

**Fig. 1.** Sketch map of Point Spencer, showing topography and locations of beach ridges, of probing holes, of cross-sections in Fig. 8, and of samples in Figs. 5 and 6.

# PERMAFROST, WATER-SUPPLY, AND ENGINEERING GEOLOGY OF POINT SPENCER SPIT, SEWARD PENINSULA, ALASKA\*

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**P**oint Spencer (Fig. 1) is the enlarged northern tip of a spit that separates Port Clarence from the Bering Sea, near the western end of Seward Peninsula, Alaska. During construction of a temporary airfield there in 1945 army engineers experienced difficulty in excavating into permafrost and in obtaining an adequate water-supply. The U.S. Geological Survey was requested to make a geologic reconnaissance of the spit in the autumn of 1945, and this was done by the writer, aided by William P. Brosgé. The purpose was to determine the character of permafrost and the availability of potable water for use by the construction group and the service group succeeding it. Inasmuch as many spits and bars along the shores of western and northern Alaska resemble Point Spencer, the results of that reconnaissance are of general interest to construction projects in similar areas.

During the period from October 10 to November 1, 1945 inclusive, a small area on Point Spencer was mapped with plane-table and telescopic alidade on a scale of 500 feet to the inch and with a contour interval of 2 feet. At that time the spit was covered with as much as 30 inches of snow, and the ground was frozen in places to a depth of 26 inches. In the area mapped (Fig. 1) the top of permafrost and the water-table were located with a  $\frac{3}{4}$ -inch steel drill rod 8 feet long. The rod was driven into the ground with a sledge hammer and extracted with pipe-wrenches. In a protected water-supply area, established by the engineers, holes were dug to check the results obtained by this probing for the water-table. Samples of vegetation and surface materials were collected for laboratory study.

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**Fig. 2.** Barrier ridge with sparse beach grass (*Elymus mollis*) near U.S. Coast and Geodetic Survey Azimuth 14.90 on the west side of Point Spencer, looking northeast. October 15, 1945.

### Geography and geology

Point Spencer lies at latitude  $65^{\circ}17'N.$  and longitude  $166^{\circ}50'W.$ , about 69 miles northwest of Nome. The spits extends more than 15 miles northwest and north from the mainland, although perhaps only the northern part is wave-deposited. (The base was not examined by the writer, but is reported by David M. Hopkins to be erosional). The enlarged northern part of the spit is about 3 miles long and 1 mile wide. It is joined to the mainland on the south by a low sand- and gravel-bar ranging in width from less than 100 to over 10,000 feet. The west shore of the northern part is smoothly arcuate to the hook at the tip of the spit. The east shore has two pronounced lobes that protrude into Port Clarence. The northern part is nowhere more than 14 feet above sea-level and averages between 6 and 8 feet. A prominent sand-ridge or barrier, 10 to 14 feet high, parallels the west shore (Fig. 2), and a much less pronounced, broad ridge, or set of parallel ridges, 6 to 10 feet high, parallels the east shore. Eastward-trending ridges, 6 to 12 feet high, transect the southern end of the enlarged part of the spit and terminate at the west and east shores. North of this group of eastward-trending ridges the spit is crossed by arcuate ridges that have a more northeasterly trend (Fig. 3). The old beach-ridges, which are shown in Fig. 1, are accurately located only in the small area mapped topographically, and even in that area no attempt has been made to map all ridges. At the northern end of the spit the ridges parallel the northwest shore. The relief between ridges and troughs is of the order of 2 to 4 feet. Several small ponds and swampy hollows are present, of which only a few are shown in Fig. 1; streams are absent.

The spit is covered with stunted arctic vegetation, except in a zone, 100 to 200 feet wide, along the western shore and in an area of several thousand square feet in the northern part. Grasses, sedges, mosses, and other small plants, predominate. Trees are absent, but small, prostrate willows of several species are common. In general, each type of vegetation tends to segregate into zones or patches according to type of soil and drainage. No attempt was made to map vegetational zones, most of which are too small to be mapped on the scale used.

Sparse beach-grass (*Elymus mollis*) forms a belt, 100 to 200 feet wide, along the crest of the ridge that parallels the west shore (Fig. 2). To the east the beach-grass gives way to a mixed assemblage of grasses and sedges that were not identified. Along the almost bare crests of the former beach-ridges, where coarse gravel permits rapid drainage and drying, almost no soil exists, and mountain avens (*Dryas octopetala*) and caribou moss are in many places the only plants. Along the back slopes of the ridges the sandy soil is 0.5 to 2 inches thick and the *Dryas* and mosses grade into a zone that contains elongated patches of grasses, sedges, and willows. Peaty soils, 2 to 12 inches thick, cover sand in the troughs, where water-loving sedges, crowberry (*Empetrum nigrum*), and mosses prevail.

The spit is principally the result of transportation and deposition of material by wave action and longshore currents, and is similar in origin to the barrier-bars (or offshore bars) that extend almost continuously along the southwestern coast of the Seward Peninsula. The ridges were formed by waves and represent a series of former storm-beaches. Thus they record stages in the construction and destruction of the spit and suggest that the



**Fig. 3.** Former beach ridge and trough that trend diagonally northeast across Point Spencer, from a point near U.S. Coast and Geodetic Survey Azimuth 14.90, looking northeast. October 15, 1945.

spit was intermittently extended from south to north and at the same time was moved eastward.

Material is now being transported generally northward by longshore currents and waves on the Bering Sea shore and is being deposited at the tip of the spit on the northern and eastern sides. Only a negligible quantity of material is moved by ice-shoving compared with that transported by waves and currents. Wind has sorted some of the sand and has deposited several layers a few inches thick on the barrier-ridge along the west shore. Deposition of gravel by wave action from Port Clarence has filled in and smoothed out the indentations of the east shore.

Constructive and destructive wave actions vie with one another, and during October 1945 measurements made on the northern tip of the spit revealed a change in position of the shore-line of as much as 100 feet during one stormy night. The changes in the shore-line are brought about mostly by wave action resulting from sudden changes in wind direction and velocity and only to a smaller extent by the tides, which are less than 2 feet.



**Fig. 4.** Gravel and sand in stratified layers and lenses exposed in an excavation about 200 feet southeast of well No. 1 (Fig. 1). October 15, 1945.

Undecayed driftwood covers the barrier-ridges on the western and northern sides of the spit (Fig. 2) and extends inland for several hundred feet. Storm waves have washed over the barrier-ridges through passes and breaks 10 feet above sea-level and have built recent deltas and fans a few inches to 2 feet high and 10 to 50 feet wide on the land side of the ridges. These features suggest partial, if not complete, inundation by the sea in comparatively recent times. One complete inundation, during a storm accompanying or following the eruption of Mount Katmai in 1912, has been recorded.

The old beach-ridges are composed of gravel and sand in stratified layers and lenses (Fig. 4). The upper surface of the lenses parallels the surface of the former beaches, and the lenses are a fraction of an inch to 30 inches thick, a few inches to 20 feet wide, and as much as several hundred feet long. In general, the coarser material makes up the ridges, whereas most troughs contain a layer of sand or peaty soil at the surface. About 85 per cent of the coarse-grained surface material is composed of discoidal limestone pebbles. The pebbles may have been derived from the limestone of uncertain age that outcrops on the mainland to the east and south. However, the writer has not seen these outcrops. Most pebbles were deposited in such a way as to form an overlapping shingle-like structure. Smaller pebbles of fine- to coarse-grained granitic rocks, slate, and schistose rocks, are present in small quantities. The finer material is principally quartz but includes fragments of garnet, hornblende, pyroxene, epidote, mica, feldspar, chert, dolomite, and other minerals. Heavy minerals such as magnetite and ilmenite were not seen. Shell fragments in small quantities are common. Silt-sized particles of rocks and minerals are negligible in quantity (Figs. 5 and 6).

According to two well-logs made by the army engineers the typical wave-deposited sand and gravel section is 34 to 36 feet thick and rests on 8 to 36 feet of black muck. The muck is underlain by a series of alternating beds of black clay, black silt, sand, and gravel, to a depth of at least 298 feet.

### Climate

The climate at Point Spencer is subarctic-marine; that is, cold, cloudy, windy, and humid, but with only low to moderate precipitation. Incomplete records from the U. S. Weather Bureau station at Teller, on the mainland 14 miles east of Point Spencer, show that from 1931 to 1940 the mean annual temperature there was 25.2°F. and the mean annual precipitation was 11.1 inches. Table 1 shows the mean monthly temperature and precipitation at Point Spencer for 1 year. During that period the minimum temperature was -33°F. and the maximum was 74°F.; the annual mean temperature was 21.8°F. The greatest precipitation during one day was 1.13 inches on January 23, 1945. The low temperature, high winds, high humidity, and cloudiness, are favourable for the growth of permafrost at Point Spencer.

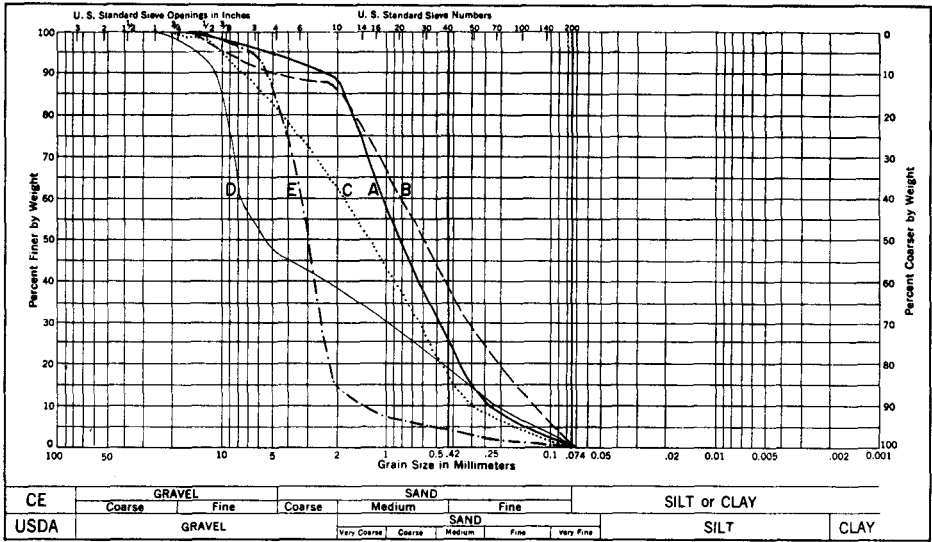


Fig. 5. Graph showing grain-size distribution of samples of sand and gravel from Point Spencer. See Fig. 1 for locations.

From October 10, 1945 to November 1, 1945 inclusive there were falls of sleet or snow flurries on 19 of the 22 days and the surface of the ground, except for the higher ridges, was covered with as much as 30 inches of snow. During October the average wind velocity was 16 miles per hour and the greatest velocity was over 47 miles per hour. The prevailing wind direction was NNE. During that month 66 per cent of the days were overcast, 14 per cent had broken clouds, 12 per cent had scattered clouds, and 8 per cent were clear. On October 18 and 19 very strong winds from

Table 1. Temperature and precipitation data for Point Spencer, Alaska. Compiled from records of the 16th Weather Region, Regional Control Office, U.S. Army.

	Average mean temperature in degrees F.	Precipitation in inches
November 1944	11.5	0.25
December	6.5	0.50
January 1945	4.8	1.54
February	-0.8	1.29
March	-7.7	1.16
April	19.8*	0.12*
May	25.0	0.66
June	37.4	0.11
July	47.9	1.65
August	45.2	2.49
September	43.0	1.87
October	28.8	1.32
Annual mean temperature	21.8	Annual precipitation 12.96

\* First seven days in April were not recorded.

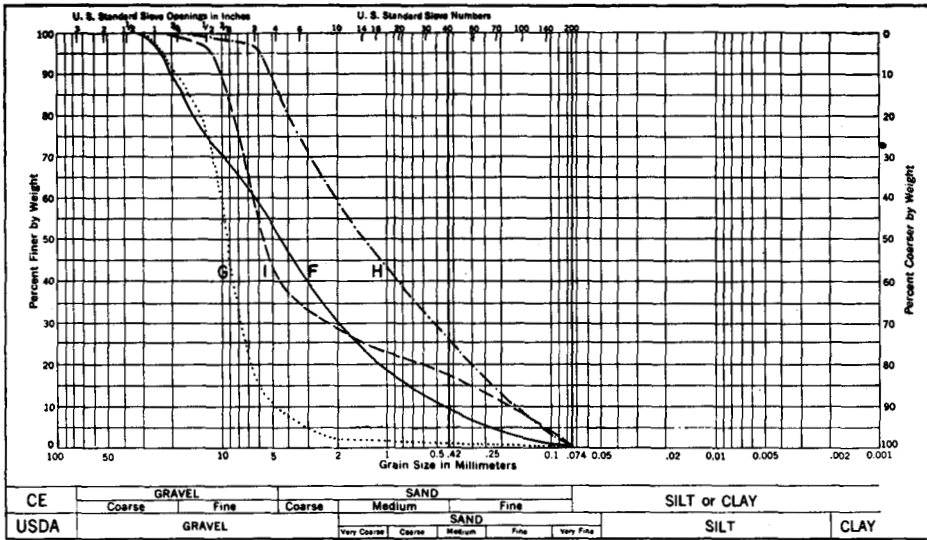


Fig. 6. Graph showing grain-size distribution of samples of sand and gravel from Point Spencer. Samples G, H, and I were taken at the spot marked G in Fig. 1 at depths of 30 to 35 inches, 25 to 30 inches, and 4 to 17 inches, respectively.

the north blew much of the snow cover off the spit. After several more inches of snow had fallen, very strong easterly winds on October 25, 26, 28, and 29, repeated the process. These winds caused the flooding by salt water of borrow pits along Port Clarence.

**Permafrost**

Perennially frozen layers of gravel and sand cemented with ice underlie most, if not all, of the enlarged northern part of Point Spencer pit and extend outward for several feet beyond the shore. The pores of the sediments are entirely filled with ice and in many places there is more ice than normal pore space. In the area shown in Fig. 7 the depth to permafrost ranged from 3 feet to more than 8 feet in October 1945. The top of permafrost was roughly parallel to the surface of the ground, but irregularities on the permafrost-table commonly were less pronounced than irregularities in surface relief. Thicker vegetation and abundant moisture in the swales prevent rapid thawing, and permafrost is there closest to the surface. The top of permafrost in a small area on the Point is illustrated by contours in Fig. 7 and by cross sections in Fig. 8. At wells No. 1 and No. 2 (Fig. 1) the base of the permafrost was 12.5 and 17.0 feet below the surface or 7.5 and 8.0 feet below sea-level, respectively. It seems likely that the base of the permafrost is irregular and that it is in general roughly parallel to the top.



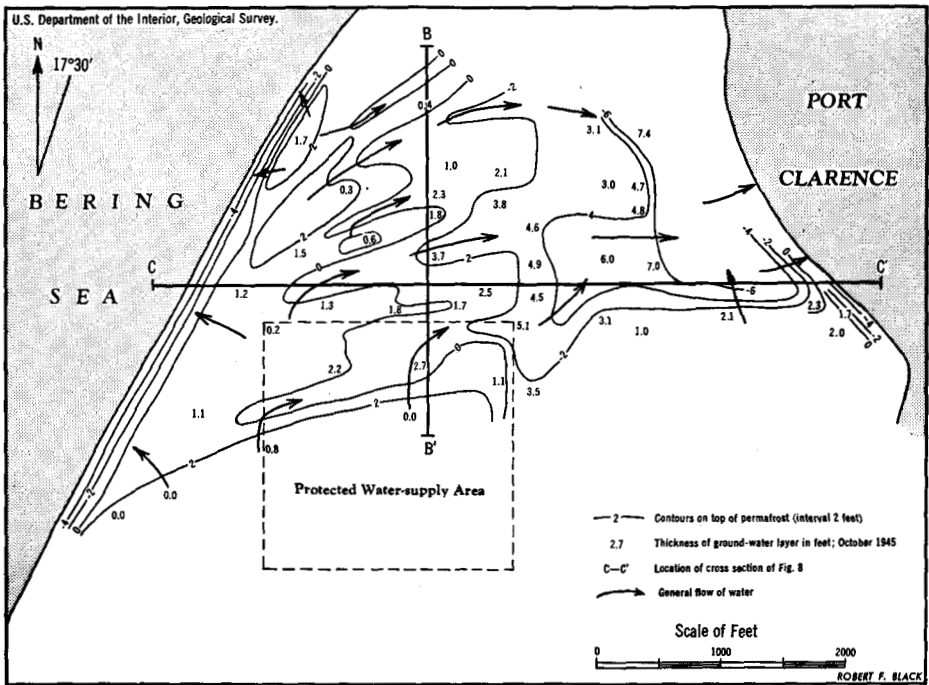


Fig. 7. Map showing contours on top of permafrost and thickness of groundwater layer on part of Point Spencer spit.

Records kept by the 331st Engineers show that the frost-table was from 6 to 30 inches below the surface in July 1945. In order to obtain material from the deeper borrow pits it was necessary to allow the frozen ground to thaw to a depth of several inches from time to time, so that another layer of sand and gravel could be removed by bulldozers. By November 1945 the depth to which freezing from the surface had advanced was as much as 26 inches and it is believed that during normal winters the active layer freezes completely down to permafrost. Freezing penetrates deeper and more rapidly where snow cover and vegetation are thin or lacking.

According to records of the army engineers one icing mound or ice laccolith near the north end of the runway was removed when the runway was constructed in July 1945. The icing mound consisted of a dome-shaped lens of ice, 30 feet in diameter and 1 foot thick, under 1 foot of peaty soil. Such ice lenses are common features in other areas of the Arctic; they are formed in the fall when the active layer freezes, trapping soil water under pressure between the downward-freezing surface and the impermeable permafrost below. Polygonal patterns were recognized to the south of the pond area (Fig. 1) in the older part of the spit; they were not investigated in the field, but presumably are analogous to the ice-wedge polygons of other parts of Alaska.

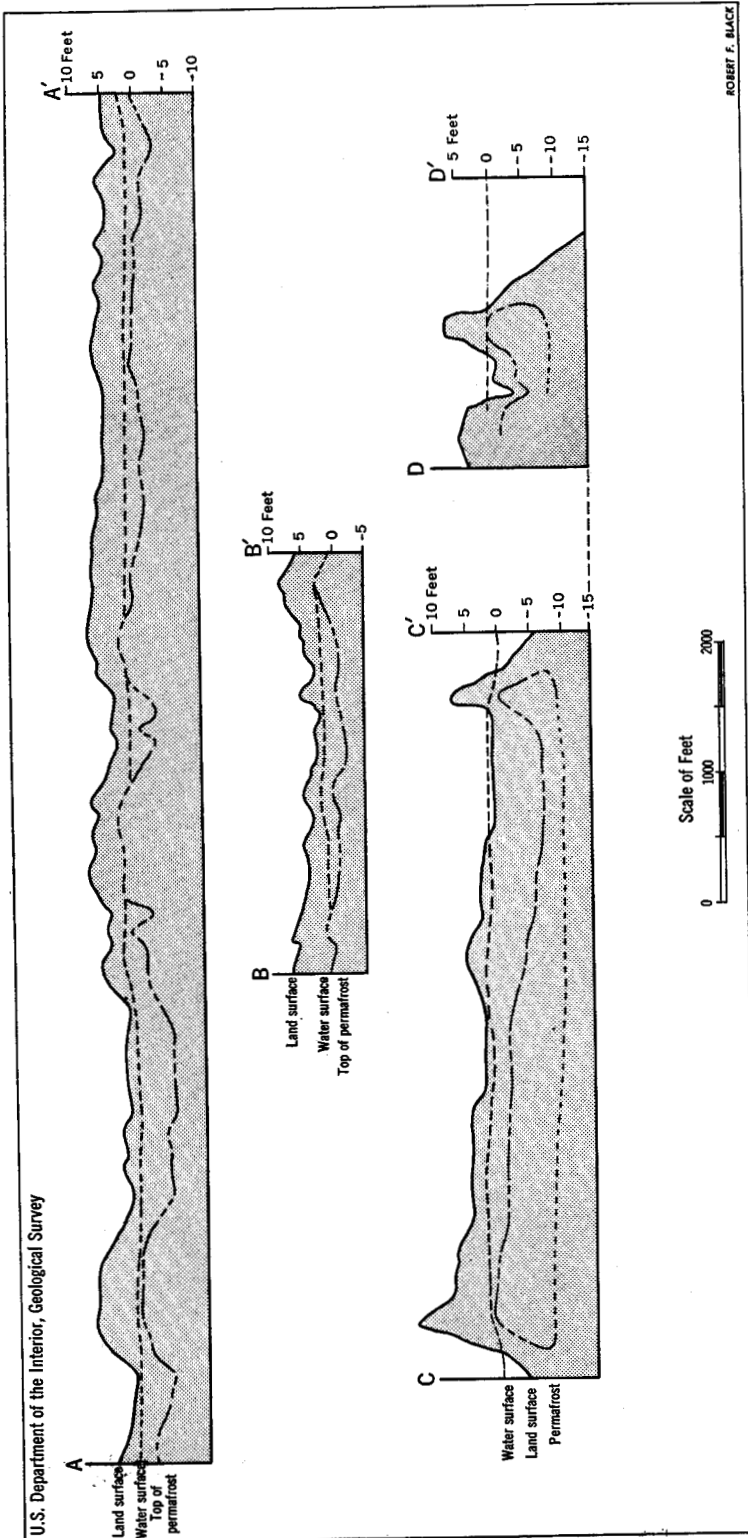


Fig. 8. Representative cross-sections across part of Point Spencer spit, showing land surface, top of permafrost, and water surface.

### Hydrology

Fresh water on Point Spencer is derived from rain that falls directly on the spit and snow that falls or is blown on to it. Water from rain and melting snow that is not evaporated or transpired is trapped in irregularities on the permafrost in form of a perched water-body. It is normally available for use only in the summer, because during the winter it is contained as ice within the active layer. The average annual precipitation is only 11 inches according to records of the U.S. Weather Bureau, and much of it is in the form of snow that drifts off the spit before it can melt and augment the water supply. In the fall and early winter the snow blows into the open water before ocean and bay freeze and is lost. Hence, recharge of fresh water is limited. In Fig. 7 the presence of ground-water is indicated by figures, which show the thickness of water-saturated material on top of the permafrost. Cross sections of the ground-water body and the permafrost are shown in Fig. 8. Irregularities in the water-table are due in part to the fact that measurements at different places were made at different times. The probable ground-water circulation during October 1945 is indicated by arrows in Fig. 8. The porosity of the sand and gravel averages about 15 per cent and the permeability is very high; hence, the water-table rises and falls very rapidly after rains or thaws.

The permafrost-table is the principal factor controlling the distribution of ground-water, which is essentially absent above the higher permafrost ridges. Water is most abundant in the large borrow pits excavated into permafrost between the runway and Port Clarence, and in the freshwater ponds near the southern end of the runway. Under the barrier-ridges along the edges of the spit the permafrost-table rises slightly to form a natural dam, less than 2 feet above sea-level on the western side and even lower on the eastern side. This dam impedes the drainage of ground-water out to sea and also prevents sea-water from polluting the fresh water on the spit. Thus the fresh water lies in natural basins in the upper surface of the permafrost.

Rapid rises of the water-surface are caused chiefly by precipitation, melting of the frozen ground, and flooding by sea-water. Graphs supplied by the army engineers of daily positions of ground-water levels show that the maximum variation in the water-level during August and September was 1.2 feet in a freshwater pond in the borrow pit at cross section D—D' (Fig. 1) and less than 1 foot in the freshwater pond at the southwest corner of the runway and in the borrow pit north of the tent area (Fig. 1). The water-levels were highest when precipitation was greatest and they dropped, in places as much as 0.6 feet in 3 days, when precipitation ceased. From June 25 to October 10, 1945 the water-table in the protected water-supply area (Fig. 7) dropped steadily and probably closely paralleled the annual melting of the active layer and the resulting lowering of the frost-table.

During some storms sea-water flows through the gravels over the low permafrost barriers bordering the spit and contaminates at least part of the fresh water on the spit. An instance of this took place on October 26, 1945 when very strong winds from the southeast brought about the flooding with salt water of most of the borrow pits along the Port Clarence side. At least 14 inches of sea-water flooded a borrow pit (not shown in Fig. 1) at the southwestern corner of the runway; at least 13 inches of strong salt water flooded the large borrow pit north of the tent area. On October 30 water on top of the permafrost dam on the Port Clarence side was still salty. Fresh ground-water, which had been pumped since July 1945 from an excavation at a septic tank (south of the tent area, but not shown in Fig. 1), turned brackish on October 28 and was too salty for use the next day.

Fresh water near the centre of the spit is usually not contaminated, although the water-level commonly is raised by the introduction of salt water into the border areas of the spit and by the damming of the out-flowing fresh water. At times salt water apparently has flowed under near-shore bodies of fresh water, both ground- and surface-water, on the spit, floating the fresh water and raising the water-level. Double layers of ice, separated by water, in the pond in the borrow pit at cross section D—D' indicated flooding by 14 inches of water. Furthermore, the double layers of ice in the pond at the southwestern corner of the runway indicated a sudden rise of water-level of at least 13 inches. These rises in water-level occurred during a time of no recharge of fresh water. It was reported by the officer in charge of the base that the water in the borrow pit crossed by section D—D' became salty about November 7 after a week of pumping the fresh surface-water.

The best source of water on the spit is probably the pond area to the west of the south end of the runway. The ponds contain 2 to 3 feet of water over a few inches of organic ooze and are underlain by sandy gravel. Permafrost is more than 6 feet below the surface. Even here, however, salt water may have contaminated the fresh water just above the permafrost-table in October 1945. Tests should be made to determine the nature of the situation before any extensive use of water from the area is made.

The two wells, one 298 feet deep, did not show any source of fresh water, and it is improbable that a good source could be found at a greater depth. When permafrost was pierced by these wells, salt water rose in them to about sea-level at depths of 5 and 9 feet, respectively.

### Engineering geology

The following comments and recommendations, though made specifically for Point Spencer, are applicable in large part to other bars and spits in western and northern Alaska. The ground at Point Spencer spit is characterized by layers of well-sorted sand and gravel that in general assure a stable subgrade, whether or not permafrost is present or is

disturbed by construction work. Except for subsurface drainage, effects of temperature, and additional induration of the unconsolidated sand and gravel by ice, the construction problems are similar to those in areas of well-sorted sand and gravel free from permafrost. Although sand and gravel are abundant, other types of construction materials are essentially not available. Fine silt and clay are scarce or absent at the Point, but are reported 6 to 7 miles to the southeast. No bedrock is present at or near the surface. However, crushed limestone pebbles make an excellent binder for the loose gravel. Sand, a few inches to several feet thick, is found most commonly at the surface of the swales, whereas the ridges are composed chiefly of gravel. Sand also caps the barrier-ridge along the western side of the spit. Permafrost makes the removal of material from borrow pits or other excavations difficult because it acts as a cement in the gravels and sands. Thawing of permafrost proceeds relatively rapidly on exposure during June, July, August, and early September, but during the rest of the year artificial thawing is necessary.

The supply of fresh water on the spit is very limited and is not replenished rapidly. Therefore, precautions should be taken in any construction on the spit to determine whether or not the work will affect the water supply. Sanitation regulations to preserve the supply of fresh water must be rigid and strictly adhered to.

The construction of traps to retain as much snow on the spit as possible would help to replenish the water-supply. Excavation of hollows in the top of permafrost would tend to prevent the escape of fresh water over the permafrost barriers around the edge of the spit. However, these hollows must be kept shallow or permafrost may be pierced. This may have occurred in the deep borrow pit north of the tent area. The construction of earthen ridges around the freshwater pond area and elsewhere would tend to raise a permafrost barrier, and thus aid in preventing the pollution of these areas by the lateral flow of salt water and the escape of the fresh water to lower areas.

Heated buildings or excavations on the barrier-ridges along the edges of the spit would lower the permafrost dam and result in pollution by sea-water of the freshwater supply. Deep excavations or construction that would pierce or destroy the permafrost underlying the fresh water would allow salt water to rise or the fresh water to flow downward to sea-level, thus destroying much of the storage capacity of the area.

The withdrawal of fresh water from any part of the spit should be accompanied by surveys in the vicinity to determine if polluted or saline waters are replacing the fresh water withdrawn, and if so, to determine possible methods of preventing pollution. Surveys to determine the top of permafrost should be made annually to determine any dangerous lowering of a permafrost dam either on the edges of the spit or between areas of polluted and fresh water now existing, such as the area between the polluted borrow pits adjacent to Port Clarence and the freshwater ponds to the west of the south end of the runway.

Construction of drainage, sewage-disposal, and water-distribution systems, requires special measures to counteract the freezing temperatures encountered in permafrost, but utilidors laid on or near the surface of the ground have proved satisfactory elsewhere in areas of permafrost.

The position of the shore-line, particularly at the northern tip and at the southeastern corner of the enlarged portion of the spit, changes as much as 100 feet overnight as the result of longshore currents and wave action, and no permanent construction should be attempted on or directly adjacent to the shore, unless adequate breakwaters can be established. Frequent storms and the ease with which the sand and gravel can be transported by water or ice would make the establishment of permanent breakwaters costly and difficult.

The presence of driftwood on the highest parts of the spit and the fact that the entire spit has been inundated at least once within recent years indicates the possibility of another inundation.

### Conclusions

As a terrain type for engineering considerations a spit, such as Point Spencer, can be classed among the barrier-bars or offshore bars. They can be identified by their position in relation to the mainland and by the nature of the unconsolidated, wave-deposited materials of which they are composed. From Norton Sound northward along the Bering Sea and arctic coasts of Alaska offshore bars are common. Permafrost, water-supply, and availability of construction materials in many bars probably are similar to those at Point Spencer. Such wave- and current-formed bars are commonly composed of lenses and layers of well-sorted sand, or sand and gravel. The size and composition of the material is dependent in part upon the material on the ocean floor adjacent to the spit and upon the character and proximity of bedrock in the vicinity. For example, at Point Spencer much of the material consists of flat, disk-like plates of limestone, whereas at Point Barrow most of the material in the beach is composed of well-rounded spheroids of chert. The thickness of the coarse material in a bar depends principally upon the accessibility to waves, the availability of material, and the stage in the development of the bar. The sand and gravel may be only a few inches or as much as several tens of feet in thickness, and may or may not rest on fine-grained silt or muck containing considerable organic matter. Perennially frozen, fine-grained silt or muck characteristically contains much ice as cement, grains, and clear masses of various shapes, as at Point Barrow. Therefore, before any large-scale construction is attempted, bars should be thoroughly investigated for subsurface conditions. The effects of frost-heaving and slumping are likely to be relatively slight in bars of coarse sand and gravel, but disastrous in bars of fine-grained materials.

The supply of fresh water on offshore bars and spits is always limited, and to obtain an adequate supply is likely to be the most difficult problem

in construction. Permafrost commonly is the factor that permits the water to be retained. Therefore, it must receive first consideration in the utilization of the bar or spit for engineering purposes if the current water-supply is to be maintained on a yearly yield basis.

Although the general geological history, permafrost, water-supply, and availability of construction materials, at Point Spencer have been established in reconnaissance fashion, direct comparisons should not be made with other bars or spits unless it can be determined that they had a parallel geological history and are subject to a similar climate. Most must be treated as individual cases; however, many problems and their solutions are undoubtedly common to all. In particular, the principle seems well-established that water-supply is usually economically feasible only if natural or artificial basins in permafrost can be preserved.