall, however, where the water table is higher than the artesian-pressure surface, some of the unconfined ground water is discharged by downward flow into artesian aquifers. Conversely, far out in the lowland the artesian aquifers have higher head than the unconfined aquifers; consequently, part of the artesian discharge there must be upward through the confining beds and into the unconfined aquifers. The confined aquifers also discharge in part through springs, some of which are on land and some of which may be in the estuaries.

Most wells drilled in the Anchorage area have obtained water, and it appears that domestic ground-water supplies can probably be obtained in most places in the area; locally, however, wells as deep as 200 to 300 feet are necessary. The part of the area near Anchorage is the most favorable for the development of supplies of several hundred gallons per minute or more because the more permeable deposits are more common, thicker, and perhaps better interconnected there.

Ground water in the Anchorage area is in general chemically suitable for human consumption, although in some places it contains objectionable quantities of iron. Samples analyzed contain an average of about 150 ppm (parts per million) of dissolved solids; their average hardness is about 120 ppm. The water is of the calcium magnesium bicarbonate type. The average temperature of the ground water is 37° to 38° F, but near one stream the temperature of shallow ground water is known to range from 39° to 43° F, depending on the season.

Community water supplies for Anchorage and the nearby military bases have long been obtained from a surface stream. However, low stream flow and temperature of the water during late winter have led to the drilling of several wells, which are now pumped on a part-time basis to augment the surface supply and prevent the freezing of distribution lines in winter and early spring.

WATER-BEARING CHARACTERISTICS OF THE ROCKS

CONSOLIDATED ROCKS

The hard rocks along the flank of the Chugach Mountains provide a few small domestic water supplies. However, these rocks are so poorly exposed and so few wells penetrate them that little is known of their hydrologic character. Three wells (532, 539, and 587) extend 91 to 114 feet into the rock; wells 532 and 539 yield small quantities of water but 587 is a dry hole. The rate of inflow to well 539 was observed by the driller to be 8 gallons per hour when the well had penetrated 55 feet of rock and 76 gallons per hour when it had penetrated 95 feet; the bedrock part of the hole was not cased. Well 588, which penetrates 14½ feet of rock, has been pumped at the rate of several gallons per hour for as long as 4 hours. Wells 532 and 588 are easily pumped dry. Where exposed near Turnagain Arm, in and south of the Anchorage area, the rocks are tight and appear likely to transmit little water except along fractures. Data from the wells are consistent with this conclusion. The only places where these rocks are likely to be relatively permeable are in fault zones having open fractures.

The soft Tertiary rocks in the lowland are water-bearing at some places and dry (in a practical sense) at others. Well 64, drilled without casing in shale and subordinate sandstone and coal from 447 to 617 feet below the surface, was tested at two levels: at 510 feet it was pumped 42 gpm for 8 hours, with 17 feet of drawdown, and at 617 feet it was pumped 42 gpm for 6 hours, with 12 feet of drawdown. Five months later the walls of the hole had begun to slump, and even after being cleaned out the well yielded no more than a few gallons per minute. The failure of the well is attributed to swelling of the shale in the open hole, which stood nearly full of water for the period of 5 months. Four other wells (1, 17, 28, and 197) have been drilled into the Tertiary rocks to depths of 100 feet or more, but none yielded more than a small quantity of water. The water-bearing beds are thought to be layers of sandstone or coal in the shale.

UNCONSOLIDATED DEPOSITS

TILL

As compared with sand or gravel, the till is relatively impermeable. Although saturated it is in many places dry in the practical sense that it does not yield water readily to wells, and numerous wells have been drilled 50 to 100 feet or more through it without obtaining appreciable quantities of water. Dug wells are commonly more effective than drilled wells in intercepting small quantities of water from the till, but even a few large-diameter holes dug into the till were dry. The relative impermeability and wide distribution of the till make it an effective confining bed at many places. At some places where till is at the surface in tracts of irregular topography, the slow rate of infiltration of water into the till at the surface leads to the formation of bogs. Finally, because of its relative impermeability, till that is at or near the surface limits the quantity of recoverable ground water in the upper part of the saturated zone.

Recoverable ground water in the till generally is in gravelly, sandy, or silty layers which are interbedded with the massive silty or clayey till. (See logs of wells 28, 64, and 324.) These layers are thought to consist chiefly of stream-deposited sediment laid down beneath or near the margin of the ice, and later covered by younger till deposits of the same glacier; probably they were formed during glacial recession when the margin of the ice moved back and forth repeatedly, when many masses of ice were left stranded in front of the wasting glacier, and when there were numerous melt-water streams and ponds associated with both active and stagnant ice. Study of many well logs suggests that these layers are somewhat more common in the shallower tills than in the deeper ones; this occurrence is readily explained, if the layers were formed chiefly during glacial recession, by removal of the upper parts of the older till sheets by later glacial erosion. The abundance of these layers of sorted material in the till is difficult to evaluate because many wells which reach sandy or gravelly material beneath till penetrate only a few feet of the sorted material; hence, it is impossible to determine whether these wells tap but do not completely penetrate thin layers in till, or whether they tap the upper parts of thick outwash deposits that underlie the till. The logs suggest, however, that in some places these layers are fairly common. Some, tapped by wells, provide enough water to indicate a fairly wide lateral extent, it is reasonable to suppose that extensive layers of sandy material in the till are either wide sheetlike deposits or intersecting layers which form networks laced through the till.

Several deep wells have penetrated sandy layers far from the surface. (See, for example, the logs of wells 28 and 324.) In some of these deep layers the sand easily becomes quicksand and hence is not favorable for development. (Presumably the material in these layers is fine and well sorted, and, of course, it is under high head and is free to move, once the layer has been tapped by a well.) In other places, however, the sand is stable and provides modest domestic water supplies.

In most places where they have been completely penetrated these permeable layers are not more than a few feet thick. However, several wells near Ship Creek penetrated thicker sandy beds (see the logs of wells 17 and 23) in which the material is silty and of relatively low permeability. What seems to be the same beds have been found in several other wells nearby.

In shallow wells which tap till, the water table is likely to be very responsive to changes in precipitation and may decline markedly during dry seasons or dry years. However, decline of the water table in some of these aquifers is probably due to the progressive draining of sandy layers in the till for some distance around newly constructed wells. This drainage, although slow, is probably nonetheless faster than the rate at which the water is replaced by percolation from the land surface and through the till. Such drainage is thought to explain why some wells have required deepening after a period of use.

SAND AND GRAVEL

Sand and gravel are the important water-bearing materials in the Anchorage area. The deposits are chiefly those of outwash streams, but lake(?) and nonglacial stream sediments are present also. In most places where they have been penetrated, the deposits consists of sand or gravelly sand, but gravel, silty sand, and silt are also common. Most of these materials are relatively permeable, but the silt and the part of the sand commonly are unstable (become quicksand) during drilling and pumping and flow into wells.

Near the land surface many of these deposits form continuous wide sheets which are thin relative to their lateral extent. The outwash-plain deposits between Eagle River, the International Airport, and Turnagain Arm form the largest of these sheets; others formed by older outwash-stream deposits to the south and southeast appear to be overlapped by the younger sediments and may be hydraulically continuous with them. Some of the buried deposits may also be of sheetlike form, but the data available are not sufficient to show this. Part of the surficial sand and gravel is in long, relatively narrow bodies formed in valley floors or stream channels, and it seems likely that some of the buried deposits may have this form also.

Ground water in the surficial deposits is unconfined; in some places it is perched or semiperched above layers of less permeable material in the zone of aeration. Water in the buried deposits is confined under pressure and rises in wells which pierce the overlying till or clay.

The more important water-bearing deposits and wells are discussed on pages 57–63, but it is of interest to note here that the actual pumpage from single deposits of sand and gravel have ranged from a few gallons per minute in many wells to more than 800 gpm in well 606; the potential yield of several wells which tap single deposits in more than a thousand gallons per minute, and that of well 606 is probably limited only by the size of the pump that can be installed in the casing of the well.

CLAY AND SILT

The extensive deposits of clay, silt, and associated deposits that are interbedded with the till and outwash-streams deposits are important in the ground-water hydrology of the Anchorage area. The clay, silt, and stony clay are relatively impermeable; they are saturated but transmit water so slowly that they are impermeable in the practical sense. In a large part of the area these beds confine water under pressure in underlying aquifers of sand and gravel. The clay prevents effective downward drainage of water in surficial sand in a large tract in the western part of the Anchorage area, and extensive bogs have formed.

Layers of sand and silty sand associated with the clay and silt are relatively permeable. In many places the sand is unstable under the head differences produced during drilling and pumping, however, and it readily becomes quicksand and flows into wells.

UNCONFINED GROUND WATER

Unconfined ground water in the Anchorage area occurs in outwash-stream and lake(?) deposits, in nonglacial stream deposits, and in till. Most of the wells which tap unconfined aquifers are in Mountain View, in Anchorage west of Merrill Airport, and in and south of Spenard; at these places the water is in sand and gravel that overlie clay. Most of the remaining water-table wells are in outwash or ground-moraine deposits between Homesite Park and O'Malley Road, in the southeastern part of the area. A few wells have obtained water from stream deposits along Ship Creek.

The outwash-plain deposits that extend from Eagle River nearly to Point Woronzof and from Knik Arm at Anchorage to Turnagain Arm, together with older outwash deposits south and southeast of Anchorage and between Point Woronzof and Point Campbell, are thought to form a single unconfined aquifer. Small bodies of perched or semiperched water appear to be present locally, above the level of the main water table, in these deposits. The thickness of saturated material in the outwash-plain deposits ranges from 30 to 40 feet in Mountain View to a few feet in much of Spenard. The material is sandy gravel and gravelly sand to the east and sand and silty sand to the west. In general the water table slopes westward, and the ground water flows in that direction.

Natural discharge of the unconfined ground water is through seeps and springs, by evaporation, and by the transpiration of plants. Seeps and springs are common in the bluffs along Knik Arm and at many places along the valley walls of Ship Creek and Chester Creek; they generally are at the contact of the water-bearing material and the underlying clay. In addition, the main unconfined aquifer is believed to lose water by percolation to underlying artesian aquifers in the eastern and southeastern parts of the area, where the water table stands higher than the piezometric surface.

Artificial discharge of unconfined ground water in the Anchorage area is insignificant. Only small quantities of water are pumped from water-table aquifers. An infiltration gallery at Ship Creek in Anchorage, formerly used as a source of water for the city, is reported to have had a capacity of 5 mgd; it has not been used for several years because of contamination of the ground water near Ship Creek by kerosene.

Replenishment of the unconfined ground water is from precipitation that falls on the land surface; the water enters the ground by infiltration at the surface and by infiltration through the beds of streams. The best evidence of stream-bed seepage has been found near the upper and middle courses of Ship Creek. There a high content of sulfate in the stream water and in the ground water indicates that the ground water is derived, in significant degree, from the stream; in contrast, water from water-table wells far from streams characteristically has a low content of sulfate. (See analyses, in table 3, of water from Ship Creek and from wells 18, 24, and 63 nearby, and, in contrast, the analysis of water from well 144, northeast of O'Connell Lake, in Spenard.) Water temperatures and water-level data along upper Ship Creek also indicate recharge from the stream.

Percolation directly from the land surface probably occurs in much of the area. Its importance is not known but the writers believe that the amount of recharge by this means is small. About 30 percent of the mean annual precipitation falls as snow and is removed by sublimation, evaporation, and overland runoff before the ground thaws. Much of the remaining 10 inches of precipitation is intercepted by vegetation before it reaches the ground, or is withdrawn from the soil by plants and transpired, or is evaporated from the soil. Probably only a small part of the water which falls to the ground becomes ground water by infiltration at the surface.

Fluctuations of the level of the water table (fig. 17), observed periodically in a well in Spenard, follow seasonal trends which suggest that recharge occurs chiefly in late spring (probably in part from melting snow and in part from spring rains which fall before the vegetation becomes active) and in early autumn (probably from rains after the vegetation becomes inactive). The water levels in some wells (for example, an old dug well at the site of well 394) are reported to have

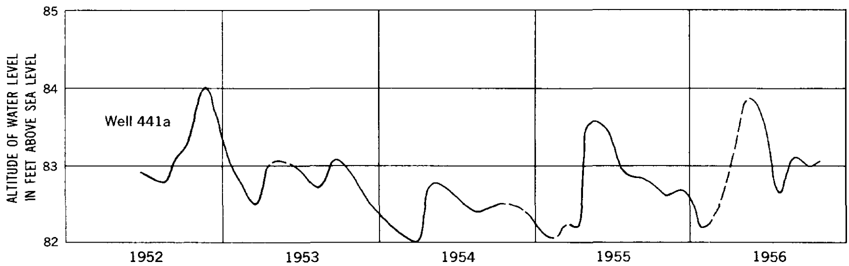

FIGURE 17.—Water-level fluctuations in a water-table well (441a) in Spenard.

declined progressively over periods of several years. Such decline might be due to removal of water from the aquifer more rapidly than it is replenished, or to an increase in the rate of natural discharge as a result of clearing and drainage of the land. Each of these effects has probably occurred at various places in the Anchorage area.

The poor drainage of the land surface in much of the area is due to the presence, near the surface, of relatively impermeable till or clay. The water table in till, or in thin sand above till or clay, stands high and has a steep gradient that causes effective outward flow of water that percolates from the surface. At some places, however, as south of Fireweed Lane in Spenard, the water table is at the land surface, but its gradient is still not high enough to produce outflow of the water as rapidly as it enters the aquifer; as a result, large areas are marshy or contain lakes. At many places vegetation which grows in poorly drained tracts has probably impeded drainage and contributed further to the growth of marshes.

THE ANCHORAGE ARTESIAN SYSTEM

Water tapped by deeper wells in the Anchorage area is almost everywhere artesian water. The water is confined, has migrated to the well site from some distance, rises in the casing appreciably above the formation in which it occurs, and in some places flows from wells at the surface. However, the artesian system in the Anchorage area differs somewhat from the classical artesian basin. These differences are important hydrologically.

First, the confining beds of till, one of the essential factors in the existence of an artesian system, are rather permeable. If we assume the presence of a layer of gravel, overlain by a 40-foot layer of till that has a coefficient of permeability of 0.5 gpd per sq ft, and that the till is overlain in turn by 10 feet of saturated gravel, we may utilize the equation (Wenzel, 1942, p. 59)

$$P=\frac{Ql}{Ath}$$

to calculate the downward recharge that would take place if pumping from the buried layer lowered the water level to the top of the layer. In the equation, l is height of the water table above the top of the buried water-bearing bed (50 feet), h is the thickness of the till (in feet), A is the area through which flow occurs (in square feet), and t is the time of flow (in days). Calculation shows that, under these conditions, the recharge Q is about 0.4 gpd per sq ft. Under these same conditions about 11 mgpd per sq mi would percolate into the water-bearing stratum. Where the height of the water column in the shallow beds was higher or where the till beds were more permeable, the amount of recharge would be greater; where the till beds were less permeable or thicker and the head difference smaller, recharge would be less. Conversely, flow upward (loss) from the buried artesian stratum, through the overlying till, occurs where the piezometric level is higher than the shallow water table. Thus it is likely that in some of the western parts of the Anchorage area much of the shallow water did not come directly from the land surface by the infiltration of rain, but indirectly through the upward leakage of artesian water.

The second factor that may explain some of the peculiarities of the Anchorage artesian system is the form and disposition in space of the artesian beds. Many, perhaps most, of the water-bearing strata in the Anchorage area are not blankets of sand and gravel of wide lateral extent, such as occur in marine deposits in some great artesian basins. It is commonly impossible to correlate the buried sand layers with assurance over even short distances, especially where they are thin beds enclosed in till. Most of strata appear to be long lenticular deposits, many of which may not be continuous for as much as a mile. They were probably deposited in short-lived, areally restricted channelways beneath or in front of the ice. Except where extensive outwash-plain deposits are present, the chance that any one stratum joins another a considerable distance away is small. For example, no single stratum has been demonstrated to underlie Spenard, or to extend continuously back to the flanks of the Chugach Range. Rather, the beds of sand and gravel in Spenard probably form an interlacing network of sheetlike and stringer deposits, many of which pinch out completely over moderate distances. Hydrologic evidence suggests that many sand lenses, although of limited extent, intersect or are imperfectly separated from other lenses and thereby form a hydraulic system of considerable extent that is comparable in effect to a thick, areally extensive artesian stratum. Pumping tests described on pages 57–63 indicate that some of the interconnected beds are very extensive, because the effects of hydraulic barriers do not appear until pumping has continued for several hours. In these systems, nearby sources of recharge are most reasonably interpreted as upward or downward leakage through overlying or underlying beds of till of lower permeability, induced by lowering of pressure in the stratum being pumped.

The piezometric-level map (pl. 3) shows the height to which water will rise in drilled wells of moderate depth throughout the area. The contour lines are isobars, lines connecting points of equal artesian-pressure head. Elevations were established in large part by barometric surveys; they are considered to be accurate within a few feet, and errors are thus small relative to the 50-foot contour interval used in the map. The water-level measurements used are those in wells of intermediate depth obtaining water from confined aquifers. Water levels in shallow wells (less than about 60 feet deep) seem to reflect water-table conditions, which may differ considerably from levels in wells that penetrate a buried aquifer, and they were not used. Nor were the water levels of very deep wells used in drawing contours on the piezometric surface. In Spenard, water levels in wells deeper than 200 feet are as much as 50 feet higher than those in wells 100 to 200 feet deep.

In general the water levels in drilled wells stand about 300 feet above sea level at the foot of the mountains and decline progressively to the north and west. In Mountain View the Piezometric level is about 150 feet above sea level; in Spenard it is generally between 40 and 90 feet above sea level. In the vicinity of the International

Airport water rises to less than 50 feet above sea level in most wells, but near Sand Lake (where the land surface and the water table are higher) it rises to more than 70 feet above sea level in some wells.

In areas intermediate between the recharge and discharge areas, the isopotential lines for the artesian aquifers are vertical and water will rise to the same height in both deep wells and shallow wells.

AQUIFER EVALUATION

Pumping tests to evaluate the coefficients of transmissibility and storage of water-bearing beds were carried out where practicable; concepts and methods described by Theis (1935), Wenzel (1942), and (Brown, 1953) were used.

RANGER STATION WELL

The first successful test was made when the USGS test well (64) on Oilwell Road had reached a depth of 175 feet. (See log, table 4.) Here open-end casing extended to the bottom of a medium- to coarse-sand stratum 20 feet thick. Six feet of coarse sandy gravel lay immediately below. The observation well, 1,050 feet distant, was a recently completed screened well (66) ending in a layer of coarse gravel 151 to 157 feet below the surface. Presumably the total thickness of sandy to gravelly material here was comparable to that in well 64.

The pumping well was discharged at a rate of 70 gpm for 5 hours and 20 minutes, and measurements of drawdown were taken in the adjacent observation well during the pumping period and during the first 95 minutes of recovery after cessation of pumping.

By the use of the nonequilibrium or Theis formula (Theis, 1935, p. 519; Wenzel, 1942, p. 87; Brown, 1953, p. 851) the transmissibility was determined to be 96,000 gpd per ft from the pumping data and 115,000 gpd per ft from the recovery data. The recovery curve seems less regular, and the lower value is therefore probably more representative of the formation. The storage coefficient was determined to be 0.00013 from the pumping data and 0.00009 from the recovery data.

DISTRICT ENGINEER WELL

An aquifer evaluation test was made on the District Engineer test well (28) when it had reached a depth of 320 feet. Observations were made in a USGS well (35) 600 feet distant, drilled especially for this purpose. The District Engineer well (see log) ended in sandy and gravelly material that extends from 304 to 322 feet; the observation well ended in a similar layer at 301 to 336 feet. The District Engineer well was discharged at 360 gpm for 34½ hours, during which time water-level measurements were made in the observation well. Recovery measurements were made for 3 hours in both wells.

Drawdown data from the observation well and recovery data from both wells were used. Analyses in which the Theis formula was used yielded three values for transmissibility: 39,500, 40,000, and 41,000 gpd per ft. According to data obtained from measurements in the observation well, the coefficient of storage is 0.00115. It was hardly surprising that the transmissibility was lower here than near Oil Well Road. There the sediments are clean and range from coarse sand to gravel, whereas in wells 28 and 35 the water-bearing beds are thinner and contain little material that is coarser than coarse sand.

The drawdown in the observation well, as plotted on log-log paper, flattened in its later portion. Because observed values of drawdown were less than those that would have been noted in a well that draws all its water from storage in the ideally homogeneous aquifer postulated for the Theis equation, the presence of a source of recharge is inferred. The distance to the source of recharge can be calculated, but in this test the calculation of this distance is misleading; geological conditions indicate that there is little likelihood of direct infiltration of water from Ship Creek or from any other surface body of water. Rather, infiltration over a wide area from another sand bed above or below the stratum being tested is the more likely source of recharge. (In fact, practically all recharge of artesian beds in the Anchorage area is attributed to percolation through confining beds of low permeability.)

An extracted curve was made from the original plot by following standard procedure. In its later history the extracted curve departs from the type curve and again flattens—a feature that indicates that yet another source of recharge is present. A third curve, extracted from the second curve, appears to depart from the type curve in its later position, but in this instance the fact that the drawdown is greater than the ideal indicates a barrier to the spread of the cone of depression. The barrier is thought to be the edge of the aquifer where it pinches out against the wall of the channel in which the sand was deposited.

The behavior of the cone of depression as it enlarges is considered typical of the artesian system as a whole. For a short time at the beginning of a test, drawdown proceeds in accordance with theory. In a very short time, however, lowering of pressure head in an artesian stratum induces infiltration from above or below, and the rate of change of drawdown decreases. The stratum recharging the aquifer being pumped may in turn receive infiltration from yet another stratum. Thinning or pinching out of the aquifer being pumped eventually provides a partial or complete barrier to the spread of the cone of depression, which also can be detected from the test data.

On July 23, 1953, when the District Engineer well had reached a depth of about 410 feet, a screen was set from 402 to 408 feet and the well was pumped at a rate of 150 gpm for 11 hours. Measurements of the recovery of water level in the pumped well after pumping had ceased were plotted on semilog paper, drawdown against the lograithm of time (Copper and Jacob, 1946, p. 526). Points representing drawdown at 32, 36, 39, 48, 57, and 70 minutes plotted as a straight line, and the coefficient of transmissibility was determined to be 39,200 gpd per ft. This value seems high because nearly an identical value had been obtained from the thicker stratum above. The driller's log of the well suggests that the till section at this lower level is not as neatly compartmented as the section tested previously; probably the value obtained reflects the water-transmitting characteristics of a much thicker section than the gravel bed tested.

The fact that the water level in the observation well was not affected by pumping of the District Engineer well on July 23 indicates that the higher strata are not directly interconnected with the gravel beds in the till.

On November 18, 1953, the District Engineer well was again tested by pumping. The well then had an effective depth of 536 feet. The 16-inch casing had been slotted with a knife-type perforator, the well had been surged, and then a test run of 44 hours was made. At the conclusion of the 44-hour test, recovery of the water level in the pumped well was measured for 108 minutes. Points taken in the interval from 13 to 38 minutes fall on a straight line in a semilog plot, but the value for transmissibility thus determined, 70,000 gpd per ft, seems low. It will be recalled that the combined transmissibilities of the two strata tested previously was about 80,000 gpd per ft. Points representing drawdown from 45 minutes to 98 minutes also fall on a straight line but are of lesser slope than the earlier points and give a value for transmissibility of 120,000 gpd per ft. The value of 120,000 gpd per ft would indicate that additional strata had been developed in the final well, although not necessarily a major part of the total of 130 feet of sandy and gravelly strata intended to be developed.

Even if the higher transmissibility is accepted as being more nearly correct, it seems likely that important thicknesses of what appear to be water-bearing strata had not been developed and that the true transmissibility is much higher.

725-300 O—64——5

CITY TEST WELL 1

Well 163, the first test well drilled by the city of Anchorage, was pumped for several weeks during March and April 1956 to supplement the supply obtained from Ship Creek, which was then in its spring period of low flow. An automatic water-level recorder which had previously been installed in the District Engineer well (28) on Elmendorf Air Force Base recorded changes in water level caused by the pumping. Because both wells penetrate thick sections of the unconsolidated deposits and are about 8,300 feet apart, the test is considered to offer an average value for the transmissibility of the water-bearing beds at Anchorage. When plotted, the test data yield graphs like those obtained from tests of single water-bearing beds where the pumped well and observation well are near each other. Therefore, even though the individual water-bearing beds may not be laterally continuous between the wells, they are thought to be hydraulically connected and to form a single artesian system.

Analysis of the data provided by this test is complicated by the fact that the hydrograph for the observation well (pl. 4) contains tidal and barometric effects in addition to the effect of the pumping. The water levels in wells 28 and 163 fluctuate with the tides in Knik Arm despite the fact that each well is about 1¾ miles from the nearest point on the shore. In well 28 the tidal fluctuations lag about 2 hours behind those in Knik Arm. The tidal efficiency of well 28 is about 0.015; that is, a tidal fluctuation of 1 foot in the estuary causes a corresponding change of 0.015 foot in the water level in the well. Because the tide range in the estuary is commonly 25 to 30 feet or more, the tidal component of the water-level fluctuation in the well commonly amounts to several tenths of a foot. The barometric effects are due to changes in atmospheric pressure. A rise in barometric pressure causes the water level in the well to decline; a decrease causes it to rise. The barometric efficiency of well 28 is 0.36; that is, a change in barometric pressure of 1 inch of mercury (expressed, for convenience, as 1.13 feet of water) produces a corresponding change of $0.36 \times 1.13 = 0.41$ foot of water.

Correction of the water-level graph for tidal effects could not be made directly because a tide record was not available. However, the daily variations in water level due to tide were smoothed by selecting the vertical midpoints of the pairs of "limbs" of the curve and connecting these points. It was then presumed that most of the remaining fluctuation in the hydrograph was due to barometric changes. The barometric component was removed from the observed hydrograph as follows: (1) An adjusted barometric curve was constructed from the products of barometric data (from Weather Bureau records) and the barometric efficiency of the well;

(2) an arbitrary base line (dashed in plate 4) was drawn across the adjusted barometric curve, and the values of this curve corresponding to the times of selected points (tidal nodes, for convenience) were subtracted from (if below the base line) or added to the smoothed curve. The resulting graph, arbitrarily referred to a convenient water level, is the "adjusted hydrograph" shown by plate 4.

The adjusted hydrograph contains small residual tidal (and barometric?) effects, but it is thought to represent the trend the water level in well 28 would have had if there had been no tidal or barometric influences. This trend was projected across the period of pumping to provide a base from which the drawdown was determined.

Values of drawdown were plotted and values for transmissibility and coefficient of storage determined by following standard procedure (Wenzel, 1942, p. 88–89; Brown, 1953). The coefficient of storage was computed to be 240,000 gpd per ft. The question then arises whether 240,000 gpd per ft fairly represents the transmissibility of the composite aquifer extending from well 163 to well 28. Aquifer tests in the city well, on a stratum at 122 to 136 feet, gave a value of 54,000 gpd per ft for the coefficient of transmissibility. A test at 320 feet in the District Engineer well (28) yielded a value of 40,000 gpd per ft. A test of a thick aquifer at the Ranger Station gave a value of about 100,000 gpd per ft. Moreover, it may be recalled that a value of 120,000 gpd per ft had been tentatively determined from an earlier recovery test of well 28 and that this value was thought too low. The individual strata tested in wells 28, 163, and 64 had specific capacities of 4½, 5, and 17 gpm per foot of drawdown. Inasmuch as the city well had a specific capacity of 36 gpm per ft the well probably was drawing water from a large part of the total section. From consideration of all these data it is concluded that a value of 200,000 gpd per ft is a reasonable estimate for the coefficient of transmissibility of the deposits tested.

SKI BOWL ROAD WELL

On October 1, 1954, an aquifer-evaluation test was made by pumping well 19, which at that time tapped only shallow sandy gravel immediately adjacent to Ship Creek, and by making measurements in well 18d, 69 feet away. Measurements made during drawdown and recovery and plotted on semilog paper show a marked flattening of the curve—a feature that indicates that recharge was taking place early, as might be expected. By using the very early values (as much as 90 seconds) in both recovery and drawdown and by applying the equilibrium formula, values of 122,000 and 125,000 gpd per ft were obtained for the coefficient of transmissibility. These seem reasonable values for the gravel, which is highly permeable (it is described in detail in the section dealing with wells on Ski Bowl Road, Fort Richardson). The measurements did not lend themselves to the log-log plot because, it is believed, a sufficient number of early points could not be taken to define the early steep part of the curve.

Test runs at Ski Bowl Road were made on July 15, 1954, when well 19 was open at a deeper artesian stratum and well 17 was cased to a comparable stratum. Very high values were obtained by the nonequilibrium formula. Calculations using the equilibrium formula gave much higher values. The lower of the two sets of values obtained for the coefficient of transmissibility approximates values determined later by pumping both strata; it is therefore concluded that the analyses are not valid. If leakage occurred from the upper aquifer in the observation well to the lower one, drawdown would be diminished during testing of the lower aquifer and values obtained for its coefficient of transmissibility would be too high. A plot of the drawdown in the observation well on semi-log paper lends itself to the following interpretation: decline of water level at a slow rate due to leakage from above for 20 minutes; even slower but regular decline as greater leakage is induced by lowering of head in the deeper stratum for the next 680 minutes; clogging of the leak at 700 minutes and rapid decline of water level in the deeper stratum for the next 3,400 minutes. (A similar explanation based on downward leakage in the pumping well is also possible.) A value for the coefficient of transmissibility based on the slope of the last portion of the curve is about 75,000 gpd per ft.

On June 6, 1955, the recharge well (19) was redeveloped with air, after which the turbine was set to pump only from the deep stratum. Measurements of water level were made on well 17. Well 17 is 1,656 feet distant and, by then, was equipped with slotted casing opposite both deeper and shallower artesian beds. In the log-log plot (nonequilibrium method) the points taken from 4 minutes to 90 minutes make an excellent fit with the type curve. The coefficient of transmissibility determined by this method is 272,000 gpd per ft and the coefficient of storage 0.00011. The writers believe that this value for the transmissibility is too high, probably because of downward leakage from the shallow aquifer in the pumped well. Actual discharge from the artesian beds may be less than that used in the calculations, and the computed transmissibility consequently too high.

CONCLUSIONS

Tests on individual strata, from which values of 40,000 to 100,000 gpd per ft were obtained for the coefficient of transmissibility of fairly thick individual artesian aquifers, probably correctly reflect the hydraulic characteristics of those beds. The value of 240,000 gpd per ft for the section as a whole may be somewhat high, but a value of 200,000 gpd per ft is considered a reasonably conservative estimate.

ARTIFICIAL RECHARGE

During the ground-water investigation, considerable attention was given to the practicability of the artificial recharge of ground water. The inadequacy of the Ship Creek supply during periods of low flow led both the city of Anchorage and the military authorities to consider alternative sources of supply. Artificial recharge offered the possibility of storing water during times of plenty and of using it during periods of low supply. As part of the investigation the Geological Survey constructed an experimental well to test the potential effectiveness of artificial recharge.

Potential sites for artificial recharge are limited to localities near the mountain wall of the valley because that is the part of the lowland where the stream water and shallow ground water, the possible sources of the recharge water, are at higher levels than the deep aquifers which offer the best promise for the underground storage of water. The two general localities which seem favorable for artificial recharge are the fans of Ship Creek and Campbell Creek. Little was known of ground-water conditions in the fan of Campbell Creek, but test-drilling had already shown the presence of favorable geologic and hydrologic conditions in the fan of Ship Creek near Ski Bowl Road. An additional advantage of the Ship Creek locality was its proximity to existing distribution facilities, both municipal and military.

Study of ground-water conditions adjacent to Ship Creek near Ski Bowl Road suggested that if a well could be constucted that would tap both deep and near-surface beds it would have a higher yield than a well which tapped only deep beds or only shallow ones. In this part of the valley of Ship Creek the static water level for the shallow beds is appreciably higher than that for the deep ones. For example, water in wells about 40 feet deep, beside the stream, stands about 15 feet below the surface, while in wells which tap an aquifer at 100 to 130 feet the water stands 40 to 50 feet below the surface. If a connection could be established between the shallow and deep aquifers, water would flow by gravity from the shallow aquifer into the well, down the casing, and out into the deeper beds. After such a hydraulic connection had existed for a time the pressure head of water in the deeper beds would have increased, and those beds presumably would yield more water to pumped wells than they did previously under conditions of lower head. A further advantage of this procedure is the possibility of storing and recovering water that is warmer than that available from Ship Creek during the winter months.

After construction of a test well (17) which established a source of moderate supplies of artesian water in the area and of three test wells which proved the presence of permeable shallow beds subject to recharge by Ship Creek, it was decided to carry the investigation further and determine whether a supply well could be constructed that would draw water from both sources and, in intervening periods of idleness, act as a recharge well, and thus permit the flow of water from shallow beds to deeper beds. Inasmuch as the greater amount of recharge would take place during the warmer months at the time of high flow of Ship Creek, heat would be added to the underground reservoir. Such a well might also provide a direct or indirect disposal source for any reject hot water that might be available, as from a power plant. In so doing, the winter fog resulting from open-air disposal of hot water would be eliminated and a desirable increment of heat would be added to the ground.

CONSTRUCTION

A deep test well (17) showed the presence of intermediate and deep artesian aquifers. Three shallow test wells near where well 18 was later located showed the presence of a productive shallow aquifer near Ship Creek. The first three shallow wells were inadvertently destroyed during construction operations on the military base; they were replaced by well 18d, which served as a supply well during the construction of well 19. Wells 18d and 17 were afterward used as observation wells.

Well 19 was finished at a total depth of 129 feet; it is screened at three levels (30–44, 82–88, and 122–129 feet; see log and fig. 18) which represent parts of the three aquifers. The well was drilled with 8-inch casing; the final string of 6-inch casing and screens was set inside the larger casing, which was then removed. To facilitate retraction of the larger casing the 6-inch casing and screens were installed in several segments. The screens used are of pipe-base construction (that is, the metal strips comprising the screen are wound upon perforated steel well casing rather than upon a structure of thin rods, as in conventional well screens) in order to support the weight of the casing above them. The two lower screens were made on 5-inch casing in order that they would fit easily in the 8-inch casing; the upper screen was made on 6-inch casing. After the casing containing the two 5-inch screens had been set and the aquifers developed by surging and pumping, the deep aquifer was tested by pumping. The deep aquifer yielded 200 gpm with 30 feet of

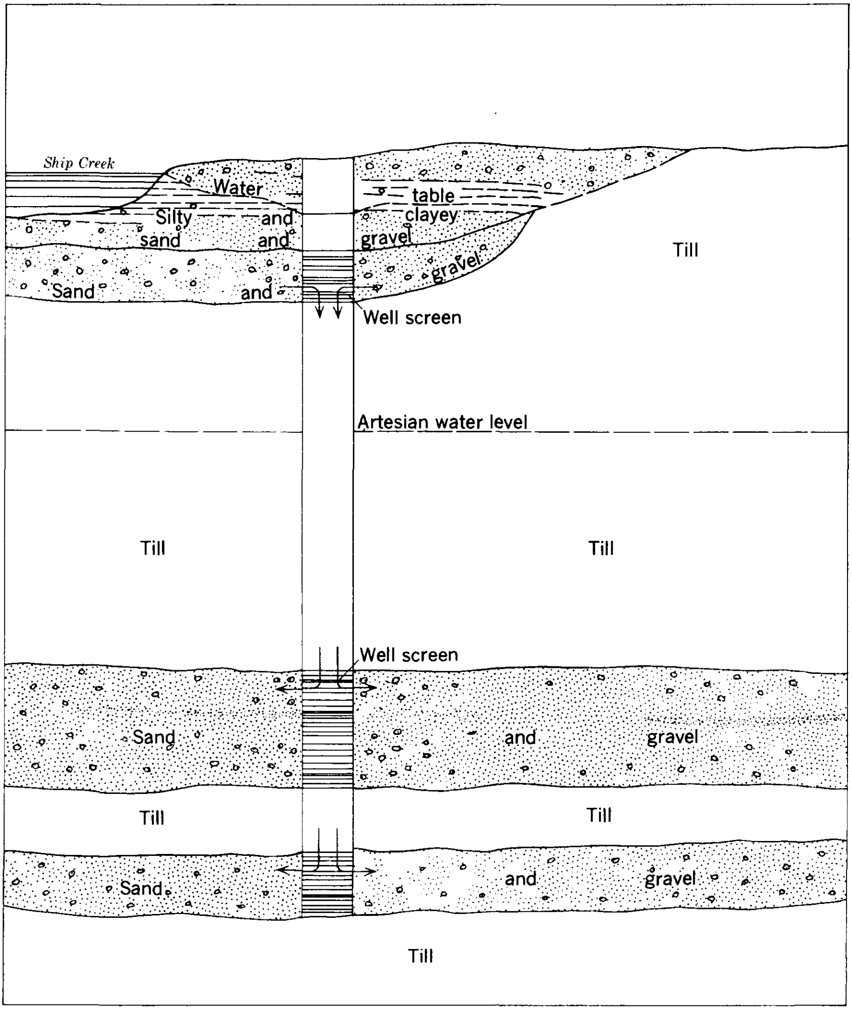

FIGURE 18.—Sketch showing construction of recharge well (19) on Ship Creek and movement of water from shallow aquifer to deep aquifers.

drawdown. Well 17, which at that time was open only to the deep aquifer, served as an observation well. Well 17 was then completed with perforated casing opposite the intermediate and deep aquifers, and well 19 was completed with the intermediate and shallow screens.

In developing the recharge well (19), the casing was plugged temporarily beneath the uppermost (6-inch) screen to prevent the development of the shallow aquifer from affecting the two deeper aquifers. While the casing was still plugged, the shallow aquifer was tested by pumping. It yielded 178 gpm with 14 feet of drawdown.

The plug was then removed from well 19 and water from the shallow aquifer began to move down into the deeper aquifers (fig. 18).

The well shows conclusively that artificial recharge of deep strata by gravity flow from shallow beds adjacent to Ship Creek is possible. However, difficulties encountered in the operation of the recharge well show that such a well probably will not be fully successful without thorough and perhaps repeated development of the well. The artesian beds here are capable of yielding, and therefore capable of receiving, several hundred gallons of water per minute, but the recharge well did not achieve this degree of effectiveness. During development of the intermediate aquifer the deep one became clogged with sand brought into the well. This sand migrated with the flow of water into the deep aquifer. Again, when the screens opposite the shallow screens at 30 to 42 feet were uncovered, recharge began immediately and sand migrated into both of the deeper beds and further reduced their recharge capacity. In addition, difficulties during the drilling necessitated pulling the original casing and redrilling the well. The adverse effects of the build up of mud cake in the permeable formations may have been appreciable.

OBSERVATIONS

An observation program, begun early in May 1954, was continued through the winter to June 1955 to determine pertinent factors affecting the gravity recharge of well 19. The flow of recharge water was measured with a deep-well current meter. These and other observations are presented in figure 19.

The recharge well (19) was completed and water from a gravel aquifer adjacent to Ship Creek began to flow down into the deeper strata on October 6, 1954. As is shown in figure 19, recharge began at a rate of about 135 gpm but declined to about 75 gpm by the end of the month. The fact that the water levels in well 17, 1,650 feet away, rose 1½ feet in the first 3-month period indicates that the recharge water was affecting a wide area. The downward flow of recharge water had diminished to 64 gpm by that time. It is of interest to note that in the recharge well (19) the intermediate aquifer was accepting 28 gpm at the end of December, while at the same time the "intermediate" aquifer in well 17 (the shallow one is absent there) was losing 20 gpm to the deep aquifer.

The water levels in the shallow gravel rise and fall with water stage in Ship Creek, as might be expected. Upon completion of the recharge well, a cone of depression was created in the piezometric surface for the shallow aquifer, and water levels declined about one-half foot in well 18d (fig. 19), 69 feet away. The water levels in the recharge well fell from the level of the shallow water

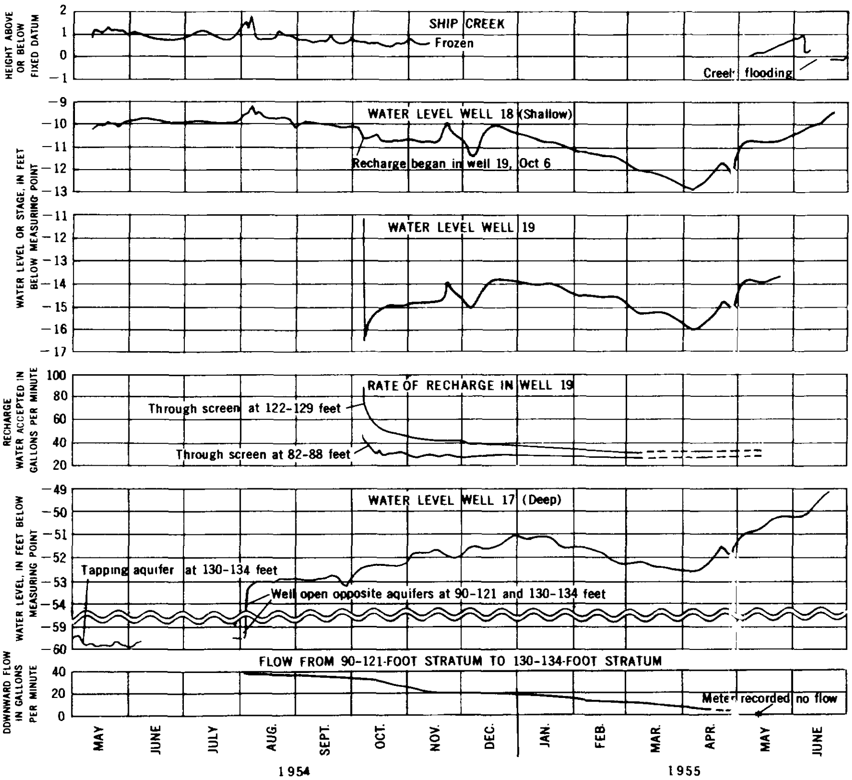

FIGURE 19.—Water levels in wells 17, 18, and 19 and in Ship Creek before and during artificial recharge of well 19, and amount of downward flow in wells 17 and 19.

table as recharge began on August 6, but tended to rise immediately thereafter.

From mid-December to early April, water levels declined in shallow well 18 and in the two deep wells, 17 and 19. This general lowering of water levels is ascribed to diminution of recharge during the cold months when streamflow had decreased markedly and when all precipitation was retained at the surface as snow and ice. The lowering of head in the shallow gravels had no discernible effect on the recharge rate which gradually decreased from 65 to 55 gpm.

Evaluation of the gain in head is difficult because it was manifestly impossible to shut off the flow of shallow water in the recharge well. The 2-foot rise of water level in the observation well (17, 1,656 feet away) in the first 3 months of operation of the recharge well may be noted. By this time more than 8 million gallons of water had flowed by gravity from the shallow gravel into the deeper beds. From mid-December to early April the water level in shallow well 18 declined 2.9 feet. In the recharge well it declined 2.2 feet in that period, and in well 17 only 1.5 feet. A gain in head of 0.7 foot in the recharge well and 1.4 feet in the observation well in that period seems indicated. About 12 million gallons of water had been added to the artesian system during that period.

A series of temperature measurements was made as part of the study of artificial recharge. On September 17 both Ship Creek and shallow ground water had the same temperature, 47°F. In the period from September 17 to November 22, water in Ship Creek became increasingly colder, and the stream was frozen over on November 29. Water temperature in shallow well 18 also declined but at a slower rate. A lag of 6° to 10°F was noted throughout. On November 22 water in the shallow well was about 38°F, or almost 8° warmer than Ship Creek water. Temperature readings taken later in the winter indicated that the temperature of the shallow ground water remained at about the temperature noted late in November. It must be supposed that if a recharge well were accepting much larger quantities of water, a less favorable temperature differential would exist as Ship Creek water migrated toward the well.

CONCLUSIONS

The recharge well allowed about 20 million gallons of water from a shallow gravel aquifer to pass downward into deeper aquifers, under gravity, during a period of 6 months. The rise in artesian water level a quarter of a mile away from the recharge well was about 3 feet. Water temperature in the recharge well tended to remain at the normal ground-water temperature. Recharging proceeded fairly well during the early part of the recharge process, but the well never accepted as much water as earlier discharge tests had shown it should accept. (It should be possible to pump water into an aquifer at the same rate at which it can be pumped from the aquifer, provided the water level in the recharge well can be maintained as high above the static water level during recharging as the pumping (discharging) level is below the static level during pumping.) The relatively low effectiveness of the well is attributed to incomplete development (probably the capacity of the pump used was too low). The decline in effectiveness during the recharging is attributed to progressive clogging of the deeper aquifers by silt carried down the well in the recharge water. In retrospect it appears that much of the difficulty with clogging of the recharged aquifer could have been avoided and further vital improvement attained by the use of a single well for recharging and another for a source of recharge water.

CONSTRUCTION OF WELLS

SHALLOW WELLS

Many shallow wells in the Anchorage area were dug by hand. One of these deserves special mention although, inasmuch as it failed to reach the water table, it cannot be properly termed a well. This excavation (542, pl. 2) was dug in till to a depth of 102 feet with a hand shovel. Since it failed to obtain water, the owner had a well (543) drilled at about the same site that reached water 12 feet below the level of the dug hole.

Many shallow wells have been excavated by power clamshell bucket; a few of them are as much as 50 feet deep. After the hole is dug, prefabricated wooden cribbing is picked up by the machine and set in place, the cribbing being installed in several sections if necessary.

A rather large number of water-table wells, some as deep as 70 feet, have been drilled; most of these drilled wells are along Fireweed Lane in Spenard, and in Mountain View.

DEEP WELLS

CABLE-TOOL DRILLING

Deep wells in the Anchorage area are drilled by the conventional cable-tool method. In 1949 there was only one machine at work in the area, but by 1955 there were at least nine machines, and two of them were heavy-duty rigs. Less progress had been made in acquisition of special tools and pumping equipment for development; some drillers still owned little more than the basic set of tools, although others had added to their stock and were equipped to handle almost any kind of job of drilling. As competition among the drillers increased there came also an increasing appreciation of the value of well screens and intensive development practices in the sandy aquifers in this area.

Most drilled wells in the area are open-end wells which tap relatively permeable gravelly sand or sandy gravel. Fewer wells end in coarse sand, and few obtain water from medium sand.

In construction of some of the wells drilled around 1950, the lowest several feet of casing had been perforated in order to admit more water. Casing perforated in this manner works fairly well at Fairbanks, where wells commonly end in thick gravel, but at Anchorage it was found that gravelly layers commonly are thin and that sand from above the gravel continues to be drawn into the well through the perforations. Several such wells failed almost immediately, and several others sanded up after a period of use. At best such perforations do not increase the yield of wells very much; where large supplies are needed well screens should be used.

Many open-end wells have rather low yields, which are attributed to lack of development rather than to low permeability of the formation or to the open-end method of construction. Most drillers pumped newly drilled wells for a few minutes to a few hours at a low rate. A few had no pumping equipment of any kind and merely bailed wells until the water cleared. Had these wells been pumped at higher rates and backwashed from time to time, there is no doubt that the yield of many of them would have been increased appreciably.

Although most wells in the Anchorage area were finished with open-end casing, at the time this study was completed some drillers were installing well screens and making an effort to develop wells to their maximum capacity. One problem which arose in some instances is due to the use of screens whose slot-size is not large enough to permit removal of the finer two-thirds of the formation. These wells did not develop an optimum amount of water. However, as is common in areas distant from sources of supply, the drillers were faced with the choice of installing the screens available locally or none at all. In most wells, the decision to install a 30- or 40-slot screen in a gravelly formation was no doubt a better choice than not installing a screen, and the result was a stabilized well of moderate efficiency. It may be pointed out, however, that installation of a too-small slot size screen may effect no real improvement in yield and that the only gain many be stabilization of the well.

Several wells that end in gravelly formations were finished with 100-slot screens; the production wells drilled by the Corps of Engineers between the Ranger Station and Ski Bowl Road offer outstanding examples. Two of the three that were finished with 20 feet of 100-slot screen yielded about 1,200 gpm of water with moderate drawdown. The Alaska National Guard well (606) represents a happy instance where a coarse thick water-bearing formation was properly screened. There, 10 feet of 60-slot and 15 feet of 80-slot screen were installed; the final yield of the well was 322 gpm with less than 2 feet of drawdown.

Well 420, west of the International Airport, is finished with 11 feet of 65-slot screen; it yields 70 gpm with 1½ feet of drawdown. Wells 66, 277, 422, and 619 are equipped with 40-slot screens. An excellent yield was developed in well 66, but the yield of well 277 (which ends in a bed of sand rather than gravel) was only about 1 gallon per foot of drawdown. On the other end of the scale, 6-slot screen was installed in well 605, south of the International Airport. Inasmuch as the formation here is silty sand, it is believed that this well could not have been completed successfully without a screen of this fine slot-size. The 6-gpm yield obtained is more than adequate for an average household. Larger supplies could be obtained by installing a longer screen and following with thorough development by pumping or surging. It seems likely that some of the several well failures in this area of fine-grained sediments might have been avoided had proper well screens been used, as was done in well 605.

ROTARY DRILLING

Conventional rotary drilling is considered a generally unsatisfactory method for use in the Anchorage area. At every location that might be chosen for a deep test well, till beds would be penetrated sonner or later, and the boulders commonly present in the till probably would be a never-ending source of trouble in drilling by the rotary method. However, city of Anchorage wells (50, 111A, and 114) were constructed successfully by the reverse-circulation rotary method, seemingly without undue difficulty.

QUALITY OF WATER

CHEMICAL QUALITY

The chemical quality of ground water in the Anchorage area is excellent. The total amount of dissolved solids is low, the hardness is moderate, and the concentration of other constituents, some of which may be very troublesome when present in more than minute quantities, is low. Practically all the water samples may be classed as calcium and magnesium bicarbonate waters of moderate hardness. (See table 3.)

HARDNESS

The total hardness of most of the water samples analyzed ranges from 80 to 130 ppm. A shallow drilled well in the northern morainal area (4, table 3 and pl. 2) has a hardness of 403 ppm. A few other samples analyzed contain from 200 to 250 ppm total hardness.

Calcium ordinarily ranges from 20 to 35 ppm and magnesium from about 5 to 15 ppm. The very hard water mentioned has a correspondingly higher calcium and magnesium content; calcium is as high as 138 ppm, and magnesium as high as 23 ppm. In some moderately soft water samples from wells adjacent to Ship Creek (17–19, 36), calcium is not particularly low but magnesium is less than 3.5 ppm.

Water from the Schwartz well (205), on Muldoon Road, has a high hardness (192 ppm), although it might be expected that in this locality the hardness would be rather low because the well is near the valley wall and may have been in the ground a relatively short time. The Schwartz well is 81 feet deep and is on a low hill just west of a large muskeg. It is believed that shallow water from the muskeg contains plant acids in solution that react with the sediments to produce calcium and magnesium bicarbonate and that this hard shallow water recharges the stratum in which the well is developed.

(The water also has a high iron content and is highly colored, as might be expected of water of such origin.)

No significant differences in hardness, nor in the concentration of the constituents, was found that can be explained as a function of depth or geographic location; for example, no progressive increase in hardness (nor in concentration of constituents) can be discerned from east to west, in the direction of ground-water flow. As is noted above, most wells in the area yield water with hardness in the range of 80–130 ppm; three exceptions in the vicinity of the International Airport (wells 420, 612, 613) yield water having a hardness greater than 200 ppm.

Water from the shallow gravel adjacent to Ship Creek (18) is somewhat less mineralized than most other ground water sampled and has much the same composition as water in Ship Creek; this water probably reached the aquifer by infiltration through the bed of the stream. Water from the three shallow test wells (of which No. 18 is listed in table 3) contained from 60 to 70 ppm total hardness.

SODIUM AND POTASSIUM

Sodium and potassium are low in almost all samples, and their concentrations ordinarily range from 3 to 12 ppm. However, water from well 33 in the lower valley of Ship Creek contains 51 ppm sodium and 4 ppm potassium, and is a slightly hard sodium bicarbonate water. The water tapped by well 33 was initially a hard calcium bicarbonate water, but has been converted by base exchange to a somewhat softer sodium bicarbonate water. Softening by base exchange occurs when a hard water passes through material holding exchangeable sodium in loose chemical combination. In such a situation, lime and magnesium are deposited from solution and their place is taken by sodium and potassium going into solution. Here, the material acting as a softening agent is probably clay that retains exchangeable sodium from the time it was last saturated with sea water.

Water in the Clover well (596), near the International Airport, in the Geological Survey test well at Anchor Park (177, sample at 210 feet), and in the District Engineer test well (28, sample at 323 feet) has also been softened somewhat by base exchange; however, in all three of these samples the sodium and potassium content is only a little higher than that of most other samples.

BICARBONATE

The bicarbonate content ordinarily ranges from about 100 to 200 ppm. Water to the west (wells 420, 612, 613), however, which is harder than the average, has a bicarbonate content as high as 250 ppm, and the very hard water from well 4 (in the northern part of

Elmendorf Air Force Base) has a bicarbonate content of 436 ppm. The hard water in the Schwartz well (205), referred to above, has a bicarbonate content of 229 ppm. On the other hand, the moderately soft water from shallow gravels adjacent to Ship Creek had 59 to 66 ppm of bicarbonate.

In most of the samples analyzed, bicarbonate is present as calcium and magnesium bicarbonate.

SULFATE

The concentration of sulfate is low in most samples analyzed and commonly is not greater than 10 ppm; many samples contain less than 5 ppm. Sulfate is somewhat higher (as much as 17 ppm) in water from some shallow wells (18, 24, 63). One well (11) that is 116 feet deep yields water containing 27 ppm of sulfate. In this instance, however, a slight degree of saline contamination is apparent.

CHLORIDE

Chloride concentration is almost everywhere very low. However, samples from the old Atwood Well (278) and a well (11) east of Lake Beebe on Elmendorf Air Force Base contain, respectively, 795 and 58 ppm of chloride, low nitrate, high sodium and potassium relative to calcium and magnesium, and high sulfate. These undoubtedly are samples of fresh water contaminated by sea water.

It does not follow that the salt water is brackish water drawn into the beds from Cook Inlet. In well 11, near Lake Beebe, the water-bearing formation is more than 150 feet above sea level, and contamination by inlet water is unlikely because the well is not pumped heavily enough to form a landward hydraulic gradient down which water from the inlet can move into the aquifer. The high-chloride water from these two wells probably represents contamination of fresh water by a small residuum of sea water trapped in the sediments when (rather recently) the area was covered by sea water.

The sample from well 4 has a higher-than-usual chloride content, 24 ppm. However, the fact that this water also has an extremely high nitrate content suggests that both the chloride and nitrate were derived from organic pollution.

It is not surprising to find high-chloride ground water in a region whose geologic history indicates that some of the sediments were deposited in salt or brackish water and that the area was temporarily drowned in marine or brackish waters at a relatively recent date (Cederstrom, 1946, p. 239). It is surprising that more examples of brackish- or salt-water contamination have not been found. The rarity of high-chloride water is undoubtedly a function of the relatively high permeability of till as compared to that of clay. The Anchorage artesian system is a dynamic system through which water is moving rather rapidly. In this dynamic system the flushing action of fresh water, originating from local precipitation, as well as that moving in underground from the east, has effectively removed the brackish water with which many of the sediments were probably once saturated.

Even near the estuaries, at places where wells are pumped heavily or moderately heavily, the chloride content of the ground water is low. Particular attention is called to the analyses of water from the deep wells at Turnagain Heights (280, 282), the International Airport (425), and the Campbell Point ACS station (420), and from the Steinhauser well (613), southwest of Sand Lake, in all of which the presence of higher-than-usual chloride contents might be expected. In samples from all these wells the chloride content is very low. Samples of water from the deep-lying shale beds tapped in the Geological Survey test well on Oilwell Road (64), in which normal ground-water circulation might be presumed to be poor, contained a very low chloride content, even after the well had been pumped at a moderate rate for 6 to 8 hours.

FLUORIDE

Fluoride is not a troublesome constituent in ground water at Anchorage; the maximum concentration found in samples analyzed is 0.4 ppm, and many samples contained no fluoride at all. Concentrations of fluoride above 2 ppm are undesirable because mottling of the enamel of teeth of children under 10 years of age occurs commonly where such water is used regularly (Dean, 1936, p. 1269). However, smaller concentrations are desirable in inhibiting tooth decay in children. Thus, the small concentration of fluoride in some samples of ground water at Anchorage is desirable with reference to use of the water by children.

IRON

Most samples of ground water collected at Anchorage are low in iron (<0.5 ppm), but some wells yield water that contains iron in troublesome amounts. A few of the deep water-table wells (137, 138, 192, 430, 283) in the western part of the area yield water with concentrations around 0.5 ppm. Water from the Schultz well (620), at Sand Lake, contains 1.1 ppm of iron. A well near Fireweed Lane (144) contains 5.0 ppm iron, and water from another in the valley of Ship Creek (33) contains 5.9 ppm. Water from a shallow drilled well that taps a thin sand lens in till on O'Malley Road contains 1.5 ppm iron. Water from the Schwartz well (205), at the east end of Tudor Road, has 11 ppm of iron; as was noted above, this water is thought to be derived in part from a nearby muskeg. Other wells which yield water containing undesirable amounts of iron are 471, 517, and 532; these wells tap aquifers in or beneath till.

The presence of iron in shallow ground water in the vicinity of Spenard was reported by householders and verified by analysis (well 144). In addition, conspicuous iron staining of the upper surface of clay and of the lower part of the overlying sand exposed in the bluff along Knik Arm west of Spenard, particularly where water seeps from the base of the sand, shows the presence of iron in the ground water there. The presence of ground water containing objectionable quantities of iron in or near areas of extensive bogs suggest to the writers that the ground water and its contained iron were derived from water in the bogs where the acid character of the water facilitates the solution of iron-bearing minerals.

TEMPERATURE

The temperature of ground water in the Anchorage area is commonly 37° to 38°F. The writers measured the temperature of the water from 16 wells where it was possible to obtain measurements after the wells had been pumped long enough to ensure representative measurements. In these wells, which tap all the important types of unconsolidated aquifers and range in depth from 8 to 443 feet, the range in temperature was from 36° to 39°F and the average temperature was 37°F. There seemed to be no correlation of temperature with depth. The temperature of shallow ground water near Ship Creek (well 18, not included in the 16 wells noted above), however, was found to be conspicuously warmer than the average for wells in the Anchorage area which are not near streams. This relatively high temperature is evidence that infiltration from the bed of Ship Creek replenishes the shallow ground water near the stream. Probably similar conditions prevail along the upper reaches of other streams in the Anchorage area where the surface water recharges shallow aquifers.

GROUND-WATER SUPPLIES AT VARIOUS LOCALITIES

ELMENDORF AFB–FORT RICHARDSON

DISTRICT ENGINEER TEST WELL

In the spring of 1953 a test well (28) was drilled under the direction of the District Engineer, Corps of Engineers, to determine the full extent of the water-bearing sands present at one location at Elmendorf Air Force Base and to test the water available from such permeable beds as might be present.

The hole was drilled to a depth of 850 feet. (See log, table 4; and fig. 11.) Unconsolidated sediments extended at least to a depth of 704 feet, and possibly to a depth of 778 feet. Below near-surface gravel the unconsolidated beds consist of marine sediments to a depth of 208 feet, where rather poor water-bearing material was present between 208 and 237 feet. From 301 to 476 feet the well penetrated till beds that are interbedded with or contain sandy or gravelly water-bearing layers. In this interval, deposits of sand and gravel made up 73 feet of the total 175 feet of section. Water-bearing beds were not found at greater depth.

A pumping test was made when the well had reached a depth of 320 feet. No screen was set for this test; water entered the well through the open end of the 16-inch casing. In a 36-hour run a yield of 350 gpm was obtained, with 77 feet of drawdown. (See discussion of this and subsequent tests on p. 57.)

During continued drilling, numerous thin sand strata penetrated were tested by bailer but no data on these tests are available. However, another pumping test was made at 402 feet. Eight feet of 40-slot screen, 10 inches in diameter, was placed at 402 to 408 feet. In a 9-hour pumping test 140 gpm was discharged with a drawdown of 130 feet. The 40-slot screen used in this test was probably not of the optimum slot size because the material penetrated was largely sandy gravel; an 80-slot screen, or even a coarser one, may have been necessary to develop this formation properly. Hence, the 140 gpm discharge obtained probably represents only a fraction of the potential yield of this stratum at the drawdown stated.

The level at which bedrock was reached is not known. The bailer sludge between 704 and 764 feet is reported to have had a brownish scum floating on the liquid, but no cuttings were found that could be identified as shale. In the USGS test well at the Ranger Station (64) the bailer sludge was similar in appearance, and only an occasional hard grain of shale was seen but, when the bailer sludge was passed through a simple screen, many cuttings were recovered and there was no question that shale had been penetrated. The writers are therefore inclined to place the upper limit of the shale at 704(?) feet rather than at 764 feet.

Upon completion of the test hole, 16-inch casing was left in the ground to a depth of 542 feet and the bottom was plugged; hence the completed well was 536 feet deep.

The well was finished by perforating the casing opposite all the water-bearing formations indicated in the log (table 4). A total of 130 feet of the casing was perforated; each perforation was one-fourth inch wide and 2 inches long, and 76 perforations were made in each foot of casing perforated. The well was developed by surging. When the well was pumped at a rate of more than 1,000 gpm, the water cleared in 4 hours; after 18 additional hours of pumping with no increase in rate, the pump was operated intermittently to promote further development. This operation was carried on for 55 hours, at which time no further increases in yield were noted. As a result of this operation, the capacity of the well increased to 1,400 gpm at a 265-foot pumping level.

A sustained discharge test of 44 hours' duration was then conducted. The well was discharged at a rate of 1,340 gpm for 44 hours with a drawdown of 218 feet (a pumping level of 263 ft). This very large yield, by far the largest discharge from any well in the Anchorage area, showed that larger quantities of ground water were available in the Anchorage area than had hitherto been proved. Despite this high total yield, however, the well was not so effective as several others in the area. Well 28 yielded slightly more than 6 gallons per foot of drawdown. By way of comparison, wells 64, 420, and 606 had specific capacities of 17, 45, and 169 gpm per foot of drawdown, respectively. (These wells had, of course, been pumped at much lower and less impressive rates.)

Two pumping tests had been made in well 28 at 320 feet and at 402–408 feet; in these tests 350 gpm had been pumped with 77 feet of drawdown and 140 gpm with 130 feet of drawdown. However it appears that if a drawdown of 218 feet had been used in these tests, 1,000 gpm might have been obtained at the 320-foot level and 230 gpm might have been obtained at the 402- to 408-foot level (Bennison, 1947, p. 209). Adding these yields, a combined yield of 1,230 gpm with a drawdown of 218 feet is indicated. The potential yield at 320 and 402–408 feet is thus only slightly less than the 1,340 gpm yield obtained when more than 100 feet of water-bearing formation was drawn upon. Development of the well with perforated casing probably did not achieve the potential effectiveness of the well, and hence use of the final test as a basis for evaluation may lead to underestimation of the total amount of water that might be obtained from a properly constructed production well at this location.

Figure 20 shows that the well was not stabilized at the end of the 44-hour pumping test. The drawdown, plotted against time, shows a rather wide variation from hour to hour instead of a steady decline at a progressively decreasing rate. During the course of the test the discharge was nearly constant; in the last 32 hours of the test it ranged from 1,326 gpm to 1,364 gpm but was most frequently recorded as 1,341 or 1,334 gpm.

The variations in drawdown and in the trend of the specific capacity (efficiency) curve seem to indicate progressive sand clogging. The sharp decline in pumping level from 7 to 9 a.m. on November 17, which was followed by a rise in efficiency and decrease in drawdown, probably indicates removal of sand from the formation. However, the general trend of the efficiency curve is down-

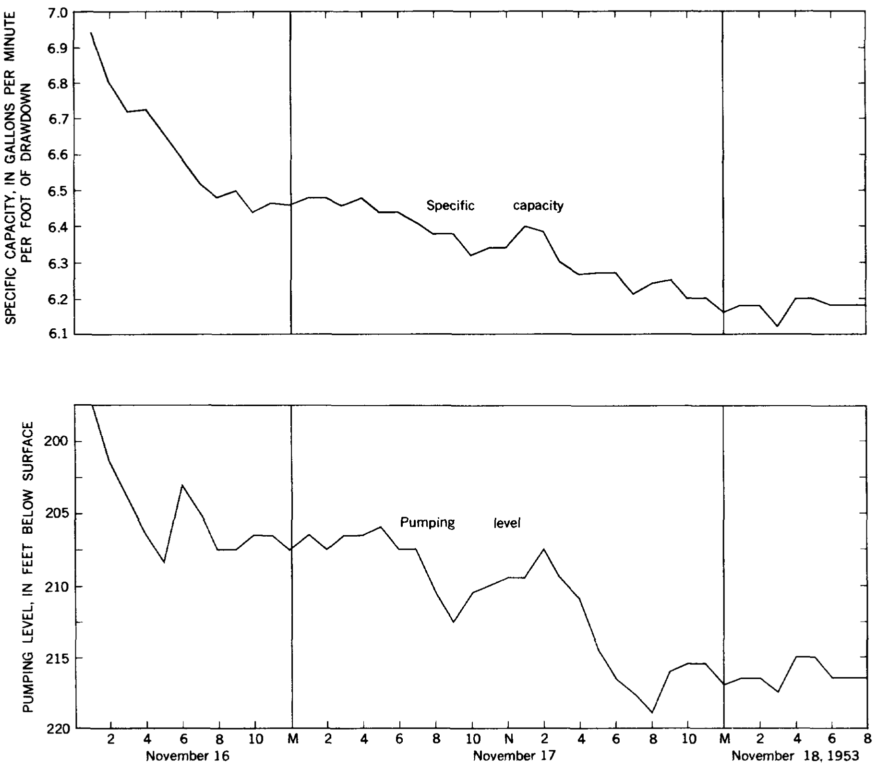

FIGURE 20.—Drawdown and specific capacities, District Engineers well (28) during pumping test, Nov. 16–18, 1953.

ward. At the end of 10 hours of steady pumping the efficiency had declined by 7 percent, and by the end of the 44-hour test run it had declined by about 10 percent. The accumulation of much brown sand, believed to have come from the 320-foot zone, in the bottom of the casing during the test is considered to bear out the conclusion arrived at from study of the test data. However, it is not known whether all this sand accumulated in the latter stages of development or whether some of it might have accumulated during the sustained yield test.

OTHER WELLS ON ELMENDORF AFB

Several wells (2–13, pl. 2) are on Elmendorf Air Force Base in the hilly area north of the airfield. These wells range in depth from 60 to 406 feet; only a little is known about them. Well 12, south of Fish Lake, is reported to have yielded 80 gpm; the driller's log (table 4) suggests an alteration of estuarine (dominant) and glacial-outwash deposition. Well 13, just to the west of well 12, is on a hill 380 feet above sea level, penetrates a thick section of till, and taps gravel beneath the till at a depth of 388 feet. Wells 7 and 8 also penetrate thick sections of till. Wells 7, 8, 12, and 13 are all on the end moraine of the last glacier that reached the Anchorage area.

Well 3 north of the end moraine and on low ground (60 feet above sea level) flows at a rate of 44 gpm. This well is 294 feet deep; it taps a 7-foot gravel bed that is about 230 feet below sea level, at the base of a section made up largely of blue clay.

South of the end moraine, well 34, just northeast of well 28, is reported to yield 143 gpm from an 8-foot stratum reached at 232 feet; this stratum is the uppermost aquifer reported in well 28. Well 25, still farther to the north, seemingly ends in this stratum also, but it has a very low yield. Well 24, at Whitney, is 78 feet deep and may end in outwash-plain gravel.

OILWELL ROAD

In the summer of 1952 a well (66) was drilled by a commercial driller at a small Army installation near the intersection of Oilwell Road and Glenn Highway. A sandy cobble gravel was tapped between 151 and 157 feet that was subsequently screened with 7 feet of 40-slot screen. Development procedures are not known, but at the end of a 72-hour pumping test the well yielded 60 gpm with 3½ feet of drawdown. The water level was 5 feet below the surface. If the 150 feet of available drawdown had been utilized, the potential yield might have been about 1,500 gpm or, roughly, 2 mgd (Bennison, 1947, p. 208). The effects of friction in an 8-inch diameter well must be discounted at high rates of discharge; moreover, the tables used to determine the potential yield are empirical, and utilizing low values on one end of the scale to determine the 100-percent values may not be safe. Greater reliance could be given the estimate of the greatest possible yield if the discharge and drawdown had been greater. The writers are somewhat less optimistic in their evaluation of this well, but believe that at least a million gallons a day should be available from the well if a 150-foot column of water is utilized and a sufficiently large pump to discharge that amount of water can be installed in an 8-inch well.

Evidently the formation is highly permeable, because the well was finished with a 40-slot screen, which will pass only medium sand and is suited for developing wells in medium to coarse sand. In well 66 the screen provided a relatively large intake area, but could have done very little toward increasing the permeability of the formation. An 80- or 100-slot screen, had it been available, would have resulted in an even higher efficiency.

A Geological Survey test well (64) drilled in the summer and fall of 1952 was located at the Ranger Station, east of well 66. It was drilled to a depth of 617 feet and ended in shale bedrock. The entire thickness of unconsolidated sediments was explored. Although bedrock was not penetrated until the drill had reached a depth of 447 feet, permeable sand beds were confined to the interval between 123 feet and 181 feet. (See log, table 4; and fig. 11.) The medium to coarse sand 166 to 175 feet below the surface was tested without setting a screen, and a yield of 70 gpm was obtained with 18 feet of drawdown. The potential yield, utilizing 150 feet of drawdown, would be about 450 gpm. Sandy gravel at 175 to 181 feet was tested with the bailer. The test (30 gpm with 9 feet of drawdown) is hardly indicative of the full potential of that bed; such a bed probably could easily produce 200 to 300 gpm with less than 100 feet of drawdown. Beds of sand higher in the well (at 153 to 166 feet and 123 to 139 feet) were not tested, but should be considered in evaluating the total possible yield of this well. The till beds from 214 feet to 252 feet contain thin streaks of sand. A yield of 30 gpm with 9 feet of drawdown was obtained from them. Thus appreciable additional water might also be obtained from these sands.

More than a million gallons of water per day should be available from a properly screened and developed well at this location, if the water level were drawn as much as 100 feet.

Clayey sediments that extend from 348 to 447 feet below the surface rest on the bedrock which is shale.

Tests of 8 and 6 hours' duration were made to determine the water-yielding characteristics of the shale. In these tests the well was pumped at a rate of 42 gpm. However, about 6 months later, when tested again, the well failed to yield more than 2 to 3 gpm, even after redevelopment work was done. The broken ends of the layers of shale that form the walls of the hole apparently swelled during the period after the first test and effectively cut off the inflow from openings in the rock.

Test wells 68 and 69 were later drilled by the Corps of Engineers a mile east of the Ranger Station. Well 68 developed 255 gpm with 31 feet of drawdown; it taps a gravel stratum 104–125 feet below the surface and may also draw water from beds at 245–256 feet.

UPPER SHIP CREEK

A USGS test well (17) was drilled near Ski Bowl Road in 1953. Water-bearing sand was tapped at 90 to 121 feet and 130 to 134 feet (see log, table 4; and fig. 11). Bailing tests of the upper strata were not encouraging, but at 134 feet the lower aquifer yielded 190 gpm with 30 feet of drawdown. Proper screening and development of both aquifers would make possible a much higher yield.

Well 19, which was constructed as a recharge well on the north bank of Ship Creek, has been discussed on page 64. It may be noted here that a yield of 200 gpm with 30 feet of drawdown was obtained from gravelly strata between 122 and 127 feet; the well was finished with an 80-slot screen. Other gravelly beds at 72 to 80 feet and 82 to 90 feet were given only brief bailer tests. Again, a very substantial yield could be obtained here if all the beds were screened and fully developed.

Shallow beds adjacent to Ship Creek have very high yields. The first well drilled tapped a medium to coarse sand and developed 190 gpm with 8 feet of drawdown. It was finished with 4 feet of 100-slot screen In the second well, 7½ feet of medium sand and 1½ feet of coarse gravelly sand were screened with 60- and 100-slot screen respectively. The well yielded 290 gpm with 12½ feet of drawdown. An appreciably greater yield is easily available here, for only the lower 1½ feet of the gravel extending from 19 to 28 feet was screened. In the third well, medium to coarse sand at 25 feet graded downward to gravel at at 39 feet. Screen on hand was set as follows: 60-slot from 26 to 31 feet, 40-slot from 31 to 36 feet, and 100-slot from 36 to 39 feet. In a 3-hour pumping test a yield of 230 gpm was obtained with 2½ feet of drawdown. The pumping level was 12½ feet below the surface. It appears that by use of the proper screen and of the full available drawdown a yield of more than a million gallons per day (about 700 gpm) could be obtained here.

Figure 21 shows the distribution of grain sizes in the shallow sandy gravel penetrated in the three shallow wells. According to these graphs, the coarsest 30 percent of the three finer grained samples would be retained by a 150-millimeter sieve or a 60-slot well screen. The other four curves represent material that is appreciably coarser. The curve at the extreme left of figure 21 represents the coarsest material penetrated in the third well (which had the highest yield).

An aquifer test at this site showed that recharge began in about 6 minutes and that the distance to a point of recharge was as little as 14 feet or as much as 200 feet distant from the pumping well. The source of the recharge was Ship Creek. Shallow gravel adjacent to Ship Creek obviously could supply large quantities of water. The overlying material is of low permeability and would adequately protect the underlying permeable beds from gross contamination. Induced recharge from Ship Creek would begin soon after pumping started, and a few hundred feet of travel through the sandy sediments would be sufficient to filter out not only trash but organic contaminants as well.

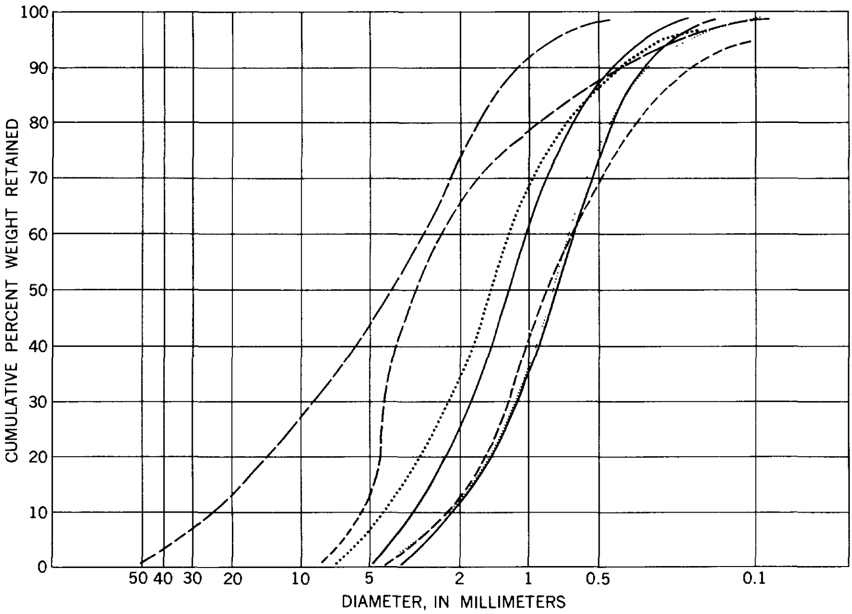

FIGURE 21.—Diagram showing mechanical analyses of sandy gravel adjacent to Ship Creek. Samples were taken between depths of 25 and 39 feet.

Subsequently the Corps of Engineers had several test wells drilled southwest of this locality. These wells (20, 21, 22, and 23) were, respectively, 96, 162, 170, and 210 feet deep. (See log of well 23, table 4.) Still later, 16-inch production wells were constructed there. In one well, near well 21, 20 feet of 100-slot screen was placed opposite gravelly sand at 132 to 152 feet. The developed well yielded 640 gpm with 71 feet of drawdown, or 9 gpm per foot of drawdown. A well near well 23 yielded 1,180 gpm with 64 feet of drawdown, or about 19 gpm per foot of drawdown; and a third well, still farther southwest, has a yield comparable to the second well. In these wells water stands 20 to 25 feet below the surface. In 1959 these wells furnished about 133 million gallons of water to the military establishment, of which nearly half was pumped in March and April.

MOUNTAIN VIEW AND ARTESIAN VILLAGE

Artesian Village derives its name from a flowing well (51) completed at that locality by the U.S. Army in 1943. This was the first well to show that artesian aquifers exist in the Anchorage area. The well is 154 feet deep and is reported to have had a flow of 104 gpm when it was drilled. It is at an elevation of 170 feet above sea level.

Of 48 household wells in the Mountain View-Artesian Village area for which records are available, 31 range in depth from 40 to 70 feet. The shallow wells on higher ground to the north obtain water from the outwash-plain gravel, but wells of comparable depth on lower ground to the south tap clay or till a short distance below the surface; these wells obtain water from sand or gravel layers in the till. The relatively shallow wells ending in the gravel of the outwash plain in Mountain View and Artesian Village have excellent yields. Well 46 is reported to yield 30 gpm with 5 feet of drawdown, and well 55 was pumped at 55 gpm with 3 feet of drawdown. Wells which tap sand layers in till to the south have much lower yields—ordinarily less than 10 gpm with moderate to rather large drawdown. The remaining household wells are deeper and tap beds of sand or gravel in or beneath till that underlies the outwash plain. Most of these wells are from 100 to 200 feet deep.

A producing well was constructed by the city of Anchorage at the site of test well 111A (Nyman, 1958, p. 10). Eighty-slot screen was placed at 175 to 190 feet (opposite what the driller's log of the test well records as 3 feet of "sand and gravel," 5 feet of "clay with sand and gravel," and 7 feet of "cement gravel"), at 200 to 210 feet (opposite "hardpan"), and at 280 to 290 feet (opposite "clayey sand and gravel"). There seems to be little correlation between data from the driller's log of the test well, optimum placement of screens, and the surprisingly large yield of 1,600 gpm with 40 feet of drawdown that was obtained in a 72-hour test. If the formations screened are largely till, as the log suggests, loose sandy till may be a prolific aquifer in places. Such formations may require wide-slot screens and more vigorous (and longer?) development than had been previously given in any drilling in the Anchorage area.

A producing well was also constructed by the city at the site of test well 50 (Nyman, 1958). Eighty-slot screen was placed from 270 to 320 feet, opposite a bed of sandy gravel at 280 to 319 feet. This well produced 1,900 gpm with 27 feet of drawdown, thus being an appreciably better producer than well 50.

The formations found in a third city test well (52), at the eastern edge of Artesian Village, were considered too poor to justify construction of a production well. Comparison of the log of this well with that of well 111A suggests that had well 111A been completed as a production well before well 52 was drilled, rather than vice versa, test well 52 might have been considered to show reasonable promise of yielding a large amount of water. The many wells of moderate depth in the area, almost all of which end in till, strongly suggest that the till here is generally quite permeable.

In summary, except in the terrace gravels and the outwash-plan deposits, there appears to be little constancy in the depths and characteristics of water-bearing beds in the vicinity of Mountain View and Artesian Village. The logs of test wells 50, 52, and 111A show few similarities. Many thin, fairly permeable aquifers are present in deposits that are predominantly till; these aquifers appear to consist in large part of relatively poorly sorted materials rather than the clean sand and gravel characteristic of the outwash-plain deposits exposed at the land surface. For this reason, drillers should carefully test all beds which appear in any way promising—it may be possible to construct a well yielding a moderate amount of water from an unlikely looking formation.

LOWER SHIP CREEK

In 1956 there were 10 wells in lower Ship Creek valley; wells 30–32, 36–37, and 116 are from 150 to 170 feet deep and wells 33 and 115 are, respectively, 210 and 235 feet deep. Wells in the first group obtain water from sand and gravel that is about 80 feet below sea level, beneath a thick cover of clay. The two deeper wells appear to have struck till at depth and were continued to deeper sands. (See log 115A.) Water rises above the surface in all these wells. Well 31, finished with 10 feet of 80-slot screen, flowed 55 gpm at 79 feet above sea level; the other wells have smaller flows.

CITY OF ANCHORAGE

Few wells have been drilled in that part of the city between Chester Creek and Ship Creek. Most of those drilled are in the Eastchester subdivision, north of Chester Creek along Seward Highway. Eleven shallow wells, many of them drilled, range in depths from 25 to 35 feet; the water stands 20 to 25 feet below the surface. Yields are small; the best yield reported is that of well 124 (7 gpm with 1½ feet of drawdown).

Three drilled wells (126, 167, 168) about 90 feet deep obtain water near sea level in what appears to be a somewhat permeable zone in the uppermost till sheet. (See log of well 163.) In the C. R. Lewis Co. well (122), in downtown Anchorage, "silty water" is reported from this zone.

In a test well (163) drilled at the south end of the north-south runway at Merrill Airport by the city of Anchorage, the first prolific aquifer was reported at 122 to 136 feet, or about 28 to 42 feet below sea level. Less promising sand and gravel were penetrated at 188 to 199 feet. (This stratum appears to be the same from which water was obtained in the C. R. Lewis Co. well (122) at 223–227 feet and in several wells in the valley of Ship Creek to the north.) A thick and prolific series of water-bearing sands in well 163 was tapped from 268 to 338 feet below the surface (174 to 244 feet below sea level). In this well, 57 feet of screen was set at 337 feet but settled to 350 feet in the hole (previously drilled and then backfilled) during development; the screen was thus left opposite water-bearing strata from 293 to 338 feet. The well was pumped at a rate of 2,600 gpm with 75 feet of drawdown. The static level is about 13 feet above the surface in this well. The deep thick sandy bed may be correlated with the lower sands and gravels penetrated in well 177 (see fig. 11), at Anchor Park, about half a mile to the southeast; however, 1 mile to the east-northeast, in well 111A, no thick sand bed is present at the corresponding level.

Northwest of Merrill Field another city test well (114) penetrated a 20-foot aquifer at 160 to 180 feet which can reasonably be correlated with the first thick aquifer in test well 163, less than a mile to the south. What appears to be the "second aquifer" of well 163 is also present (at 219 to 224 feet), but it apparently was not tested. On the other hand, the 70-foot layer of sand and gravel which yielded 2,600 gpm to well 163 appears not to be represented in well 114; only till is present in the interval from 224 to 415 feet.

When a production well was constructed near well 114 (Nyman, 1958, p. 10), 60-slot screen was placed at 160 to 180 feet opposite "coarse gravel and sand." Another 10 feet was placed at 190 to 200 feet, opposite a formation described as "gravel and clay" (probably till) which yielded a little water. This well was the poorest of the four production wells constructed by the city; it yielded 1,300 gpm at an efficiency of 24 gpm per foot of drawdown.

CHESTER CREEK

About a dozen wells are along Chester Creek near where it is crossed by Seward Highway. Most of these wells penetrate a rather thick section of blue clay and obtain water from gravel beneath the clay or from a gravelly layer in till at a slightly greater depth. (See log of well 134.) Water occurs here under stonger head than in wells in the higher ground to the north and south, and several wells have strong flows. The Moring well (133), at an elevation of 60 feet above sea level, is 120 feet deep; it had an initial flow of 150 gpm and a pressure head of 76 feet above land surface. The Anchorage Oxygen Co. well (134), 157 feet deep, flowed 100 gpm at an elevation of 67 feet; this well was finished with 9 feet of 60-slot screen set at the base of a 16-foot gravel stratum. The Boeke well (137), drilled in 1951 on the south bank of Chester Creek at an elevation of 77 feet, had an initial flow of 200 gpm; although on higher ground, it is only

103 feet deep. The Ballard well (139), which is about the same depth, flowed 134 gpm at an elevation of 61 feet; it had a head of 58 feet above land surface. The Grundy well (171), drilled in 1955 to a depth of 77 feet, had an initial flow of 200 gpm at an elevation of 72 feet; it obtains water from a sand or gravel directly beneath the blue clay. A somewhat deeper well (173) at Club International obtained a smaller flow (15 gpm) but is reported to have had a pressure head of 73 feet above the surface or 134 feet above sea level; this well taps a sand layer in till.

Although it is to be expected that the flow of these wells diminished greatly soon after they were brought in, the observed initial flows and pressure heads give an index of potential yields and efficiencies of wells here. If it is assumed that the pressure head at the Grundy well (171) was the same as that at well 173, nearby, the maximum yield in this locality may be estimated as 200 gpm with 52 feet of drawdown, or about 4 gpm per foot of drawdown. The Boeke well (137) may have had a similar efficiency. Pressure head at the Ballard well (139) was reported to be 58 feet above the surface. The well had an initial flow of 134 gpm and its efficiency is, therefore, slightly more than 2 gpm per foot of drawdown. The efficiencies of other flowing wells in this area do not exceed this value. Pressures in the valley of Chester Creek decline to the west. In the Miller well (287), water rises about 26 feet above sea level; still farther downstream, water in wells on the south bank of Chester Creek apparently rises as much as 35 feet above sea level.

ANCHOR PARK AND ROGERS PARK

The thick aquifers of sand and gravel in well 177, at Anchor Park, are described in detail in the log in table 4. Tests made during the course of drilling indicated that at least 1 million gallons per day should be available at this site, and proper screening and development might prove two or three times that amount of water. The formations appear to be much more favorable than in any one of the four city wells (in which yields of as much as 2,600 gpm were obtained). The upper sandy aquifer in well 177 thins toward the northwest, (well 163) but the lower aquifer thickens slightly; it is the lower bed from which 2,600 gpm has been pumped in well 163. Both of the thick sandy beds at Anchor Park thin toward the north-northeast (well 111A). Nevertheless, the upper bed contributed the greater part of the 1,600 gpm developed in a production well drilled at the site of well 111A. A study of logs indicates that the lower sand extends as far as well 50 in Mountain View, but neither bed appears to reach well 52 at Artesian Village.

Deep holes are lacking to the south and west, and the possible extension of the formations in those directions is unknown. To the west, what may be the lower sand is tapped by well 324 in Spenard. (See log.)

At Rogers Park, wells 180 and 181 reach the upper sand, but well 179 appears to end in a thin sand higher in the section.

FIREWEED LANE

Along Fireweed Lane (north of O'Connell Lake) most wells range from about 65 to 150 feet in depth, though a few are deeper. These wells are thought to tap sandy or gravelly streaks in till. Till is reached beneath a stratum of blue clay, and in it the water is in sandy streaks that seem to occur at random levels. Water stands about 10 feet below the surface in most wells that are 100 feet deep or more, and somewhat higher in the deeper wells. In wells less than 100 feet deep the water stands at a wide range of depths and at some places is as much as 60 feet below the surface. Most of the drilled wells are reported to yield 5 to 10 gpm with as much as 50 feet of drawdown. Well 145 yielded 83 gpm with 4 feet of drawdown, however, and well 161 yielded 60 gpm with 19 feet of drawdown; these wells are both about 150 feet deep.

SPENARD

Wells which yield supplies suitable for domestic use are, on the average, somewhat deeper in Spenard than farther east. Records of about 120 deep wells in the vicinity of Spenard were collected during this investigation; of these, 80 wells range in depth from 70 to 160 feet, 32 from 200 to 300 feet, and 8 from 300 to 354 feet. Most of the deeper wells are in the southern part of Spenard. Several wells penetrated a layer of clay and then a layer of till, or two layers of clay and an intervening till, or even two layers of clay and two of till, before reaching an aquifer. Not only are the aquifers farther from the surface, but thick aquifers are less common than farther east. In most places where aquifers were completely penetrated they are only a few feet thick. Moreover, the beds are even less extensive laterally than they are farther east; during the course of this study, individual water-bearing beds could not be traced for more than short distances, despite the fact that detailed and abundant information was available for this part of the area. Many of the water-bearing beds are layers of sand in till, or layers of sand associated with the deposits of silt and clay. Some of the beds of sand in the clay are several tens of feet thick, but commonly this sand is fine grained and well sorted, becomes quicksand during drilling and pumping, and hence is difficult to develop. Few of the aquifers

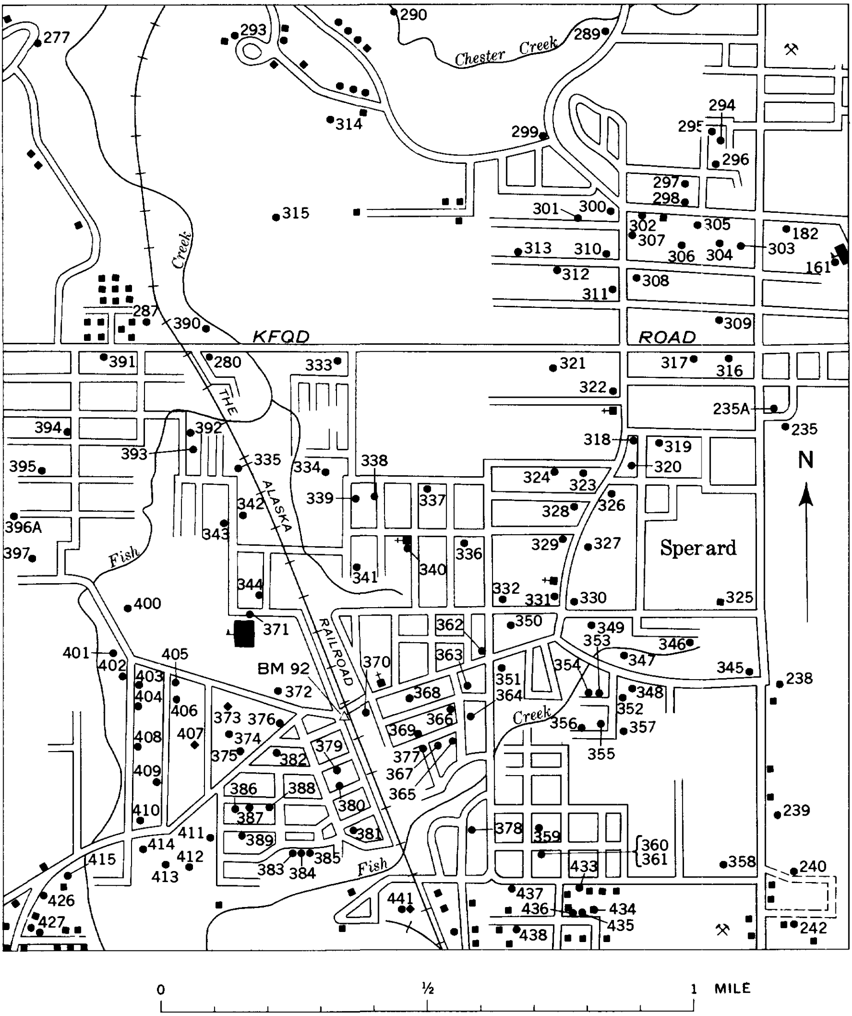

FIGURE 22.—Map showing location of wells in Spenard.

seem to be thick outwash-stream deposits of the sort found between till sheets farther east.

Spenard is believed to lie nearer the site of the deeper part of the lowland than Anchorage and Mountain View. As a consequence the estuarine deposits are thicker beneath Spenard, where estuarine deposition probably continued for longer periods, than beneath Anchorage; outwash-stream deposits are more important at Anchorage than at Spenard because subaerial conditions prevailed there for longer periods and because Anchorage lies nearer the site of the source of the outwash sand and gravel.

Water stands from 10 to 40 feet below the surface in most drilled wells in Spenard. Water rises higher in the deeper wells, and in a few places the deeper wells flow at the surface. The Hooper well (324, see log), 285 feet deep, is reported to have had a flow of 33 gpm at the surface, 102 feet above sea level. Pressure head was said to have been 26½ feet above the surface. The Bendix Launderall well (330), 269 feet deep, flowed at a rate of 60 gpm. The well at Center Theatre (363, see log) flowed 30 gpm at an elevation of 91 feet; this well is 324 feet deep. The Crawford well (411), in southwesternmost Spenard, is reported to have had a pressure head of 33½ feet above the surface, which is 70 feet above sea level, and to flow 50 gpm; the well is 318 feet deep. Several other wells, some only a little more than 200 feet deep, have had small flows. In southeastern Spenard a small flow was obtained from well 358 at an elevation of 142 feet above sea level. The well is 252 feet deep but it is on high ground, about 40 feet higher than the average well in Spenard.

Well 235A, 244 feet deep, flowed 60 gpm at the land surface when it was drilled, and was pumped at 550 gpm at a pumping level 12 feet below the surface. Subsequently (1959) a private-utility water system had a well drilled nearby. A sandy bed extending from about 240 to about 260 feet below the surface was screened and developed. Flow at 6 feet above the surface was 300 gpm from a 10-inch casing, and the yield to a pump was 1,000 gpm; the drawdown is not known but it is presumed to be small. The private water system (which includes also wells 282 and 398, in Turnagain Heights) was purchased by the city of Anchorage in 1960 and connected to the city distribution system.

Well 299, at Romig Park, which is one of the few screened wells in Spenard, yielded 300 gpm with 55 feet of drawdown; this well is 199 feet deep. Well 321, at Martin Subdivision, is of approximately the same depth; it was finished with open-end casing and developed 25 gpm with 5 feet of drawdown from pea gravel. In well 344, in the western part of Spenard, the driller bailed 50 gpm with 70 feet of drawdown from a sand 278 to 282 feet below the surface.

Those wells cited above are exceptional, in Spenard, where only a few high-yield wells or very efficient wells have been constructed because the amount of water required from any one well has not been great. The average efficiency is perhaps about 1 gpm per foot of drawdown, and few wells are pumped at a rate of more than 5 or 10 gpm. Nearly all other wells yield less water and are less efficient than these cited. No doubt larger yields and more efficient wells could be developed here if time, money, and skill were expended in construction and development. It should be borne in mind that strong recharge takes place east of Spenard at the head of Campbell Creek (see pl. 3), and interference here from the city wells and from pumping on the military reservation is probably small.

TURNAGAIN HEIGHTS

Well 282, at Turnagain Heights housing development, taps alternating layers of gravel, sand, silt, and clay (see log), beneath layers of clay and of till, at 385 to 452 feet. A second well at this development (398) is of about the same depth. Well 282 was finished with a 40-slot screen and obtained a yield of 150 gpm with 16½ feet of drawdown, but well 398 was less efficient and obtained 205 gpm with 101 feet of drawdown. Well 283, at Susitna View housing development nearby, was finished at 211 feet in sand and gravel. The clay stratum in well 282 overlies the aquifer here; the till layer is absent or was not reached by well 283. Although finished with a 40-slot screen, the well has a yield of only 60 gpm with 55 feet of drawdown.

The water level stands from 20 to 25 feet above sea level in this part of the area.

LAKE SPENARD AND INTERNATIONAL AIRPORT

Several wells in this part of the area (415A, 428, 429, 432A) range from 216 to 258 feet in depth. However, the sediments differ greatly from place to place and persistent water-bearing formations are lacking. Well 415A, north of Lake Spenard, penetrates clay, silt, and sand to a depth of 238 feet; well 432A, at the Cordova Airlines hangar south of the lake, penetrates glacial till and clay between 32 and 233 feet. A domestic well (427) east of Lake Spenard penetrated a 22-foot stratum of "floating gravel" (coarse quicksand), beneath clay and above till, at 329 feet. This sand rose in the casing and water was not obtained until a gravel beneath or in the till at 392 feet was penetrated. Another domestic well (431) nearby developed 40 gpm with 10 feet of drawdown from a 2-foot stratum of pebble to cobble-size gravel in till at a depth of only 67 feet. Still another variant is seen in well 426, at South Shore Motel, which developed a little water from a sandy bed in the silt and clay sequence at a depth of 112 feet.

At the International Airport considerable variation in the sediments is seen in short distances. The Sea Airmotive well (418), at Lake Hood, is finished at 250 feet in a thin gravelly bed below silt and clay, whereas well 422, at Union Oil Co. nearby, reached till at 105 feet and taps a sandy layer in the till at 354 feet. The well at the International Airport terminal building (425) was originally 308 feet deep and developed only a small amount of water from 18 feet of medium sand. When this well was deepened to 354 feet, fine gravel was penetrated but only 40 gpm of water was obtained, apparently because the old 40-slot screen was reinstalled in the well. The sample of the water-bearing formation representing the interval from 327 to 345 feet, collected at the time the well was drilled, was sandy gravel. The sample representing the 345–351 foot interval was coarse gravel. A sieve analysis indicated that a 250-slot screen would be necessary to permit removal of the finer two-thirds of the coarse gravel. A larger quantity of water would obviously be available at this depth if a screen of at least 100-slot-size were used and the well fully developed.

The water stands 14 to 22 feet above sea level, or 50 to 65 feet below the surface, in most wells in this part of the area.

DE LONG LAKE

In well 595, northeast of De Long Lake, till was tapped about 200 feet below the surface. This well, and wells 594 and 596 nearby, penetrate the till and develop water from sandy or gravelly layers in the till at from 300 to 349 feet. The other wells in this area develop water at depths less than 220 feet. Wells 597, 602, and 608 end in sand beds in the deposits of clay and silt which overly the till. Well 606, just south of the airfield, taps coarse water-bearing sediment, below a stratum of clay, in the interval from 213 to 268 feet; the aquifer is at a level where a layer of till and a second, older layer of clay occur in several other wells nearby.

No large yields are reported from wells in this immediate area, except from well 606 which obtained 322 gpm with 1.9 feet of drawdown. This well was finished with 60-slot screen placed at 243 to 253 feet and 80-slot screen from 253 to 268 feet, after which the well was surged for 6 days.

A few wells of moderate depth are reported to have sanded up. In this connection it may be noted that well 605 (125 feet deep) is finished with a 6-slot screen and is reported to function admirably. It seems likely that throughout most of this part of the area, where fine-grained sediments are so common, successful small-yield wells of only moderate depth can be constructed if proper well screens are used. The silty sand, silt, and clayey silt may not be amenable to development but there is no reason to think that the fine to medium "running" sands cannot be developed as sources of water supply.

The water level in most wells here, which are relatively shallow, is from 35 to 45 feet above sea level; however, in well 608, a well of intermediate depth, the water is reported to stand 65 feet above sea level.

STRAWBERRY ROAD

The record of well 632, at the intersection of Jewel Lake Road and Strawberry Road, shows that till was found at 230 feet; drilling was discontinued at 260 feet because of damaged casing. Wells 629 and 633 are finished in this depth range, but other wells are from 34 to 163 feet deep and obtain water from the silt-sand-clay sequence. Only small yields have been developed. The water stands 70 to 85 feet above sea level in most wells but does not rise quite as high in the deeper wells. The water table stands higher than the piezometric surface in the low hills in this part of the area, and the high water levels in the shallower drilled wells may reflect recharge from the unconfined aquifer.

SAND LAKE–JEWEL LAKE

An incomplete log of well 620 indicates that the section between 238 and 516 feet is "clay" and thin beds of till; the well taps a gravelly layer in the till. A nearby well (619) develops water from a thin gravel stratum in till at 354 feet. In well 624 material described by the driller as "clay with occasional streaks of hardpan," reported from 285 to 454 feet, underlies 35 feet of "hardpan"; all this material is thought to be till. It is believed that all the wells here deeper than about 240 feet develop water from permeable beds in the till. Wells 626, 621, and 615–617 develop a little water from medium sand near the base of the silt-clay sediments at 177 to 243 feet. Only moderate or small yields have been reported from these wells. The water stands 60 to 70 feet above sea level in most wells; however, in the three wells (615–617) nearest Turnagain Arm the water level is about 15 feet above sea level.

POINT CAMPBELL

There are five wells in the hilly area west of the International Airport and Sand Lake: 419, 420, 610, 613, and 618. The well of the Civil Aeronautics Authority (419) penetrated till at 78 feet above sea level and ended in a pea-gravel stratum just below sea level. The screen installed was 35-slot and the yield obtained was 10 gpm. The water stands a little above sea level. In well 420, at an Alaska Communications System station, a thick till bed is penetrated at about sea level, below which gravelly beds are present. Gravel at 235 to 240 feet was screened with 65-slot screen, and after development the well yielded 70 gpm with 1½ feet of drawdown. Water was developed at a comparable depth in well 610. In well 613, "sand, gravel, and clay, in alternating streaks," thought to be till, was reported in the interval from 27 feet above sea level to 96 feet below sea level. A gravel stratum just below the till was developed as a source of water. In well 618, till was tapped at about sea level and water was developed within a few feet of the top of the till.

FIRE ISLAND

Wells 449 and 450 on Fire Island penetrate a thick section of till and develop water in gravel in or beneath the till; in well 449 the gravel is at 54 feet below sea level, and in well 450 it is at 74 feet below sea level. These wells obtain about 1 gpm per foot of drawdown.

Conflicting reports of water levels have been obtained. In the deeper well, water is reported to stand at about sea level, and in the shallower well at 9 feet above sea level. Thus it is not possible to state whether the water-bearing beds here are recharged from the mainland, or whether they are isolated from the mainland and receive only recharge from shallower deposits on the island.

CAMPBELL STATION

Wells 252–257 and 443–448, near Campbell station, are 106 to 160 feet deep, with the exception of well 445 (239 feet deep). Most of them probably tap layers of permeable material in the till. Only small yields have been developed from these wells; from 5 to 10 gpm with 10 to 80 feet of drawdown is reported.

Only two water-bearing formations were tapped in the USGS test well (590) at Campbell, and they are not promising. The upper aquifer was penetrated at 139 feet, the lower at 246 feet. The water level in the upper stratum was about the same as in other wells in the vicinity (about 115 feet above sea level, or 10 feet below the surface). However, the water rose to 130 feet above sea level (5 feet above the surface) after the well had penetrated the lower stratum and had been developed.

Comparison of the logs of wells 177 and 590 suggests that the upper sand and gravel in well 177, at Anchor Park, is not present at Campbell Station. The thick stratum at Anchor Park extends from about 70 to 100 feet below sea level. The Campbell Station well extends to more than 200 feet below sea level. Even allowing for moderate dip of the formation, it seems likely that if the formation were present at Campbell, it should have been reached by the test well.

HOMESITE PARK

Records of a dozen wells in Homesite Park indicate that water is obtained from wells ranging from 61 to 177 feet in depth, the deeper wells being on the hill that rises 50 feet or so above the surrounding lowland. The depth to water ranges from 15 to 80 feet. All the wells are for domestic supply; they develop water from sandy or gravelly streaks in the till. None of the wells was developed to yield a maximum amount of water; however, the Frank well (75), reported to yield 30 gpm with 45 feet of drawdown, shows that appreciable yields are available at least locally. Most other wells have been pumped at lesser rates but are comparable in efficiency; an exception, the Miller well (71), is reported to have yielded 10 gpm with 1 foot of drawdown.

NUNAKA VALLEY

At the time this study was completed, four wells had been drilled at the Nunaka Valley housing project, at that time in the process of construction. Well 198 was drilled to a depth of 138 feet and yielded 65 gpm with 9 feet of drawdown; it was later redeveloped with air and produced 250 gpm. Well 197 was sunk to a depth of 492 feet; below 341 feet the well was in bedrock. (See log.) However, the only water developed was in black sand at 87 to 94 feet. These wells supply the housing area.

Two wells drilled later were less successful. Well 195, which is 157 feet deep, tapped only till below 15 feet of surficial gravel. Well 196 was drilled to a depth of 300 feet and also tapped only till below a depth of 65 feet. Seemingly about 100 gpm was available from "stony hard red sand" at 50 to 65 feet; these beds may be weathered till. A little water was obtained from gravelly till at 259 to 300 feet.

Whether or not larger quantities of water might be developed from beds of gravelly till here is open to question. Thick beds of permeable sand and gravel, such as those at Anchor Park to the west, are lacking; efforts to develop large quantities of water will necessarily include efforts to develop such beds of gravelly till as may be present. It should be noted that the city of Anchorage well (111A) east of Merrill Airport appears to obtain water from material that is predominantly till. Whether or not any of the "hardpan" beds here are loose enough (water-worked and uncompacted) to yield an appreciable quantity of water remains to be seen.

LAKE OTIS ROAD

Near the intersection of Lake Otis Road and Tudor Road about a dozen drilled wells obtain water from layers of permeable material in or beneath the till. Most of these wells range from 50 to 100 feet in depth, but a few are deeper. A 182-foot well (258) at Homestead Acres housing development is the only well in this part of the area that penetrates a stratum of water-sorted gravel. This stratum is relatively higher than the upper layer of sand and gravel at Anchor Park, to the north (well 177). Neither the 188-foot Rogers and Babler well (220), a mile to the east nor the Smith well (262), a little to the south, quite reaches the gravel stratum penetrated at Homestead Acres; both end in gravelly till.

Most of the wells mentioned above have developed yields of 5 to 10 gpm. Well 258, however, obtains 70 gpm with 28 feet of drawdown; it is equipped with 10 feet of 30-slot screen (the only screen readily available at the time the well was completed).

One shallow dug well obtained water from surficial sands.

The water level in most wells here is from 10 to 35 feet below the surface.

Another group of wells is on Spruce Road off Lake Otis Road, and along Lore Road and Lake Otis Road. These wells range in depth from 50 to almost 200 feet, the deeper wells being on high ground. All end in gravelly or sandy layers in till. The depth to water ranges from 15 to 70 feet. The drilled wells have developed only small supplies of water. A few dug wells are in this area; of these, well 478 is reported to yield 20 gpm from a sandy layer in till.

O'MALLEY ROAD

Eighteen wells along O'Malley Road range in depth from 46 feet (well 517) to 222 feet (well 526). In these wells the water stands from 30 feet (486) to 207 feet (526) below the surface. The shallower wells have the higher water level. All the wells appear to end in sandy or gravelly layers in the till. Only small yields have been developed from these wells.

SEWARD HIGHWAY AND KLATT ROAD

A group of wells on Klatt Road and along Seward Highway between O'Malley Road and Huffman Road range, with few exceptions, from 44 to 160 feet in depth. Wells 512 and 513, among the shallowest of this group, obtain water from silty sand. All the others appear to obtain water from gravelly or sandy layers in the till. Wells in the group at the end of Klatt Road (647–651) range from 44 to 49 feet in depth in spite of the fact that they are at appreciably different elevations. This fact suggests that where coarse gravelly till is present, small supplies of water might be obtained at any one of many levels if enough effort were made to develop the formation. In this area, water stands 15 to 45 feet below the surface; the depth in a given well depends on the elevation of the ground at the well.

A wide range of types of deposits is present in the southermost part of the Anchorage area. The log of well 505, on the Seward Highway near O'Malley Road, shows that both till and clay are important components of the glacial drift. The clay is believed to represent estuarine or lake deposits preserved along the edge of the Turnagain Arm depression.

A yield of 200 gpm with 40 feet of drawdown was obtained from well 505. The well is believed to have an open-end finish. Other wells in the area were constructed for domestic supply and only small yields were developed, although well 498 (54 feet deep) is reported to yield 20 gpm.

HUFFMAN ROAD

Several wells are along Huffman Road and on the higher ground east of the end of Huffman Road. With two exceptions these wells range from 48 to 101 feet in depth; water stands 19 to 39 feet below the surface. Well 536 is 111 feet deep and the depth to water is 97 feet. Well 532 is 324 feet deep, and here the water stands 184 feet below the surface. All the wells appear to end at random depths in gravelly or sandy layers in the till except well 532, which tapped limestone at 213 feet and was continued into the limestone to a depth of 324 feet. All these wells are reported to have small yields.

SEWARD HIGHWAY AND RABBIT CREEK

Records were collected for more than 50 wells along Seward Highway south of Furrow Creek and east from the highway. Along the highway the ground elevation is from 100 to 200 feet above sea level. To the east the land rises sharply, but most of the wells are within half a mile of the highway and at elevations not higher than 400 feet above sea level. The depths of these wells range from 35 to 180 feet except for three which are 272, 285, and 295 feet deep.

Water stands from 6 to 100 feet below the surface in most wells. The water level was reported to be 8 feet above the surface in well 563, on DeArmoun Road, at the time the well was completed. Well 564 was reported to flow at the time it was completed, but a few days later the water level had fallen to 34 feet below the surface. In well 538, high on the mountain side, water stands 187 feet below the surface. In other wells in that general area it stands about 100 feet below the surface.

Nearly all the wells end in gravelly or sandy layers in the till. Well 587, on Little Rabbit Creek, completely penetrated the till and tapped bedrock at a depth of 171 feet (136 feet above sea level); although continued to a depth of 285 feet, the well failed to obtain water. Well 588, just east of well 587, tapped bedrock at a depth of 108 feet (249 ft above sea level).

TABLE 3.—*Chemical analyses of water in the Anchorage area, Alaska*

[Results expressed in parts per million. Analyses by U.S. Geological Survey]

Well	Depth (feet)	Date of collection	Silica (SiO_2)	Dissolved iron	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$ (calcium, magnesium)	Specific conductance (micromhos at 25° C)	pH
4	60	1-6-53	20	0.02	0.09	0.00	138	14	19	2.8	436	11	24	0.0	64	508	403	837	7.5
11	116	11-15-50	16	.01	.10	.00	23	13	-------	72	192	27	58	.1	.7	304	111	538	8.2
17	132	7-3-53	13	-------	.64	.04	33	4.5	2.7	.9	110	14	.0	-------	1.2	124	101	198	6.2
18	39	5-5-54	9.9	.00	.00	-------	19	3.4	2.3	.4	59	16	2.0	-------	1.0	83	61	135	7.7
19	(1)	6-8-55	11	.00	.08	.00	25	4.0	2.6	.7	80	17	1.0	.0	1.0	101	79	169	7.6
24	78	1-6-53	10	.02	.04	.00	27	4.2	2.3	1.0	87	17	2.0	.0	.8	107	85	168	7.2
28	323	6-20-53	12	-------	.02	.00	23	5.0	17	1.2	131	8.7	.5	.0	.4	132	78	215	7.5
33	210	12-1-52	6.1	.59	5.9	.02	7.0	4.9	41	1.9	144	5.0	4.0	.4	.2	142	38	238	7.8
36	152	1-18-55	9.0	-------	.09	.00	26	2.2	29	2.0	146	13	4.0	.2	.6	158	74	258	7.7
63	32	11-28-52	18	.02	.05	.00	35	10	5.7	1.1	127	17	11	.0	1.9	162	130	285	6.6
64	176	9-2-52	20	.02	.20	-------	33	11	2.8	.8	134	10	2.0	-------	1.1	147	126	219	7.7
64	617	11-5-52	18	.04	-------	-------	29	10	4.3	1.2	138	8.0	4.0	-------	.7	143	116	227	7.2
144 [2]	20	12-8-52	21	-------	5.0	.54	22	7.6	9.4	1.8	83	2	28	-------	6.0	139	87	258	6.2
177	209	6-23-52	21	-------	1.4	-------	19	9.1	12	1.7	128	5.0	5.0	-------	.2	136	86	208	7.7
205	81	10-20-52	48	1.2	11	.21	50	16	2.8	1.3	229	1.0	2.0	-------	2.8	238	192	337	8.1
278	150	8-12-49	4.8	-------	.03	-------	22	37	674	-------	188	381	795	.2	.7	2,010	207	3,490	7.7
280	250	4-6-53	21	-------	-------	.01	31	8.8	5.1	1.4	145	5.0	1.0	.1	.3	145	115	232	7.4
282	452	4-21-53	19	-------	.02	-------	29	8.1	6.7	1.2	143	5.1	1.5	.0	.5	142	107	219	7.5
403	244	11-25-52	17	.08	.21	.02	21	6.6	4.1	1.2	103	3.0	3.0	.1	.4	107	80	170	7.2
420	240	11-19-52	32	.02	.15	.01	42	23	5.4	2.0	224	3.0	4.0	.2	.2	222	203	344	7.5
425	308	11-18-52	20	.02	.04	-------	21	18	4.4	1.8	166	3.0	4.0	-------	.3	154	128	256	7.5
596	317	11-18-52	14	.02	.20	.00	27	10	16	1.8	173	3.0	2.0	.3	.3	159	110	264	7.3
612	96	11-19-52	18	.02	.08	.02	58	13	4.1	1.1	239	5.0	5.0	.0	.7	223	198	385	7.2
613	285	11-19-52	28	.02	.35	.00	44	20	6.2	1.9	246	4.0	8.0	.0	.2	234	196	375	7.3
620	515	8-19-55	23	.08	1.1	.11	26	7.2	16	2.1	164	.5	2.0	.1	.0	158	94	250	7.5
Ship Creek (near well 18)	-------	5-5-54	8.1	-------	.00	-------	18	3.7	2.2	1.0	54	17	2.0	-------	1.3	-------	60	131	7.4

[1] Sample from bottom of well screened in three aquifers; water flows from upper aquifers into deepest aquifer.

[2] Sample from dug well at site where well was later drilled.

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*

Well 1, Fort Richardson

[Altitude 321 feet. Log by District Engineer]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Gravel, sandy	50	50	Silt, sand and gravel (till)	117	305
Silt, sand, and gravel (till)	130	180	Clay, tight, blue-gray	15	320
Silt, sandy; clay balls and a little gravel; some water between 180 and 182 ft	5	185	Sand and clay, gray; contains some sandstone (shaly bedrock)	148	468
Sand, silt, and gravel; water (5 gpm)	3	188	Shale and coal streaks	5	473
			Shale; some water at about 510 ft	67	540

Well 3, Elmendorf Air Force Base

[Altitude 60 feet. Log by U.S. Army]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Gravel	78	78	Gravel, sandy	1	211
Mud, blue	32	110	Clay, blue	76	287
Quicksand	56	166	Gravel, fine, sandy	7	294
Clay, blue	44	210			

Well 5, Elmendorf Air Force Base

[Altitude 246 feet. Log by District Engineer]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Gravel, silty and sandy (till), brown-yellow; no water; open hole drilled ahead of casing	111	111	Gravel, sandy; water	4	117
Sand, medium; water	2	113	Sand, medium; water	17	134
			Clay, silty, blue; contains small pebbles	13	147

Well 8, Elmendorf Air Force Base

[Altitude 300 feet. Log by District Engineer. Presence of brown till in interval from 75 to 158 feet suggests presence of an unconformity marked by a weathered zone]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Topsoil	1	1	Sand, medium to coarse; water	4	162
Gravel, silty and sandy (till), brown	44	45	Sand, medium; water	4	166
Gravel, sandy (till), blue-gray	30	75	Gravel, medium, and coarse sand; water	24	190
Gravel, silty and sandy (till), gray to brown	83	158			

Well 12, Elmendorf Air Force Base

[Altitude 250 feet. Log by J. C. Merrington]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Sand and silt	70	70	Gravel and sand	34	225
Mud, blue	15	85	Sand, fine	75	300
Sand	42	127	Gravel; water	14	314
Mud, blue	64	191			

Well 13, Elmendorf Air Force Base

[Altitude 350 feet. Log by Sylvester Ko-loski. Deposits interpreted as one till unit above the yellow (weathered?) material at 150 feet, and one or more till units below 150 feet.]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Clay and medium gravel, yellow	60	60	Clay and gravel, tightly packed	20	270
Clay and medium gravel, blue	20	80	Sand and silt; a little water	40	310
Hardpan	10	90	Clay, tightly packed, blue	40	350
Clay and medium gravel, blue	10	100	Gravel and clay, coarse; contains boulders	13	363
Clay and some gravel, blue	28	128	Gravel, medium, and sand; water at 366 ft	6	369
Hardpan; a little water	6	134	Gravel, medium; contains silt and clay	19	388
Clay and some gravel, blue	4	138	Gravel, medium; water	18	406
Clay, tightly packed, blue	12	150			
Clay and some gravel, yellow	40	190			
Gravel, fine; contains some clay; a little water	60	250			

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 17, USGS, Ski Bowl Road, Fort Richardson

[Altitude 290 feet. Log by G. H. Ramsey, F. W. Trainer, and D. A. Morris]

Material	Thickness (feet)	Depth (feet)
Gravel	12	12
Till	37	49
Sand, coarse to fine; a little water	11	60
Till	30	90
Sand, gravelly; water	9	99
Sand, medium	3	102
Sand, gravelly; water	9	111
Sand, fine to coarse, very hard	6	117
Sand, gravelly; water	4	121
Till	9	130
Sand, gravelly; water	4	134
Till	96	230
Shale, brown; open hole below 236 ft	18	248
Shale and subordinate sandstone, in alternating beds; shale, brown or gray, in part sandy, in part coal-bearing; sandstone, gray, in part clayey; dry except for a little water in one sandstone bed	422	670

Well 18, USGS, Ski Bowl Road, Fort Richardson

[Altitude 281 feet. Log by G. H. Ramsey]

Material	Thickness (feet)	Depth (feet)
Fill: gravel	5	5
Gravel and clay	14	24
Gravel, silty and clayey	3	27
Sand, medium-coarse; water	4	31
Gravel, silty and clayey	5	36
Gravel and medium to very coarse sand; water	3	39
Hardpan (till)	1	40

Well 23, Corps of Engineers, Fort Richardson

[Altitude 249 feet. Log by A. R. McInroy and L. A. Schachle]

Material	Thickness (feet)	Depth (feet)
Gravel, sand, and silt, mixed	30	30
Sand, silty	6	36
Clay, blue	7	43
Sand, silty; water (30 gpm)	4	47
Silt, gravelly and sandy; dry	10	57
Sand, gravelly; water	4	61
Gravel, sandy; water	4	65
Sand, fine, silty; water	5	70
Sand, gravelly; water	3	73
Sand, silty; water	3	76
Gravel and sand; water	3	79
Sand, silty; water	4	83
Silt and clay; dry	16	99
Sand and gravel, coarse; water	4	103
Clay, blue; dry	6	109
Sand, silty and gravelly; water	22	131
Sand, silty; water	17	148
Gravel, sand, silt, and clay, mixed; dry	62	210

Well 25, Elmendorf Air Force Base

[Altitude 162 feet. Log by U.S. Army]

Material	Thickness (feet)	Depth (feet)
Gravel	30	30
Mud, blue; probably represents the Bootlegger Cove Clay, overlain by outwash-plain deposits	100	130
Gravel	55	185
Sand	5	190
Mud, blue	13	203
Gravel; water	25	228

Well 27, city of Anchorage

[Altitude 35 feet. Log by Tippetts-Abbett-McCarthy-Stratton, Engineers]

Material	Thickness (feet)	Depth (feet)
Sand and gravel (fill)	6	6
Silt, soft, organic, gray	17	23
Silt, soft to firm, organic, gray; in part clayey; contains layers of sand and gravel	13	36
Silt and clayey silt, gray; contains layers of sand and gravel	46	82
Till, dense, silty, gray	4	86

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaskc*—Continued

Well 28, Corps of Engineers, Elmendorf Air Force Base

[Altitude 144 feet. Log by Corps of Engineers]

Material	Thickness (feet)	Depth (feet)
Gravel, sandy, gravelly sand, and sand	58	58
Clay, gray; quicksand, 188–192 ft	150	208
Sand, gravelly; some water	15	223
Till, hard; contains sand streaks; water	14	237
Clay, soft, sticky, blue	64	301
Till	3	304
Sand, brown	2	306
Sand, grading from fine to coarse; water	16	322
Till	18	340
Till, hard, clayey	2	342
Till; water in sand and gravel lenses at 352–355, 358–360, 366–369, 373–376, 381–393, 403–411, 417–421, 426–431, 437–440, and 442–444 ft	109	451
Sand and gravel and subordinate clay	7	458
Till; water in sand lenses at 463–465 and 473–476 ft	82	540
Silt and clay and some pebbles, gray	40	580
Silt, gray; contains coal fragments	95	675
Clay, blue-gray	8	683
Silt and placer coal	14	697
Clay, sandy, gray	7	704
Clay(?), gray	60	764
Sandstone, hard	14	778
Thin beds of coal and shale and a few thin beds of sandstone	72	850

Well 36, Boespflug-Birch Construction Co.

[Altitude 93 feet. Log by J. D. Conboy]

Material	Thickness (feet)	Depth (feet)
Gravel	9	9
Sand, brown	20	29
Clay, blue, soft	83	112
Clay, blue, and gravel	24	136
Clay, blue	3	139
Clay, blue, and gravel	13	152
Gravel		at 152

Well 50, city of Anchorage, Mountain View

[Altitude 150 feet. Log by Western Drilling Co. 80-slot screen placed at 270 to 320 ft. Yield 1900 gpm with 70 feet of drawdown. The log is interpreted as recording a deposit of clay at 64 to 220(?) ft, and till strata at 220 to 280 and 319(?) to 467 ft; each of these till strata may contain more than one unit of till]

Material	Thickness (feet)	Depth (feet)
Gravel and sand	55	55
Sand, a little water	9	64
Clay, soft, blue; contains fine sand; a little water	86	150
Clay and sand and a little gravel	22	172
Quicksand, sand, silt, and fine gravel	8	180
Sand and some gravel and clay	35	215
Sand, fine, and clay, gray	5	220
Clay and sand and gravel, very hard; gray at 220–240 and 242–250 ft; brown at 240–242 and 250–280 ft	60	280
Sand and fine gravel; bailed 40 gpm at 280 ft with 43 ft of drawdown	5	285
Quicksand	2	287
Sand and gravel; contains a little clay; bailed 34 gpm with 25 ft of drawdown	12	299
Gravel and sand, brown; water level 57 ft; bailed 34 gpm at 300 ft, with 47 ft of drawdown	12	311
Sand and gravel and a little clay; very little water	8	319
Clay, sand and gravel, hard; brown; dry	11	330
Rocks and sand, very hard; brown	10	340
Sand and a little clay, hard, brown; heaved into casing at 340 ft	17	357
Sand and gravel, hard	7	364
Clay, sand, and gravel, very hard	22	386
Clay and gravel, sand, and rocks, very hard, brown	46	432
Clay and gravel, very hard, brownish-yellow	35	467

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 52, city of Anchorage, Artesian Village

[Altitude 164 feet. Log by Western Drilling Co.]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Gravel (fill)	6	6	Clay, sand, and 60 percent gravel, hard	36	221
Gravel and clay, packed very hard	11	17	Clay, and more gravel, brown	3	224
Gravel and black sand, packed	11	28	Clay and gravel, yellow	78	302
Sand, brown	11	39	Gravel, coarse; contains sand and clay	28	330
Gravel and clay, brown	3	42	Clay and cemented gravel	22	352
Sand and gravel, brown	9	51	Clay, sand, and gravel	16	368
Clay and gravel, blue; dry	11	62	Gravel, cemented	25	393
Clay and gravel, brown	18	88	Clay and some pea gravel	37	430
Hardpan, blue	63	143	Silt and some sand, black; resembles peat	2	432
Record missing	9	152	Clay and some pea gravel	30	462
Hardpan, blue; bailed 5 gpm at 162 ft	10	162	Clay and traces of coal	--------	at 462
Gravel, sand, clay, and silt; packed hard; bailed 2½ gpm at 169 ft with 40 ft of drawdown	23	185			

Well 64, Ranger Station, Oil Well Road

[Altitude 200 feet. Log by D. J. Cederstrom and G. H. Ramsey. Compare with log of well 52]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Soil	3	3	Till, gray, very hard. Short pumping test yielded 30 gpm with 9 ft of drawdown. Water comes from sandy streaks in interval between 217 and 247 ft	38	252
Gravel; bouldery, below 18 ft	42	45	Till, brown, very hard	96	348
Clay	2	47	Clay, sticky, gray	22	370
Gravel	11	58	Clay and coal fragments	5	375
Till	28	86	Clay, sticky, gray	15	390
Sand, medium, silty; water	12	98	Clay, sandy, hard	2	392
Till, soft	11	109	Sand	22	394
Sand; water	2	111	Clay, sandy, gray. Bottom of casing at 397 ft	53	447
Till, hard	8	119	Shale, brown; contains coal streaks and organic matter	63	510
Clay, gray	4	123	Shale, gray to black; contains some coal streaks; black shale contains much organic-matter; sticky when wet. 1 ft layer of friable fine-grained green sandstone at 555 ft	92	602
Sand, fine to medium; a little water	16	139	Sandstone, fairly hard, fine- to medium-grained; gray	7	609
Till, hard	14	153	Shale, gray to black, as in interval from 510 to 602 ft	8	617
Sand, medium to coarse, silty	13	166			
Sand, harder, medium to coarse. Pumped 6 hrs from open-end hole at 70 gpm with 18 ft of drawdown. Static level 8.5 ft below surface	9	175			
Gravel, coarse, sandy. Short bailer test yielded 14 gpm with 50 ft of drawdown	6	181			
Till, brown	33	214			

Well 90, Artesian Village, Harold Bodenkeimer

[Altitude 171 feet. Log by L. A. Schachle]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Clay, brown	14	14	Sand, coarse; water	6	102
Sand; water	4	18	Quicksand	17	119
Gravel and clay, hard	7	25	Clay and mud	52	171
Clay, blue	36	61	Gravel, coarse, and clay	25	196
Sand, fine; contains clay balls; a little water	2	63	Clay, gray	39	235
Gravel and clay, hard	5	68	Gravel, coarse; dry	3	238
Sand, coarse; water, 16 gpm, but silty and would not clear; water level 30 ft below surface	4	72	Clay and gravel	8	246
Clay, silty, soft	13	85	Sand, fine	1	247
Quicksand	11	96	Clay, clean; contains no gravel	11	258
			Clay and coarse gravel, dry	5	263
			Sand; water	9	272

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 111A, city of Anchorage, south-southwest of Mountain View

[Altitude 125 feet. Log by Western Drilling Co. 80-slot screen placed at 175 to 190 ft, 200–210 ft and 280–290 ft. Yield 1600 gpm with 40 ft of drawdown. Most of material screened appears to be till]

Material	Thickness (feet)	Depth (feet)
Gravel and clay	8	8
Hardpan	2	10
Sand and clay; water	3	13
Clay, blue or gray; in part sandy or gravelly; contains thin water-bearing layers of sand, 28–48 ft	75	88
Clay, hard, in part sandy or gravelly	62	150
Clay and gravel and fine sand	23	173
Sand and gravel; water (bailed 55 gpm with 20 ft of drawdown)	5	178
Clay and sand and gravel; hard	5	183
Cement gravel	9	192
Sand and gravel; water (bailed 30 gpm with 12 ft of drawdown)	5	197
Hardpan	13	210
Cement gravel; water (bailed 30 gpm with 50 ft of drawdown)	7	217
Clay and sand and fine gravel; brown	18	235
Clay and gravel (hardpan); bailed 35 gpm with 25 ft of drawdown	10	245
Clay; contains seams of sand and gravel; hard; water (bailed 60 gpm at 249–250 ft, with 35 ft of drawdown)	12	257
Clay; contains gravel and sand; very hard	12	271
Sand and gravel; loose; bailed 100 gpm	2	273
Gravel and sand and some clay	4	277
Clay and sand and some gravel; firm	6	283
Gravel, sand, and clay, brown (material above is gray)	6	289
Record missing	10	299
Clay and sand and fine gravel, firm	7	306
Record missing	8	314
Sand; firm	1	315
Gravel, fine, and sand	12	327
Clay and gravel, firm	22	349
Clay and sand and fine gravel; blue	42	392
Clay and sand; hard	12	404
Clay and sand and gravel; hole stands open ahead of casing	11	415
Gravel and sand and clay	13	428
Clay and gravel and sand	10	438
Clay and a little sand and gravel; hard—stands open ahead of casing	32	470

Well 114, city of Anchorage, northeast of Merrill Airport

[Altitude 135 feet. Sixty-slot screen placed at 160–180, 190–200 ft. Yield, 1300 gpm with 54 ft of drawdown]

Material	Thickness (feet)	Depth (feet)
Gravel and silt	20	20
Sand, gravel, and silt	37	57
Clay, blue, sandy, 57–110 ft	61	118
Sand, coarse; contains gravel and some clay	9	127
Sand, coarse; a little water	3	130
Clay	5	135
Sand, fine, in part silty	25	160
Gravel, coarse, and sand; water (bailed 30 gpm between 160 and 168 ft)	20	180
Gravel and clay; a little water	26	206
Sand and clay; contains some gravel	12	218
Quicksand; contains driftwood	1	219
Sand and pea gravel	5	224
Clay, hard; contains sand veins	36	260
Clay shot with gravel, very hard	13	273
Gravel and clay, very hard	20	293
Hardpan	92	385
Clay, yellow; contains large rock	30	415

Well 115A, Northern Supply Co., Ship Creek

[Altitude 55 feet]

Material	Thickness (feet)	Depth (feet)
Sand, clayey	8	8
Sand, very soft, clayey	9	17
Gravel; contains brown silt	8	25
Clay, blue	25	50
Clay, blue, very soft	77	127
Sand, fine	10	137
Clay, blue	3	140
Sand, fine; contains small gravel; water	6	146
Clay, blue; contains fine sand seams	24	170
Gravel, coarse; imbedded in fine sand and silt	30	200
Gravel, coarse; imbedded in silt	14	214
Sand, coarse, and gravel: water	1	215
Clay and medium gravel, silty	8	223
Silt, brown; contains small gravel	9	232
Gravel, coarse, in brown sandy silt, very hard	5	237
Gravel, coarse; sand containing brown silt seams; water	3	240
Gravel, coarse, sand, silt, water	12	252
Sand and gravel; water	11	263
Sand and gravel, silty; water	7	270
Sand and gravel, clean; water	10	280

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 122, C. R. Lewis Co.

[Altitude 122 feet. Log by A. R. McInroy. Interpretation: Bootlegger Cove Clay, 48–189 ft; till, 190–223 ft]

Material	Thickness (feet)	Depth (feet)
Sand and gravel	45	45
Sand, fine; a little water	3	48
Clay, blue	141	189
Sand, coarse, and gravel; silty water	1	190
Gravel, cemented	33	223
Sand, coarse, and gravel; water	4	227

Well 134, Anchorage Oxygen Co., Chester Creek

[Altitude 64 feet. Log by A. R. McInroy]

Material	Thickness (feet)	Depth (feet)
Gravel (fill)	5	5
Clay, blue	55	60
Clay, black; a few stones and a little sand; water seeps	60	120
Gravel and sand; considerable water	13	133
Sand, fine	1	134
Hardpan (cement gravel)	7	141
Gravel; water flows 100 gpm at 3 ft above land surface	16	157

Well 163, city of Anchorage, south of Merrill Airport

[Altitude 94 feet. Log by A. R. McInroy. 125-slot screen placed at 271 to 336 ft but settled 13 ft 5 in. during development. At 900 gpm (with 25 ft of drawdown) no further settling occurs]

Material	Thickness (feet)	Depth (feet)
Gravel	2	2
Clay, blue; contains gravel	43	45
Sand and blue clay	2	47
Hardpan (cement gravel); contains blue clay	19	66
Gravel; stones to 1 in. diameter; some water	2	68
Hardpan (cement gravel); contains blue clay; bailed 8 gpm with 16 ft of drawdown	19	87
Clay, blue	9	96
Gravel; stones to 1 in. diameter; some water	1	97
Gravel, clayey and silty	4	101
Clay and quarter-inch gravel	6	107
Clay and sand	12	119
Clay and quarter-inch gravel	3	122
Gravel (stones smaller than 2 in.) and sand; pumped 400 gpm with 96 ft of drawdown	14	136
Clay, blue; contains quarter-inch gravel	44	180
Clay, blue; contains 2-inch gravel	8	188
Gravel (stones as much as 2 in. in diameter) and sand; bailed at 2 gpm per ft of drawdown	5	193
Sand and gravel	6	199
Sand, some gravel, heaving sand, and clay	12	211
Clay, hard, yellow; contains small angular rocks	18	229
Sand, coarse, clean	2	231
Clay, hard, yellow; contains small angular rocks	6	237
Sand, coarse; contains some gravel and clay	6	243
Clay matrix, yellow	25	268
Sand, very fine, clean	2	270
Sand, coarse, very tight	8	278
Sand, coarse, in loose and tight layers	16	294
Sand, fine, loose	1	295
Sand, coarse, in loose and tight layers	4	299
Sand, medium, tight	4	303
Gravel, medium, loose	15	318
Clay, yellow	1	319
Sand, coarse, loose; contains yellow clay	1	320
Clay and sand, hard	3	323
Sand, coarse, loose; contains yellow clay	3	326
Sand, coarse, loose; static level 13 ft above land surface	12	338
Clay, blue, gravel at 360 ft	32	370
Clay, blue; contains gravel	5	375
Sand, fine; no water	5	380
Sand, fine; contains clay	5	385
Clay and gravel	4	389
Clay and medium sand; no water	1	390
Clay, gravel, and sand	59	449
Sand, coarse, and medium gravel; water; static level about 20 ft below land surface	2	451
Clay, gravel, and sand	1	452

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 177, USGS, Anchor Park

[Altitude 129 feet. Log by D. J. Cederstrom and F. W. Trainer]

Material	Thickness (feet)	Depth (feet)
Silt	1	1
Sand and gravel	39	40
Till	39	79
Sand, fine to medium, gray; negligible water	12	91
Till	50	141
Medium sand becoming gravelly at base. With lower 4 ft screened, yielded 49 gpm with 13.4 ft of drawdown. Static level 23.5 ft below surface. Maximum yield at this stage of development at 140 ft pumping level was about 300 gpm	10	151
Till	3	154
Sand, medium to coarse	3	157
Till	16	173
Fine to medium sand. Screen set at 188–192 ft. Yielded initially 8½ gpm with 20 ft of drawdown, but yield decreased materially	18	191
Silt, clayey	8	199
Sand and gravel. Short bailer test indicated a yield of 28 gpm with 34 ft of drawdown	3	202
Sand and gravel. At 209 ft initial bailing indicated 19 gpm with 80 ft of drawdown but after setting 4 ft of screen, the yield appeared stabilized at 50 gpm with 60 ft of drawdown	14	216
Silty sand with some pebbles. Bailing open end at 220 ft yielded 20 gpm with 60 ft of drawdown	7	223
Sand, medium, pebbly	3	226
Sand, clayey	9	235
Till	40	275
Sand, medium to coarse, pebbly	1	276
Sand, clayey	8	284
Sand, pebbly	4	288
Sand, silty	29	317
Sand, pebbly. Yielded 50 gpm with 41 ft of drawdown, pumping from open end of casing at 319 ft	7	324
Sand	10	334
Till; hard drilling	62	396

Well 196, Nunaka Valley

[Altitude 227 feet. Log by J. C. Merrington. Several tills appear to be present, possibly as follows: 50–85 ft; 120(?)–141 ft; 145–170 ft; 170–230 ft; below 259 ft; see log of well 197]

Material	Thickness (feet)	Depth (feet)
Gravel and sand, brown	50	50
Sand, stony, hard, red; water, about 100(?) gpm, at 60 ft	15	65
Hardpan, blue	20	85
Clay and sand, yellow	16	101
Sand, gray; a little water	10	120
Clay, blue; contains small pebbles	21	141
Gravel, black; some water	4	145
Hardpan, gravelly	25	170
Hardpan, very hard, yellow	60	230
Sand, clayey, hard; contains gas	29	259
Hardpan, gravelly; water, about 30 gpm, at 259–260 ft	41	300

Well 197, Nunaka Valley

[Altitude 210 feet. Log by J. C. Merrington. The section is thought to comprise several till units, possibly as follows: 4–87 ft, 95(?)–164 ft, 201–241 ft, and 241–301 ft. See log of well 196]

Material	Thickness (feet)	Depth (feet)
Gravel, coarse	4	4
Hardpan	50	54
Sand, fine, and clay; a little water	8	62
Hardpan	25	87
Sand, black; yielded 97 gpm with 27½ ft of drawdown; static level 5½ ft below surface	7	94
Hardpan	1	95
Sand, gray	18	113
Hardpan	4	117
Sand, fine, gray	8	125
Hardpan	2	127
Gravel, coarse; hole easily bailed dry	9	136
Hardpan (clay and gravel)	7	145
Sand, dark	3	148
Sand, rock, and clay; hard drilling	16	164
Sand and gravel, dark; contains yellow clay and gray silt	23	187
Record missing	9	196
Sand, black	3	199
Gravel, coarse, dirty, black	2	201
Hardpan (gravel and clay), blue	14	215
Sand, black; 20 gpm water	1	216
Hardpan, clayey and gravelly, gray	25	241

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Hardpan, gravelly; contains yellow clay; 15 gpm water	6	247	Sandstone	35	419
Hardpan, gravelly, yellow; dry to 251 ft; water, about 50 gpm, between 251 and 256 ft	13	260	Sandstone; coal and shale streaks; some water	3	422
Hardpan (clay and rock), white	4	264	Sandstone	14	436
Gravel; some water	2	266	Brown clay; some coal; squeezes into drillhold	28	464
Hardpan, clayey	3	269	Coal (lignite); streaky with bone layers	13	477
Hardpan, blue; casing would not advance beyond 278 ft	9	278	Shale, brown; some coal	3	480
Bouldery material; 50 gpm water	2	280	Coal (lignite)	5	485
Clay, gray, and gravel; hard	5	285	Bone streak, hard	2	489
Gravel, dirty, black	4	289	Shale, brown; some coal	3	490
Hardpan, blue and gray	12	301	Graywacke(?)	2	492
Record missing; top of bedrock penetrated at 341 ft; chiefly shale; open hole below 344 ft	83	384			

Well 281, W. P. Odom; KFQD Road

[Altitude 72 feet. Log by L. A. Schachle]

Sand	?	?	Quicksand	84	265
Clay, soft	?	70	Clay	20	285
Sand, soft	40	110	Quicksand	55	340
Gravel	5	115	Clay	10	350
Clay	20	135	Quicksand	45	395
Sand, soft	20	155	Gravel; water	4	399
Quicksand	21	176	Sand and clay	4	403
Clay	5	181	Sand; water	1	404

Well 282, Housing Development, Turnagain Heights

[Altitude 68 feet. Log by J. C. Merrington]

Sand, pebbly, brown	12	12	Clay(?), red-blue, oily-looking, soft to hard	53	303
Clay, blue	138	150	Clay and stones, fairly hard, blue	82	385
Sand, silty, hard, gray	81	231	Gravel, sand, silt, and clay, hard, in alternating layers; water	67	452
Clay and rocks, hard	7	238			
Very hard layer	12	250			

Well 324, James Hopper, Spenard

[Altitude 102 feet. Log by Charles Schachle]

Sand	20	20	Hardpan; silty water at 245 ft; gravel and a little water at 248 ft	11	248
Clay, gray	10	30	Quicksand, mixed with gravel	14	262
Sand	23	53	Gravel; water	1	263
Clay, sandy	12	65	Hardpan	2	265
Clay, pebbly	28	93	Clay	1	266
Hardpan and coarse gravel; water at 110, 123, 132, and 139 ft	89	182	Sand, hard-packed, black	16	282
Quicksand and hard-packed sand layers	10	192	Gravel; water	1	283
Clay, gravelly	45	237	Hardpan	1	284
			Gravel; water	1	285

Well 363, Center Theater, Spenard

Altitude 89 feet. Log by L. A. Schachle. Beds between 60 and 105 ft and between 160 or 182 and 314 ft, thought to be two clay units; till, 105–140 ft]

Sand, coarse, and gravel	60	60	Sand and clay, gray	9	191
Sand, fine	45	105	Clay, blue	82	273
Hardpan (clay and gravel)	35	140	Sand, fine; some water	3	276
Sand, gray; some water	20	160	Clay, blue	38	314
Clay, blue	22	182	Sand, coarse; water	10	324

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 420, Alaska Communications System, West of International Airport

[Altitude 140 feet. Log by J. C. Merrington. Much or all of the material between 160 and 235 ft is probably till]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Sand, clayey, yellow	30	30	Clay and small gravel, gray	4	164
Gravel and clay	10	40	Sand, hard-packed, fine	6	170
Hardpan (clay and gravel), yellow	10	50	Clay and gravel, gray	5	175
Sand and rock, packed, contains coal fragments	11	61	Sand, green; a little water	5	180
Sand, hard, yellow	27	88	Clay, tough	2	182
Sand, yellow; contains coal	12	100	Sand; a little water	4	186
Clay, yellow; contains coal streaks	20	120	Clay	1	187
Sand and some clay	10	130	Gravel and sand; a little water	2	189
Gravel and sand	4	134	Gravel, fine	2½	191½
Sand and coal	6	140	Gravel and green sand, hard; a little water	8½	200
Gravel and sand; a little water	1	141	Hardpan, clayey	1½	201½
Hardpan, gravelly	1	142	Hardpan, gravelly; a little water	7½	209
Sand, fine	5	147	Clay and gravel, hard	7	216
Sand and gravel; a little water	4	151	Gravel, fine; yields about 5 gpm	6	222
Hard packed sand and gravel; a little water	3	154	Gravel, cobbly	11	233
Sand and gravel	6	160	Gravel, "rocklike", cemented	2	235
			Gravel, coarse; water	5	240

Well 430, Lake Motel, Lake Spenard

[Altitude 72 feet. Log by J. C. Merrington]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Sand, yellow	3	3	Clay, gray	4	276
Clay, silty, soft, gray	120	123	Gravel, pebbles as much as 2-in. in diameter, black, water	2	278
Clay, tough, gray	7	130			
Silt, gray	142	272			

Well 450, U.S. Air Force

[Altitude 251 feet. Log by Nickelson and Safely]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Hardpan	20	20	Sand	43	252
Sand	15	35	Clay, blue	1	253
Hardpan	58	93	Sand, brown	21	274
Sand	7	100	Sand; some water	8	282
Hardpan	6	106	Sand, fine	19	301
Sand	13	119	Hardpan	7	308
Hardpan	19	138	Gravel; some water	3	311
Sand	36	174	Hardpan	12	323
Hardpan	9	183	Gravel; some water	2	325
Sand	18	201	Hardpan	31	356
Hardpan	8	209	Gravel; water	1	357

Well 505, Alaska Aggregates

[Altitude 168 feet. Log by Charles Schachle. Clay and interbedded materials, 65–220 ft, may represent one or more clay formations; the hardpan at 220–453 ft probably comprises several till units, the top of one of which is the brown zone reported at 425–444 ft. Comparison with log of well 509, about 0.4 mile southeast, suggests that part of the gravel recorded between 130 and 150 ft is till]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Sand	65	65	Hardpan; large rocks penetrated at 397–400 and 424–425 ft; thin water-bearing layers of gravelly sand or silt at 270–274, 300–301, 324–325, 330–332, 346–347, 423–424, and 444–445 ft; brown hardpan, 425–444 ft	233	453
Clay, sandy	64	129	Gravel, pebbly and sandy; water; static water level 50 ft	--------	at 453
Hardpan	1	130			
Gravel; a little water; static water level at depth 131 ft was 40 ft beneath land surface	20	150			
Clay	70	220			

TABLE 4.—*Logs of representative wells in the Anchorage area, Alaska*—Continued

Well 516, John Herche, O'Malley Road

[Altitude 518 feet. Log by John Cox]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Clay, sand, and fine gravel, yellow	42	42	Hardpan; contains stony, sandy, and silty layers	56	144
Clay, and sand, gray	10	52	Sand	9	153
Hardpan (fine sand)	5	57	Quicksand	10	163
Gravel, fine, hard	11	68	Sand, yellow; water	11	174
Rock, coarse	½	68½	Clay, sand, and fine gravel, in hard and soft streaks; yellow	24	198
Hardpan (sand), gray	1½	70	Hardpan (fine gravel, sand, and clay), gray	20	218
Silt and sand; soft, 70–78 ft; hard, 78–81 ft	11	81	Clay, yellow	2	220
Silt and pebbles	4	85	Sand, fine, silty water	14	234
Hardpan; contains fine gravel; some water	3	88	Hardpan, tan-gray	--------	at 234

Well 606, Alaska National Guard, south of International Airport

[Altitude 106 feet. Log by A. R. McInroy]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Silt, slightly sandy	13½	13½	Sand, fine to medium	12	176
Sand, gravelly and silty	3½	17	Gravel and sand; water	9	185
Clay	28	45	Sand, silty	5	190
Sand, fine	5	50	Gravel, silty and sandy, cemented	8	198
Sand, silty, tan; some coal	40	90	Gravel, sandy	6	204
Silt, gray	7	97	Sand	9	213
Sand, fine; a few coal fragments	17	114	Sand and gravel; water	55	268
Sand, gravelly; water	4	118	Gravel, silty, tight and impervious	2	270
Sand, silty	12	130			
Clay	20	150			
Silt, sandy	14	164			

Well 615, K.D. Lancaster, west of Jewel Lake

[Altitude 163 feet. Log by Raymond Miller]

Material	Thickness (feet)	Depth (feet)	Material	Thickness (feet)	Depth (feet)
Silt	4	4	Clay	21	70
Gravel	45	49	Quicksand, silt, and mud	150	220

REFERENCES CITED

Bennison, E. W., 1947, Ground water, its use and conservation: St. Paul, Minn., Edward E. Johnson, 509 p.

Black and Veatch, 1952, Report on development of a supplemental water supply, Elmendorf Air Force Base and Fort Richardson, Alaska: Kansas City, Mo., Black and Veatch, 133 p.

Brown, R. H., 1953, Selected procedures for analyzing aquifer test data: Am. Water Works Assoc. Jour., v. 45, p. 844–866.

Capps, S. R., 1916, The Turnagain-Knik region: U.S. Geol. Survey Bull. 642–E, p. 147–194.

———, 1940, Geology of The Alaska Railroad region: U.S. Geol. Survey Bull. 907, 201 p.

Cederstrom, D. J., 1946, Genesis of ground waters in the Coastal Plain of Virginia: Econ. Geology, v. 41, no. 3, pp. 239–244.

Cooper, H. H., and Jacob, C. E., 1946, A generalized graphical method of evaluating formation constants and summarizing well-field history: Am. Geophys. Union Trans., v. 27, p. 526–534.

Dachnowski-Stokes, A. P., 1941, Peat resources of Alaska: U.S. Dept. Agr. Tech. Bull. 769, 84 p.

Dean, H. T., 1936, Chronic endemic dental fluorosis (mottled enamel): Am. Med. Assoc. Jour., v. 107, p. 1269–1272.

Flint, R. F., 1947, Glacial geology and the Pleistocene epoch: New York, John Wiley & Sons, 589 p.

Karlstrom, T. N. V., 1952, Multiple glaciation of the upper Cook Inlet area, south-central Alaska [abs.]: Geol. Soc. Am. Bull., v. 63, no. 12, p. 1269.

Karlstrom, T. N. V., 1953, Upper Cook Inlet region, Alaska, *in* Péwé, T. L., and others, Multiple glaciation in Alaska: U.S. Geol. Survey Circ. 289, p. 3–5.

——— 1955, Late Pleistocene and Recent glacial chronology of south-central Alaska [abs.]: Geol. Soc. Am. Bull., v. 66, no. 12, p. 1581–1582.

——— 1957, Alaskan evidence in support of a post-Illinoian pre-Wisconsin glaciation [abs.]: Geol. Soc. Am. Bull., v. 68, no. 12, p. 1906–1907.

——— 1960, The Cook Inlet, Alaska, glacial record and Quaternary classification: U.S. Geol. Survey Prof. Paper 400–B, p. B330–B332.

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

Miller, R. D., and Dobrovolny, Ernest, 1959, Surficial geology of Anchorage and vicinity, Alaska: U.S. Geol. Survey Bull. 1093, 128 p.

Nyman, Frank, 1958, Well water protects Anchorage water system: The Johnson National Drillers Journal, v. 30, p. 8–11.

Park, C. F., Jr., 1933, The Girdwood district, Alaska: U.S. Geol. Survey Bull. 849–G, p. 381–424.

Payne, T. G., 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–84.

Péwé, T. L., and others, 1953, Multiple glaciation in Alaska: U.S. Geol. Survey Circ. 289, 13 p.

Smith, P. S., 1939, Areal geology of Alaska: U.S. Geol. Survey Prof. Paper 192, 100 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., v. 16, p. 519–524.

Trainer, F. W., 1953, Preliminary report on the geology and ground-water resources of the Matanuska Valley agricultural area, Alaska: U.S. Geol. Survey Circ. 268, 43 p.

U.S. Department of Commerce, 1960, United States census of population, 1960: Final Rept. PC(1)-3A.

Waller, R. M., Cederstrom, D. J., and Trainer, F. W., 1961, Data on wells in the Anchorage area, Alaska: Alaska Dept. Health and Welfare, Hydrological Data Rept. 14.

Waring, G. A., 1947, Nonmetalliferous deposits in The Alaska Railroad belt: U.S. Geol. Survey Circ. 18, 10 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

The U.S. Geological Survey Library has cataloged this publication as follows:

Cederstrom, Dagfin John, 1908–

Geology and ground-water resources of the Anchorage area, Alaska, by D. J. Cederstrom, Frank W. Trainer, and Roger M. Waller. Washington, U.S. Govt. Print. Off., 1964.

vi, 108 p. illus., maps (2 col.) diagrs., tables. 24 cm. (U.S. Geological Survey. Water-supply paper 1773)

Part of illustrative matter fold. in pocket.

Bibliography: p. 107–108.

(Continued on next card)

Cederstrom, Dagfin John, 1908– Geology and ground-water resources of the Anchorage area, Alaska. 1964. (Card 2)

1. Geology—Alaska—Anchorage region. 2. Water, Underground—Alaska—Anchorage region. 3. Water-supply—Alaska—Anchorage region. 4. Borings—Alaska—Anchorage region. I. Trainer, Frank Wilson, 1921– joint author. II. Waller, Roger Milton, 1926– joint author. (Series)

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Base from U.S. Geological Survey topographic quadrangles

APPROXIMATE MEAN DECLINATION, 1964

GEOLOGIC MAP OF THE ANCHORAGE AREA, ALASKA

SCALE 1:63360

CONTOUR INTERVAL 50 FEET
DATUM IS MEAN SEA LEVEL

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1964—W63339

Geology by F. W. Trainer. Bedrock outcrops in part after Miller and Dobrovolny (1959) and unpublished map by R. G. Gastil, U.S. Army Map Service, 1956

EXPLANATION

Surficial deposits of the Anchorage area, Alaska, exclusive of windblown sand and silt

SEDIMENTARY ROCKS

QUATERNARY

Recent

Qe
Postglacial estuarine deposits
Clay and silt, locally sand and gravel; beside and in Knik and Turnagain Arms (deposits on narrow beaches not mapped); postglacial and, in part, modern. Not a water-bearing formation

Bog deposits
Peat; chiefly postglacial, in part modern. Not a water-bearing formation

Qal
Stream deposits
Sand and gravel, locally silty or clayey; in channels, valley floors, and low terraces of streams on the lowland; chiefly postglacial. May yield small quantities of water to shallow wells

Qaf
Alluvial-fan deposits
Sand and gravel, locally silty and clayey; glacial and postglacial. May be a good water-bearing formation in some places

Pleistocene

Qay_3
Younger outwash-stream deposits, of late-recessional age
Sand and gravel; chiefly north of end moraine, Qey; deposited during recession of ice from that moraine by meltwaters of the Eagle and Knik-Matanuska Glaciers. May yield small supplies of water to shallow wells in some places

Qgy
Younger ground-moraine deposits
Till and glaciomarine drift, locally mantled by sand and gravel; north of end moraine, Qey, with which they are in part contemporaneous. May yield small supplies of water from gravelly beds

Qay_2
Older outwash-stream deposits, later phase
Sand and gravel; outwash plain of Eagle and Knik-Matanuska Glaciers formed during last glaciation of Anchorage area; yield small to moderately large quantities of water to shallow dug and drilled wells in Mountain View but finer grained and a poor water-bearing formation to the west and south

Qey
End-moraine deposits of Knik-Matanuska Glacier
Till, water-laid "till," and outwash-stream deposits; formed during last glaciation of Anchorage area. Poor water-bearing formation

Qme
End-moraine deposits, Fire Island
Till, water-laid "till," and outwash-stream deposits; may be correlative with end-moraine deposits of Knik-Matanuska Glacier, Qey. Yield moderate supplies of water from gravelly beds

Qay_1
Older outwash-stream and lake(?) deposits, earlier phase
Sand, silt, and gravel; combined outwash plain of Eagle, Knik-Matanuska (?), and Turnagain Arm Glaciers formed during last glaciation of Anchorage area; may include lake deposits. Yield small quantities of water to shallow wells

Qeo
Estuarine and lake(?) deposits
Bootlegger Cove Clay; clay and silt, containing sporadic beds of sand and gravel. Finer elements yield little or no water, but in a few places coarse materials are present which yield moderate to large quantities of water to wells

Qdu
Glacial drift, undifferentiated
Outwash-stream and lake deposits west of International Airport, thought to be contemporaneous with units Qe and Qgo; till or till-like material present locally. Apparently does not contain water

Qrl
Glacial-recessional deposits, later phase
Sand and gravel, in part silty and clayey; chiefly in melt-water drainage courses that indent older deposits; include deposits graded to several different temporary base levels. Yield small quantities of water to shallow wells

Qre
Glacier-recessional deposits, earlier phase
Sand and gravel and till; largely in pitted and other ice-contact features, undifferentiated; locally thin, covering ground-moraine deposits, Qgo. Yield small quantities of water from sandy or gravelly beds

Qgo
Older ground-moraine deposits
Till, locally mantled by sand and gravel; probably include some outwash-stream deposits, not differentiated. Yield small to moderate quantities of water from gravelly lenses

Qlo
Lateral glacier-margin deposits of older glaciation
Lateral-moraine and kame-terrace deposits, in part pitted; undifferentiated. Yield small quantities of water from gravelly lenses

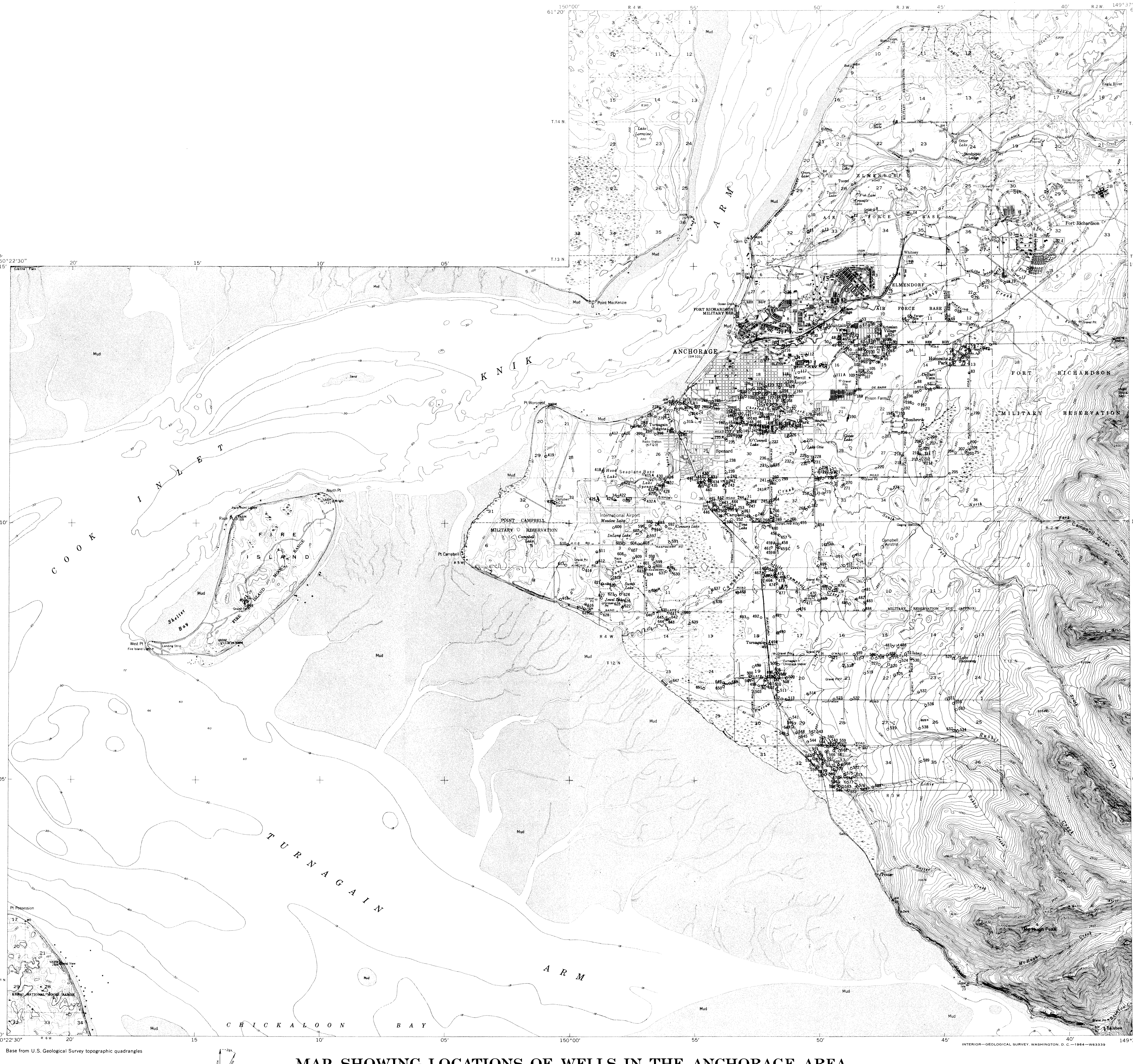
METAMORPHIC ROCKS

MESOZOIC

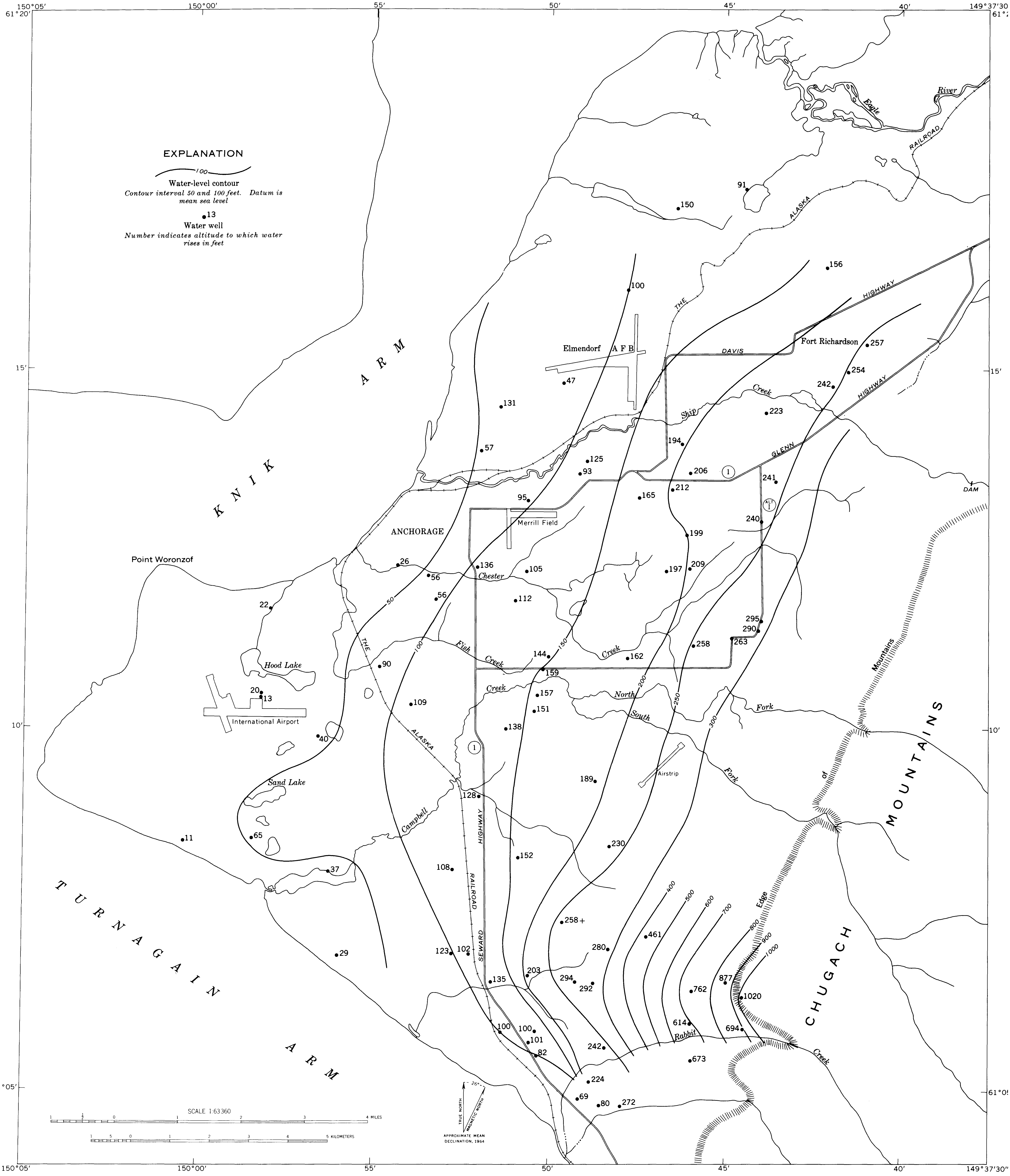
Mzu
Metamorphic rocks of igneous and sedimentary origin: greenstone, graywacke, argillite, and slate

Contact
Dashed where approximate, dotted where placed arbitrarily

River terrace
Dashed where approximate; hachures point down scarp

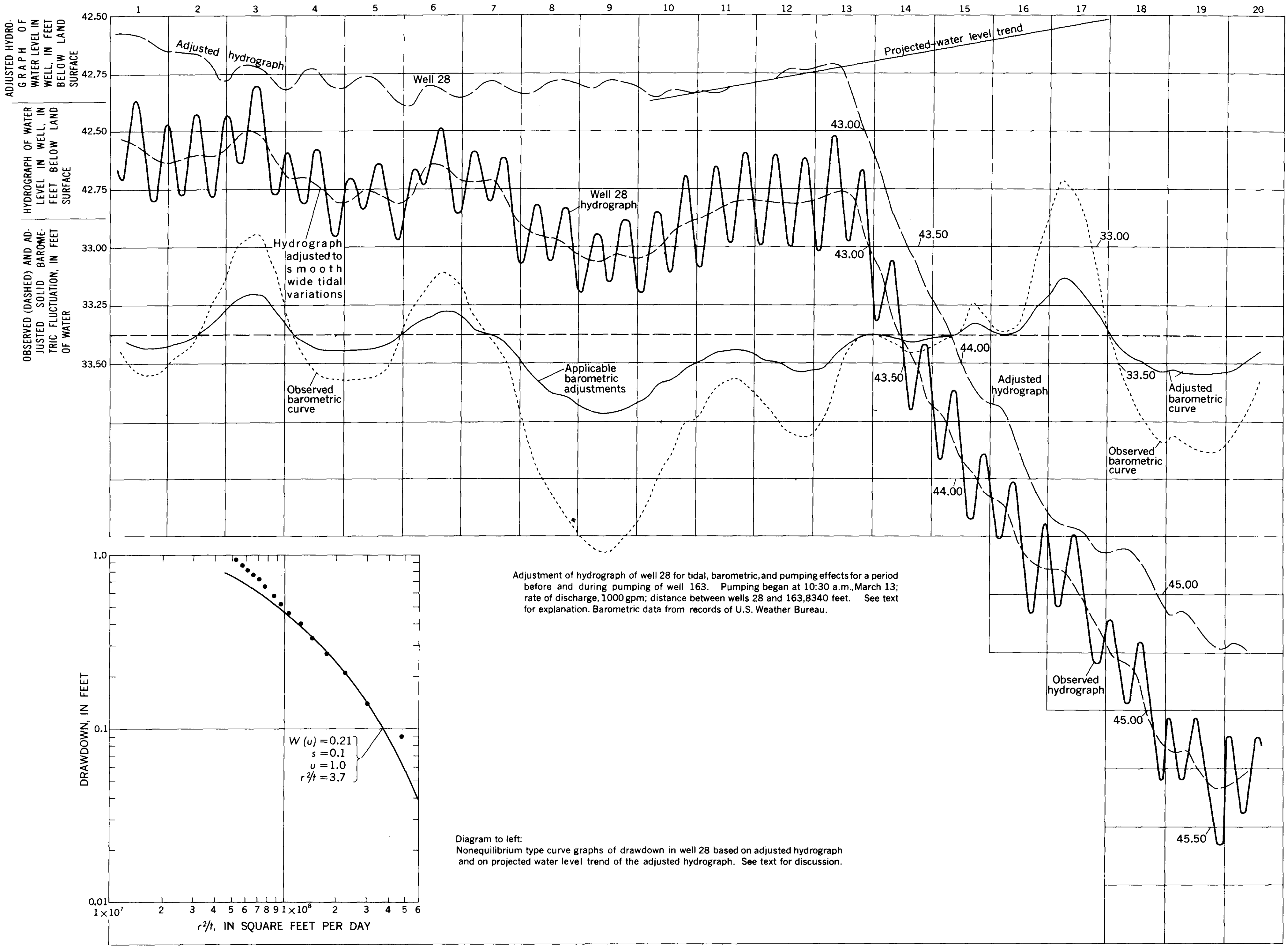


MAP SHOWING LOCATIONS OF WELLS IN THE ANCHORAGE AREA



MAP SHOWING HEIGHT TO WHICH WATER WILL RISE IN ARTESIAN WELLS OF MODERATE DEPTH

725-300 O - 64 (In pocket)



Adjustment of hydrograph of well 28 for tidal, barometric, and pumping effects for a period before and during pumping of well 163. Pumping began at 10:30 a.m., March 13; rate of discharge, 1000 gpm; distance between wells 28 and 163, 8340 feet. See text for explanation. Barometric data from records of U.S. Weather Bureau.

Diagram to left:
Nonequilibrium type curve graphs of drawdown in well 28 based on adjusted hydrograph and on projected water level trend of the adjusted hydrograph. See text for discussion.

CHART SHOWING WATER LEVELS IN THE DISTRICT ENGINEERS WELL (28) DURING PUMPING TEST ON CITY OF ANCHORAGE WELL (163)

725-300 O - 64 (In pocket)