VARIATION OF SOIL TEMPERATURES IN OGOTORUK VALLEY, ALASKA*

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Introduction

THE study on which this paper is based was made under the auspices of the U.S. Atomic Energy Commission. Its purpose was to provide sufficient meteorological and climatological information about Ogotoruk Valley so that any changes in the biosphere and ecology of the valley after the proposed atomic excavation of the harbour could be more easily related to variations in the climate rather than to radiation aftereffects.

Methods and instrumentation

The micrometeorological station network (Fig. 1) extended from the mouth of Ogotoruk Creek on the Chukchi Sea up to 6.5 miles inland, and the stations were spread on both sides of the 2-mile-wide valley. Specialized instrumentation was necessary only for the soil thermometers and pyrheliographs. The soil thermometers were of the hydrocarbon-in-steel type, manufactured by the Palmer Thermometer Company and permitted daily reading of the maximum and minimum temperature since the preceding observation. They were clamped between radiation shields for measuring air temperatures at 5 and 50 cm. above the ground and were buried at 5-, 10-, 20-, and 50-cm. depths in the soil at each of the stations. Solar radiation was measured by pyrheliographs with 7-day clockworks furnished by the Belfort Instrument Company. Almost two full summers of weather and soil temperature data were collected during 1960 and 1961.

Soil and near-surface temperatures

We are greatly indebted to Geiger (1957) for much of our knowledge and reasoning regarding soil and near-surface temperature phenomena. Fig. 2, adapted from Geiger (1957, p. 140), shows three soil temperature profiles

* Excerpts from "Microclimatology of Ogotoruk Valley". Final Report, April 1962, on a study made for the U.S. Atomic Energy Commission, Las Vegas, Nevada.

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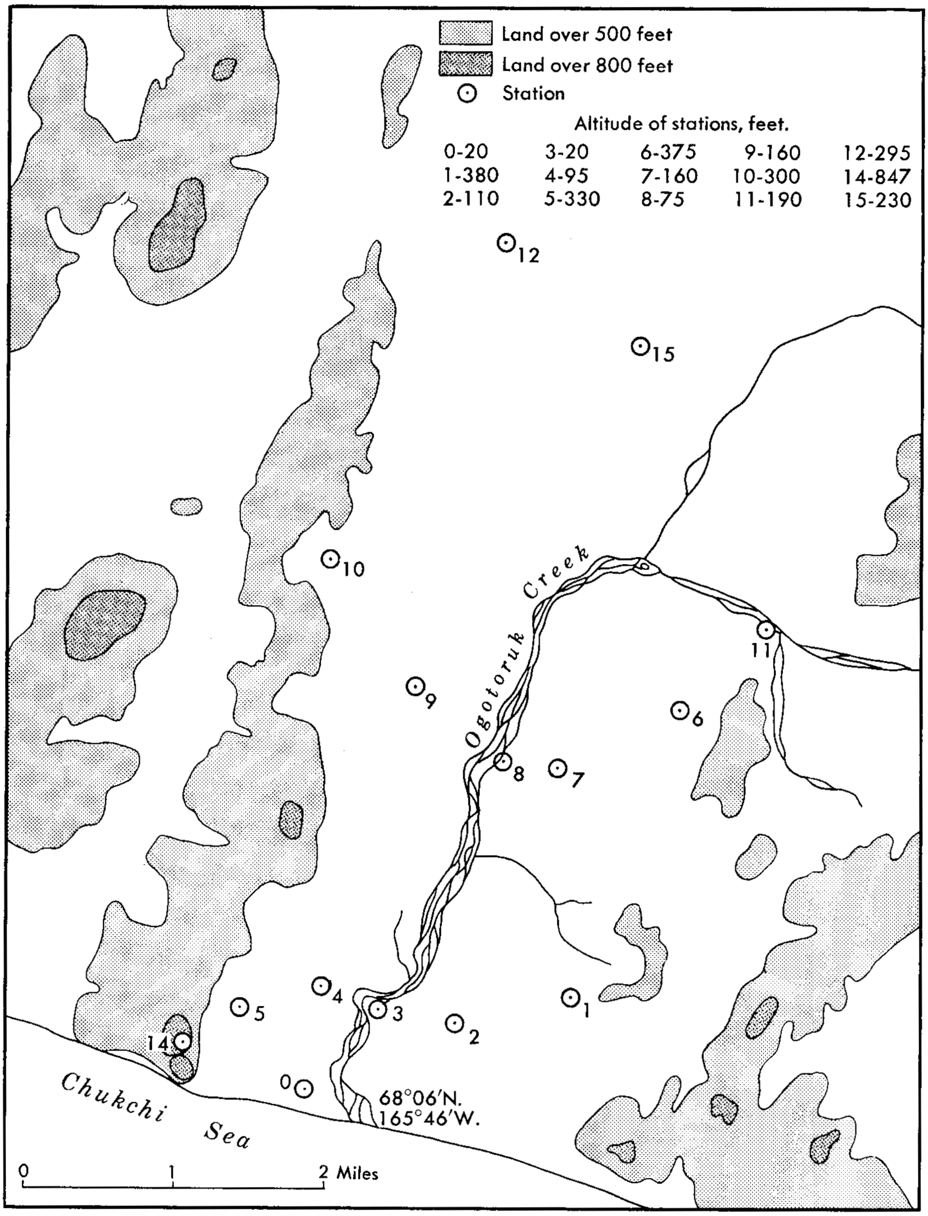
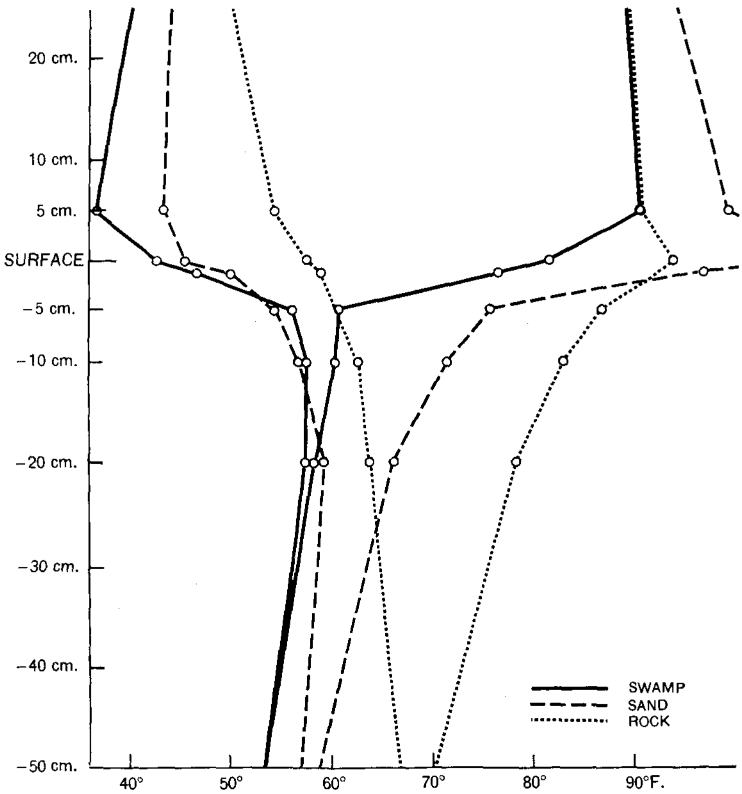


Fig. 1. Station network in Ogotoruk Valley.

measured over a dry 3-day period in August 1893 by Th. Homen in Finland for a swamp, dry sandy soil, and rocky soil. Readings from Ogotoruk Valley in August 1960 during a dry period plotted in a similar manner in Fig. 3 definitely place the valley into the category of swamp, except that the soil at all levels in Ogotoruk Valley is about 15 to 20°F. colder. Figs. 4 to 7 show that in general the same profile is evident for all representative stations shown.

Fig. 2 also illustrates different characteristics of these three soil types. Rocky granite soil has good heat storage characteristics: the maximum temperature occurs on the surface and the daily heating penetrates deeply into the rock. At night a good deal of heat is passed out from within, which accounts for the high level of temperatures in the rock at night, higher even than that of the air temperature at a height of 120 cm. Thus, dry rocky soil would have higher minimum soil temperatures.

Fig. 2. Temperature profiles showing average maxima and minima for swampy, sandy and rocky soil.



Dry sandy soil heats up to an extraordinary degree at the surface level, but the temperature decreases very rapidly both upward and downward. It has much lower heat conductivity on account of the air spaces between the sand grains and thus heat does not penetrate as deeply as into granite rock.

In the damp bog the maximum temperature is above the surface at about 5 cm., as the surface is cooled by evaporation and absorption of heat by the vegetation. The temperature drops so rapidly just below the surface that the daily range at 5 cm. depth is as insignificant as at a depth of 45 cm. in rock. At 25 cm. below the surface the range has disappeared entirely. During the night the bog shows the lowest temperature of any, with the minimum also occurring at about 5 cm. above the surface. The extreme daily variation of temperature and the low thermal conductivity are properties of the bog despite its high water content. In Table 1 the thermal conductivity and diffusivity for various substances of meteorological interest are listed and it can be seen that peaty soil is very near the bottom of the list for thermal conductivity. A soil analysis conducted at the University of Ohio (Petro 1961) shows that most of Ogotoruk Valley is overlain by at least a foot of peat. Thus, the similarity of the soil temperatures in the Ogotoruk Valley with Homen's marsh temperatures is not surprising.

Table 1. Thermal conductivity and diffusivity of various materials of meteorological interest.
Adapted from Geiger (1957).

	$\lambda \times 10^{-5}$	$a \times 10^{-4}$
Rock	1100	210
Ice	550	120
Wet sandy soil	400	100
Wet marshy soil	200	30
Motionless water	150	15
Dry sandy soil	40	13
Snow	20	67
Peaty soil	15	15
Air	5	1610

$$a = \frac{\lambda}{\rho c}$$

λ = thermal conductivity
a = thermal diffusivity
ρ = density
c = specific heat

Fig. 4 shows the mean monthly maximum and minimum figures of all stations in Ogotoruk Valley plotted in a manner similar to Fig. 2. As no surface measurements were made, the lines were drawn straight from 5 cm. above to 5 cm. below the surface. Homen's profiles showed little deviation from a straight line for the swamp readings. It is possible that in rocky or any dry sandy areas in Ogotoruk Valley the maximum temperature readings would be higher than the 5-cm. reading above the surface.

Certain facts about the mean profiles in Fig. 4 stand out. In April and May the maximum temperatures were at 50 cm., and in June, July, and August the maxima were at 5 cm. above the surface. In April the minimum was at shelter (120 cm.) level and in May, June, July, and August the minima were at 50 cm. below the surface, with a secondary minimum at 5 cm. above the surface. The greatest amount of increase in both the soil and surface temperatures occurred between the April and May mean figures and this rate of increase decreased as the summer progressed. This great increase resulted from melt water percolating into the soil. The temperature range was greatest in April and became smaller during the summer, especially at 10 cm. and lower. This was because ice has better thermal conductivity than water and the ground thawed more with the advancing season.

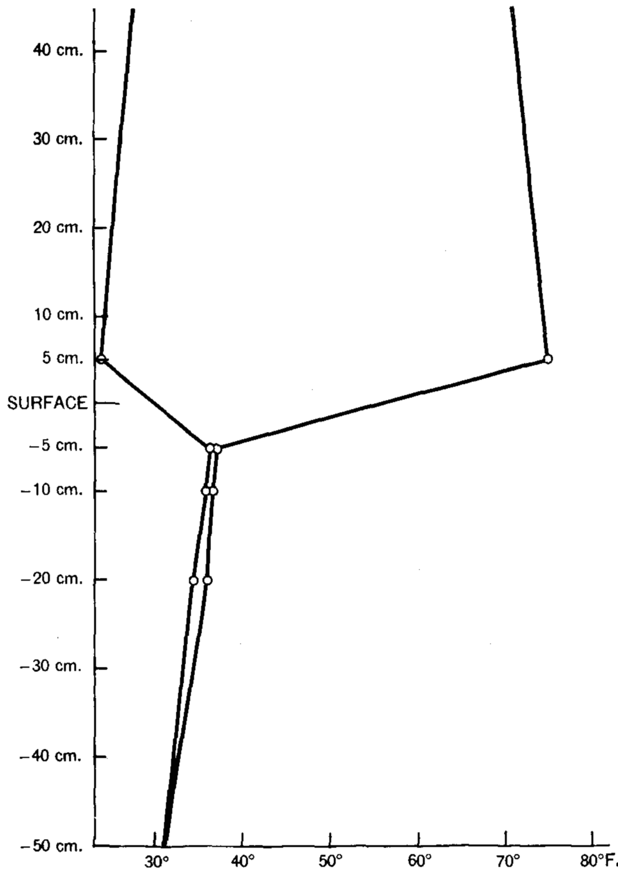


Fig. 3. Maximum and minimum temperatures from station 7, August 20, 1960.

The time lag in heat penetration to greater depths is evident even in the monthly figures from May to August, but in April the profile is almost vertical. In the winter months, over bare ground, the profile would tilt to the left, indicative of lower temperatures nearer the surface. This time lag is evident even in the daily readings when a large temperature increase appears for several days, and it has been noticed that it takes from 18 to 36 hours for the increase to penetrate down to 50 cm. in the soil. This time lag cannot be measured precisely from daily readings and for the purposes of this study the maximum amount of heat conduction of the soil was investigated more fully than the daily time rate of conduction.

Thermal diffusivities were computed from these monthly all-station average figures for all stations and gave fairly consistent results only for the layer of soil between 5 and 10 cm. The standard formula using the amplitude decrement with depth gave figures of 0.0029, 0.0014, 0.0013, 0.0023, and 0.0019 for the months of April to August 1961. For comparison, Geiger (1957) gives a figure of 0.0018 for peaty soil. The results became too inconsistent and meaningless at greater depths because the temperature ranges were too small

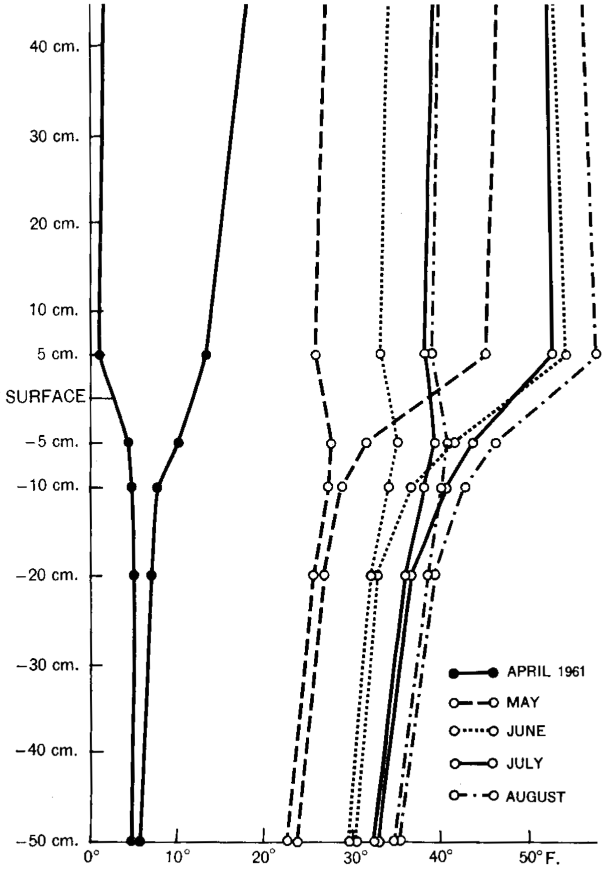
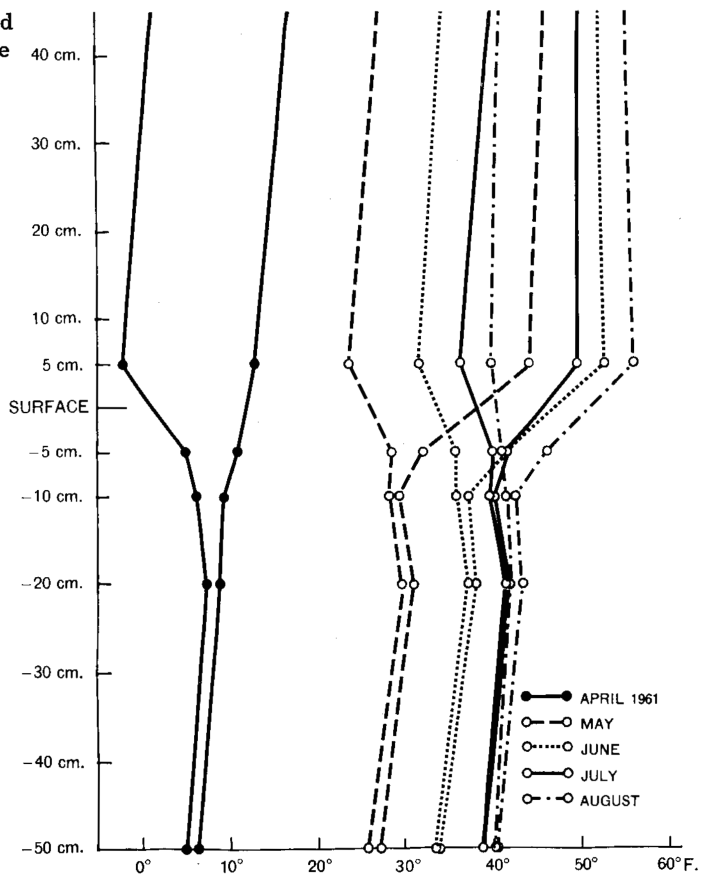


Fig. 4. Maximum and minimum averages of 13 stations in Ogotoruk Valley.

in relation to the one-degree accuracy to which the thermometers were read. Non-uniformity of the soil could be another reason for these inconsistent readings. Different degrees of compaction in the peat layer, and the change-over into the clayish soil could cause this. Some of the individual temperature profiles showed higher temperatures at 20 cm. depth than at 10 cm. and this was undoubtedly a result of these factors. Table 1 gives values of thermal diffusivities for several materials of interest here and also the relation between thermal conductivity and diffusivity. Several writers have cautioned against the computation of thermal diffusivities of natural soils because of their limited use in explaining the heat balance. For these reasons a more rigorous treatment was not attempted.

Thus, the characteristics of summer soil temperatures in Ogotoruk Valley have been examined in general and deviations from the average monthly profiles in Fig. 4 should show little variation from year to year. It is conceivable that a late thaw could make the mean figures for May resemble those for April a little more, and a dry, warm August could move the maximum soil temperature lines a little more to the right, especially near the surface. However, it is questionable whether Ogotoruk Valley ever dries out to such an extent as inland, better-drained areas, such as Umiat, described by Conover (1960) as follows: "when the cool easterlies weaken or cease, temperatures rise rapidly, sometimes exceeding 80°F. at shelter level . . . then tundra surface temperatures may reach 105°F." The highest near-surface temperature recorded during 1960 and 1961 was 86°F. at 5 cm. in August 1960 at station 5 after a 5-day dry spell.

Fig. 5. Maximum and minimum temperature profiles at station 1.



Similarities between the temperature profiles depended in general on the geographical location of the stations. Two stations, 1 and 10, were in the Dryas Fell-field hilltop areas that border the valley and for the most part appeared to be in soil composed of small pieces of greyish rock interspersed with small amounts of moss. The temperature profiles of these stations showed marked similarities during the summer of 1961. In April and May there was a smaller range of temperature at 5 cm. above the surface at station 10 due to the heavy accumulation of snow over the thermometers. More rock existed in the soil at station 10 as the temperature range after May did not become negligible until down to 20 cm. below the surface, whereas it became negligible at 10 cm. at station 1, which is shown in Fig. 5. Comparable readings from August 1960 showed larger temperature ranges at 5 cm. above the surface, indicative of drier conditions. These larger ranges also demonstrated the insulating properties of the mosses and lichens and also indicated considerable peat and decayed matter in the soil, in spite of the rockier surface cover at these two stations.

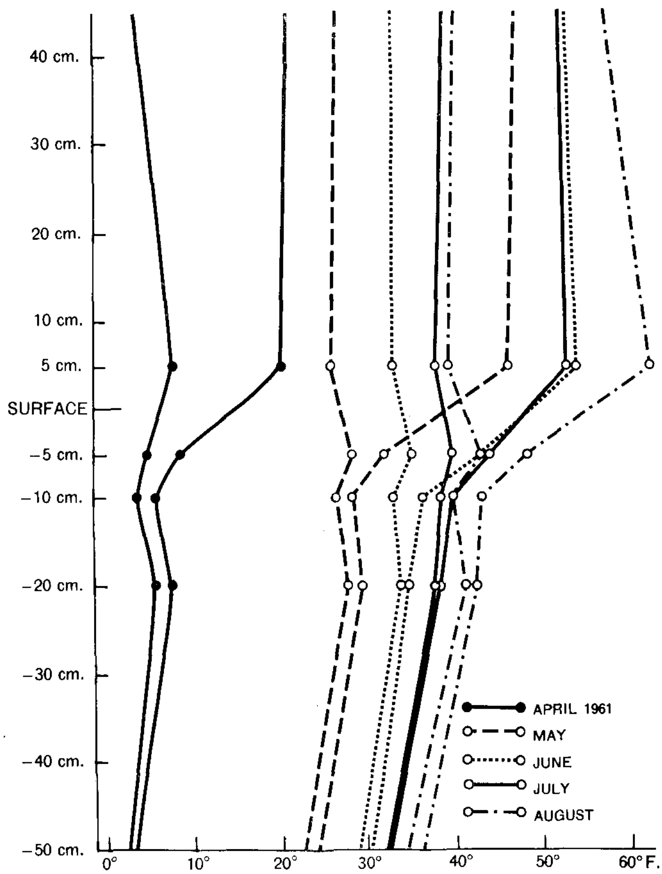
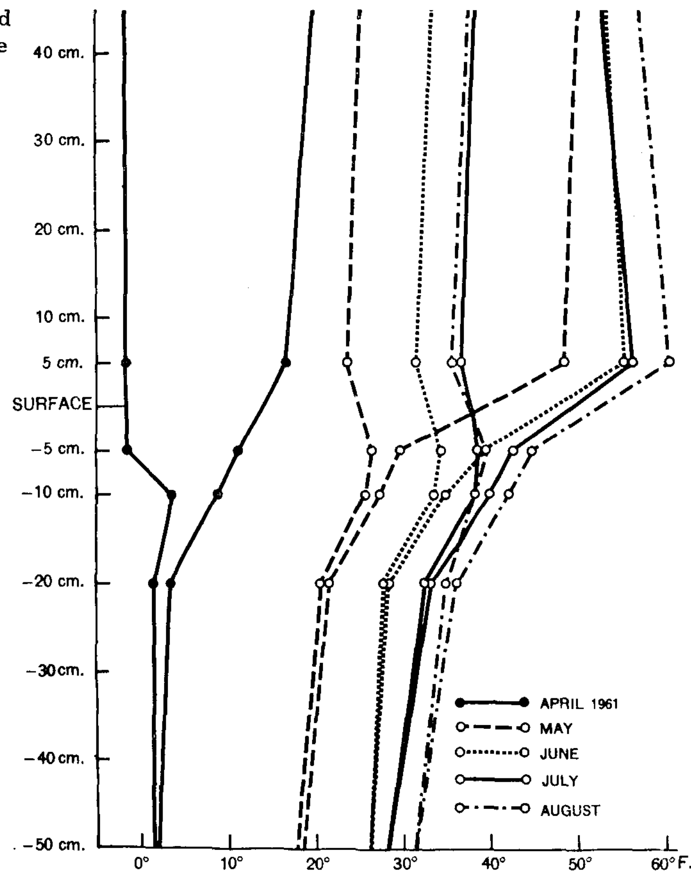


Fig. 6. Maximum and minimum temperature profiles at station 4.

The effect of altitude in the valley was noticed in the near-surface temperatures of these stations, and also those of stations 5 and 6, all four of which were between 300 and 400 feet above sea-level and near the top of the hills that overlook the valley. The temperatures at 50 and 5 cm. were generally within 1°F. of each other, and there was slightly less range between their maximum and minimum temperatures: their maxima were a little lower and their minima a little higher than the average of all stations. This agrees with Geiger's contention that "the greatest temperature extremes are found in the lower parts of a valley".

Fig. 7. Maximum and minimum temperature profiles at station 9.



Nine stations, including the two mentioned above, 5 and 6, were in the sedge and tussock areas of the valley, which begins about one-third of the way down from the crests of the hills, where the angle of slope decreases enough for the grassy vegetation to obtain a hold. The grassy area extends to the creek terraces and the sedge and tussocks presented a dull greenish-tan colour during the summer of 1961. The soil in this area is a mixture of peat and clay, with a varying amount of small rocks. Fig. 6 shows the temperature profile from station 4 and is a good example of four similar stations, 2, 4, 6, and 15, all of which had their thermometers in "mud" areas between large tussocks of *Eriophorum*. This "mud" had a sponge-like feel underfoot between the tussocks and this possibly was an indication of light compaction in this type of soil. The range of maximum and minimum temperatures of

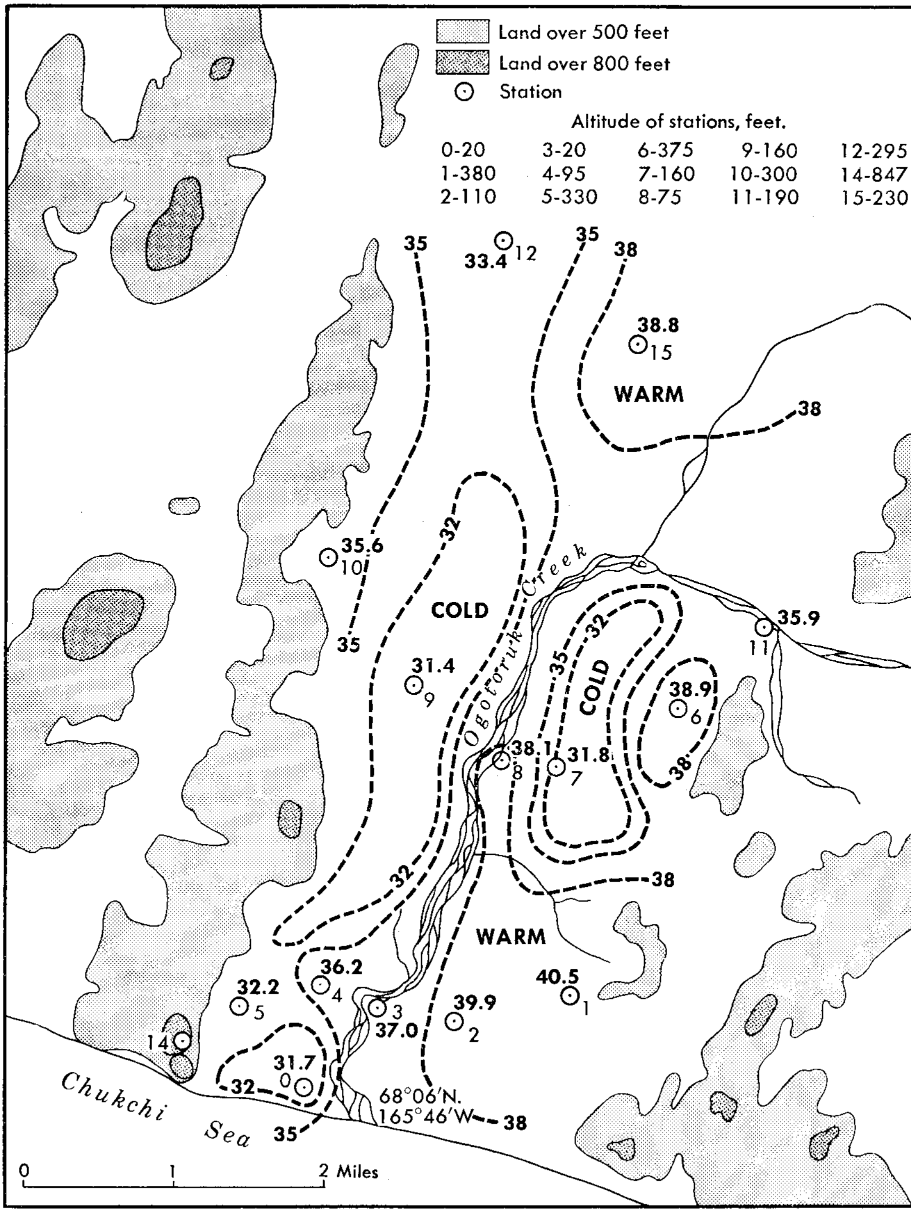
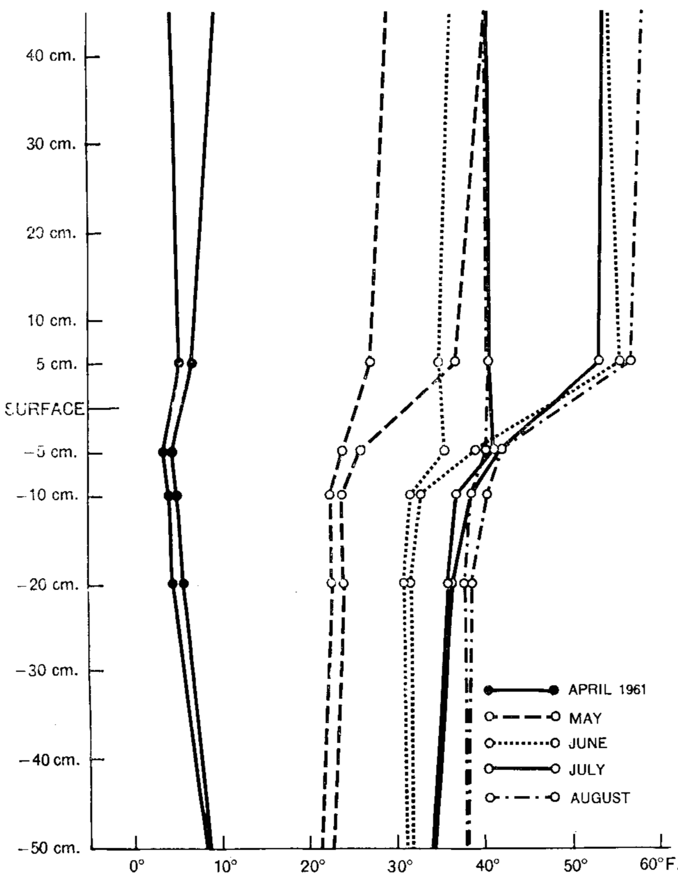


Fig. 8. Mean maximum soil temperatures at 50 cm. for August 1961.

over 1°F. below 20-cm. depth and the above average temperature at the 50-cm. depth were a more definite indication of this light compaction between the tussocks.

The other five stations in the grassy areas of the valley, stations 0, 5, 7, 9, and 12, had sedge as the dominant type of vegetation, and were all in, or as station 12, near the "wet meadow" (*Eriophorum-Carex* wet meadow) area (as shown on the map "Key to vegetation types" by Univ. of Alaska 1960). Fig. 7, which shows the temperature profiles for the summer of 1961 at station 9, is a representative sample from these stations. The striking feature of these five stations was that their mean soil temperatures at 50 cm. still hovered near the freezing point during August of both 1960 and 1961. Fig. 8 is a map of the valley with an isotherm analysis showing the mean soil temperatures at 50 cm. for August 1961 more clearly. Whether these cold areas are an indication of shallow root structure or a thicker peat layer or both has not been determined, but these areas seem to have a heavier insulating layer. Stations 12 and 9 had fairly large temperature ranges at the 5 cm. soil level, whereas 7 had a negligible range at this level. Otherwise the differences were very minor and probably due to variations in incoming solar radiation, or coastal or altitude effects.

Fig. 9. Maximum and minimum temperature profiles at station 8.



Three stations, 3, 8, and 11, were located on the creek terraces, which vary in width from 20 feet near station 11 to 200 feet near the mouth of the creek and are located along either side of, and about 3 feet above the creek bed. The vegetation in this area was mostly mosses and scrub willows 1 to 4

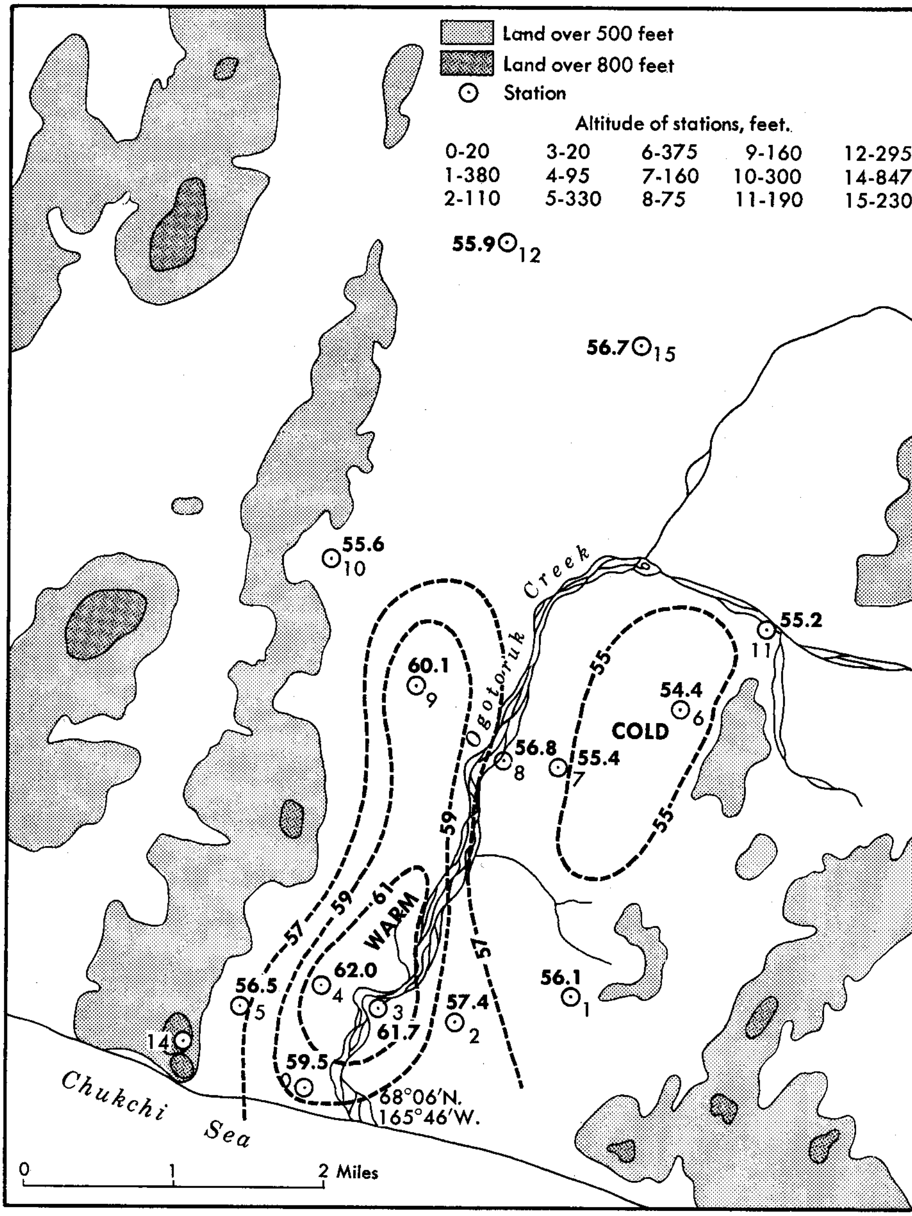


Fig. 10. Mean maximum air temperatures at 5 cm. for August 1961.

feet high. Fig. 9 shows the temperature profile of station 8. Differences between these stations and the other stations were not as pronounced as would be expected and were undoubtedly due to the equalizing effect of the peat layer. However, below this layer there was more sand and rock, as the mean soil temperatures at 50 cm. were all above 35°F. in August, and this indicated greater heat conduction from the upper layers. In addition, more rock and sand was indicated in the upper layers at station 3, as its soil temperature range did not become negligible until down to 20 cm. Its near-surface air temperatures were also 5°F. above the average. This was partly due to its proximity to the black rock of the creek bed and also to the greater amount of radiation received from being in the bottom of the valley and away from the immediate effects of the ocean.

No stations were located in the black rock of the creek bed itself as it was under water in early spring and under deep snow during most of the winter. This black rock varied in size from sand to cobbles 6 inches across. It is mentioned because this exposed black rock can absorb great amounts of heat, which results in greater warming of the air along the sides of the creek. Up-valley, near station 11, it was only about 30 feet across and widened to about 125 feet near the ocean. Several small tributaries feed the main creek and some, although only 10 to 20 feet wide, have steep banks. After the spring flood most of the creek bed is exposed, with the water confined to narrow channels on either side of the bed and only about 20 feet wide at the most.

It is instructive to review some concepts about the temperature distribution in a valley and to see how the readings taken in Ogotoruk Valley agree. Geiger (1957) pointed out that the extreme temperatures are found in the bottom of a valley and more moderate temperatures on hills or mountain tops. Isotherm analysis of the mean maximum temperatures have shown that the warmer spots are in the centre of the valley and, by the middle and end of summer nearer the relatively warm ocean. The mean minimum temperatures have also tended to be in the centre of the valley, but in late summer are displaced farther up-valley away from the warming effects of the ocean. Fig. 10 shows that at 5 cm. above the surface at station 6 and 7 an area appeared that was colder than can be accounted for merely by altitude. As the pyrheliograph recorded smaller amounts of radiation at station 7, it is possible that fog persists longer in this large "wet-meadow" area or that more stratus drifts over these stations from the nearby hills. The radiation that penetrated through to the surface turned station 6 into a "warm" spot at a depth of 50 cm. as shown in Fig. 8 because, as mentioned before, there was more rock in the soil near the top of the hills than in the meadow land. However, the peat or decayed matter that forms most of the soil in Ogotoruk Valley was seen to be an excellent insulator in maintaining the permafrost at a relatively shallow depth throughout the summer, and excessive radiation, either at the surface or in the soil, will hardly ever be encountered in Ogotoruk Valley.

Summary

Two years of study have shown that Ogotoruk Valley has unique topographic features that cause marked variations in its climate in comparison with Kotzebue and Cape Lisburne. It is the mouth of a low topographic channel extending to the northeast and is part of the channel around the

western end of the Brooks Range, through which strong northerly winds predominate most of the year. This strong stable flow of air depresses precipitation totals in the colder months and the frequent northerly gale-force winds prevent heavy accumulation of snow in the valley, besides slightly lowering the mean temperatures. Thus, normal precipitation totals are lower in Ogotoruk Valley than at Cape Lisburne, but still a little higher than at Kotzebue. The mean maximum temperatures run about 2.5°F. below those of Kotzebue and the mean minimum temperatures are about 3°F. lower. Because of the nearness of the ocean the extreme minimum temperature at shelter height should not be lower than — 52°F. and the extreme maximum should not exceed 80°F.

A study of the microclimate in the valley up to 7 miles inland has shown that marked summer differences exist. Precipitation is heavier along the tops of the hills away from the ocean. Air temperatures, and to a less extent, soil temperatures, are depressed more in May and June closer to the cool ocean, whereas in late summer near the relatively warm ocean the minimum temperatures are slightly higher than inland.

The temperature extremes occur in the lower parts of the valley, aside from the effects of the ocean. The temperature ranges are less near the rocky hill tops. The peat layer, which covers most of the valley and even parts of the hill tops and is sometimes over a foot thick, is an excellent insulator and has maintained the permafrost at shallow levels. The permafrost persists close to a depth of 50 cm. even in August in "wet-meadow" areas where sedge is the dominant vegetation. Near the creek bed and the tops of the hills, because of more rock in the soil, and in tussock areas, because of slighter compaction between the tussocks, the active layer is thicker.

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