

MEASUREMENTS OF PERMAFROST TEMPERATURES TO EVALUATE THE  
CONSEQUENCES OF RECENT CLIMATE WARMING

T. E. Osterkamp

J. P. Gosink

K. Kawasaki

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Geophysical Institute  
University of Alaska  
Fairbanks, Alaska 99775-0800

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## IMPLEMENTATION STATEMENT

This study has indicated significant regional differences in permafrost temperature profiles versus depth within Alaska. Some regions, such as the north-central portion of Interior Alaska, appeared to have stable permafrost temperature profiles, based on the limited data and coverage possible under this study. Data from the Copper Basin, Tanana Valley, and lower Yukon-Kuskokwim show a significant recent warming trend. This warming is perhaps related to the global warming-greenhouse effect predictions forecasted as a result of increasing atmospheric carbon-dioxide and methane.

The design engineer is encouraged to allow for the consequences of permafrost warming in calculations of foundation stability. These considerations will be especially critical for pile foundations, where freeze-back rates and long-term strengths are directly temperature dependent. The data from this study show that future permafrost temperatures must be taken into account and that some amount of warming above the present subsurface temperatures is extremely likely during the lifetime of a structure. The extent, rate, and regional distribution of permafrost warming trends are areas requiring further study. For estimation purposes, permafrost warming of 1° C during the next 10 to 30 years may provide a reasonable starting point for calculation purposes for Interior Alaska. Increased emphasis should be placed on pre-thawing of permafrost at construction sites, to eliminate future problems. An alternative is to increase the use of positive ground heat removal systems such as thermo-syphons.

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ABSTRACT

Fragmentary evidence indicates that permafrost in Alaska has been undergoing a recent warming, since about the mid-1800's, and that the climate has also been warming during this period. The magnitude and regional distribution of these warming events are poorly known. Twenty one holes have been drilled in permafrost for the purpose of developing a long-term program to determine the thermal regime of permafrost in Alaska and its relationship to climate. A tentative model of the thermal regime of the permafrost along the oil pipeline, based on the results of this long-term program and on other available information, was developed. While the data are sparse, the results indicate that the permafrost in the coastal areas of the North Slope has undergone a warming of about 1.5 to 3 °C during the last century but has cooled slightly, a few tenths degrees, since 1983. Data from the Arctic National Wildlife Refuge are consistent with these results. In the area from the Yukon River north through the Brooks Range, the permafrost warming has been small or non-existent. The permafrost in areas south of the Yukon River to the Copper River basin near Glennallen has undergone a warming which has persisted to this day but it has not been possible to obtain accurate estimates of the duration and magnitude of this warming. However, the permafrost in this area is generally within

a few degrees of thawing, and some of this permafrost is presently thawing!

We recommend undertaking rigorous statistical analyses of available climatological data (air temperature, snowfall, precipitation, freezing and thawing degree days) in Alaska to determine past trends, establishing a systematic program to define and monitor the thermal regime of the permafrost in Alaska, and creating new and innovative construction methodologies for projects on very warm permafrost that may begin to thaw. Pre-thawing methods are recommended rather than specialized construction techniques.

If these recommendations are not implemented and the current warming trend continues, then the State of Alaska will be faced with costly ad hoc solutions to engineering design failures in warm or thawing permafrost.

#### INTRODUCTION

Fragmentary evidence from measurements of permafrost temperatures in Alaska's Arctic region have shown that the permafrost has warmed about 1.5 to 3 °C during the last century (Lachenbruch et al., 1982; Lachenbruch and Marshall, 1986; Osterkamp, 1983). This warming must be associated with changes in climate but the precise nature of these changes has not been documented. Existing data on the thermal regime of permafrost are too sporadic spatially and temporally or are not suitable for a detailed evaluation of the effects of this climate change on the permafrost. In addition, the regional distribution of the permafrost warming cannot be evaluated due to a lack of suitable

drill holes.

Potential engineering problems associated with this warming of the permafrost include: higher permafrost creep rates under load, reduced adfreeze forces on pilings, increased frost heave forces on pilings, increased thawing under roads and structures with increased thaw settlement, slope instability, increased erosion and sedimentation, the need for increased gravel thicknesses on roads and pads, difficulties with freeze-back of pilings and others (Osterkamp, 1983).

The objective of this research was to begin a program to determine, through temperature measurements in drill holes, the thermal regime of permafrost in Alaska and, insofar as possible, its relationship to climate. Ten drill holes were sited on north-south and east-west transects of the state with an additional hole at Bethel and ten additional holes in the Arctic National Wildlife Refuge (ANWR). This report summarizes the results of temperature and other measurements performed at these sites and makes specific recommendations to alleviate the potential engineering problems associated with warming and thawing of the permafrost.

#### EXPERIMENTAL METHODS

The size of Alaska, logistical requirements, etc. and associated drilling costs preclude any large-scale systematic study of the thermal regime of permafrost in Alaska. Therefore it was decided to concentrate our investigations on north-south and east-west transects of the state. In addition, we tried to take advantage of any other drilling programs, such as the exploration

of ANWR for petroleum resources, to obtain more drill holes. The holes were sited in flat terrain with no apparent thermal disturbances within several hundred meters. In most holes, drilling was done using a rotary drill with compressed air although a few holes required water and drilling mud. Galvanized water pipe (3/4" in diameter) was used to case the holes except for the ANWR holes which are described below. The holes were backfilled around the pipe with drill cuttings from the holes. Drilling was done when a snow cover was present to minimize damage to the terrain. The sites were cleaned and seeded with grass in the summer following drilling to minimize the surface disturbance. Temperatures were measured according to the methods described by Osterkamp (1984). Methods for analyses of the temperature profiles are described by Lachenbruch and Marshall (1986). A map of the hole locations is shown in Figure 1 and additional information about the holes is provided in Table 1.

## RESULTS

### Arctic National Wildlife Refuge

During the last part of March, 1985, ten holes, 30 m in depth, were drilled along a line extending southward about 45 km from the area of the Chevron exploration well near Tapkaurak Point on the Beaufort Sea coast to the Aichilik River as shown in Figure 1. Small diameter flexible plastic tubing (0.5" OD X 0.25" ID X 100' in length) was placed in the holes which were then backfilled with drill cuttings. The cuttings indicated that the soils were fine-grained, primarily silt with some sand or gravel. The holes were logged for temperature in late May, 1985. Past

Table 1. Site names, locations and hole depths for the holes drilled as part of this study.

<u>Site Name</u>	<u>Location</u>	<u>Hole Depth</u>
ANWR (10 holes)	along a line from 69:40:43.8N, 142:50:22.6W to 70:00:49.7N, 143:05:16.0W	all 10 holes, 30 m
Barter Is.	24,9N,34E, ≈300 m SE of large lake	80 m
Galbraith	≈400 m W of tower	75 m
Chandalar	≈300 m E of S end of airstrip	60 m
Yukon River	≈400 m NE of N end of bridge	62 m
Birch Lake	≈1 km E of DOT camp, N of the fire trail	62 m
Donnelly	≈600 m SE of intersection of highway and access road	65 m
Hogan's Hill	≈300 m E of highway and 800 m S of Alyeska turnout	64 m
Eagle	≈800 m W of W end of runway	62 m
Healy	≈800 m SE of parking pad at Eight Mile Lake	30 m
Nome	≈400 m NE of bridge over Otter Creek	62 m

experience indicates that these holes should have been within 0.1 °C of their equilibrium temperatures at the time of logging. However, it has not been possible to return to the sites to obtain a second set of observations. Nevertheless, some conclusions can be inferred from the measured temperature profiles.

Permafrost temperatures measured in these ten shallow drillholes in ANWR range from -9.5 °C to -7.3 °C below the depth of annual variations, about 10 to 16 m, as shown in Figure 2. These data show that the permafrost temperatures generally increase with distance from the coast except for two sites on north-facing slopes. The variation with distance from the coast in short-term mean surface temperatures is nearly linear, about 1.9 °C per 50 km. Thermal gradients below the 18 m depth were small, ranging from +0.016 °C per meter to -0.003 °C per meter which indicate a recent surface warming at all sites. Such a warming can be seen in the meteorological data for Barter Island for the period from 1977 through 1983. These results are consistent with the permafrost temperature data available to the west of ANWR (Osterkamp et al., 1985; Lachenbruch and Marshall, 1986).

#### Barter Island

An 80 m hole was drilled on Barter Island during the last part of April, 1985 and logged for temperature in June, 1985. The temperatures in the upper 30 m of the hole are consistent with those from ANWR as discussed above. Below the 30 m depth, the temperature profiles indicate a long-term warming of the

permafrost temperatures; however, the hole is not deep enough for the extent and magnitude of this warming to be determined.

#### Galbraith

A 75 m hole was drilled to the west of the Galbraith airstrip during May, 1985 and has been logged for temperature three times. There is a curvature of the temperature profile in the top 40 m (Figure 3) that may be indicative of a recent permafrost warming; however, this could have been caused by the use of water and mud during drilling of the hole. It will be necessary to obtain additional loggings to sort out this problem.

#### Chandalar

During May, 1985, a 60 m hole was drilled to the east of the Chandalar Shelf airstrip. The temperature profile from this hole does not show any evidence of a climate warming.

#### Yukon River

A 62 m hole was drilled in the flood plain of the Yukon River to the east of the Haul Road bridge during May, 1985. There is no evidence of a climate warming in the permafrost temperature profile.

#### Birch Lake

A hole was drilled to the north of Birch Lake to the 62 m depth during May, 1985. There is some evidence for a recent warming; however, additional data are needed to carry out detailed analyses.

#### Donnelly

During April, 1985, a 65 m hole was drilled to the northeast of Donnelly Dome. This was the only hole drilled as part of this

research program that was not in permafrost. The temperature profile suggests that there is both horizontal and vertical movement of groundwater which has a temperature of about +1.5 °C at this site.

#### Hogan's Hill

A 64 m hole was drilled to the south of Hogan's Hill and east of the highway. The temperature profile shown in Figure 4 has a very strong curvature toward warmer temperatures in the upper 60 m which may be associated with a climate warming. The depth of penetration suggests that the warming must be long-term, on the order of 50 to 100 years and that the magnitude of warming at the ground surface is about 1 °C. If permafrost temperatures elsewhere in the Copper River basin are similar to those at Hogan's Hill, then this permafrost will be extremely sensitive to any ground disturbances such as those associated with construction projects.

#### Eagle

A hole was drilled between the village of Eagle and its airport to the 62 m depth during May, 1985. While there were some variations in the temperature profile, the data were not sufficient to determine whether or not they were associated with a climate warming.

#### Healy

During April, 1985, a 30 m hole was drilled about 10 miles to the west of Healy. It was not possible to drill deeper because of caving at that depth. There is a curvature toward warmer temperatures throughout the profile suggesting the possibility of

a climate warming; however, the hole is too shallow to draw a firm conclusion.

#### Nome

A 62 m hole was drilled to the east of Nome during May, 1985. This hole was one of four drilled in the Nome area at this time and was the only hole in which permafrost was found. There are some variations in the temperature profile but the data are not sufficient to determine whether or not these are associated with variations in climate.

#### Miscellaneous

Soil samples were obtained by collecting cuttings during drilling. The moisture content and electrical conductivity of the soil solution from the cuttings were measured in the laboratory. A graduate student is using some of the results of these measurements in his M.S. thesis on mass flow in permafrost which should be available sometime during the spring of 1988.

Seven computer-controlled temperature logging devices have been installed at selected hole sites to measure temperatures at twelve levels at four hour intervals and to record maximum, minimum and mean values once per day. The sensors are placed in the air, at the ground surface, in the instrument box in the ground, with three in the active layer, three spanning the permafrost table, and three in the permafrost. An example of these data (daily maximum, minimum and mean ground surface temperature) is shown in Figure 5. We are currently obtaining data at these sites but do not have funding to continue to do so.

Meteorological data from twenty eight Alaskan weather

stations for the period from 1949 to 1982 were analyzed, bar graphs for air temperature, snowfall, and thawing and freezing degree days were prepared and a report (Hoffman and Osterkamp, 1986) was forwarded to the Alaska Dept. of Transportation and Public Facilities. No attempt was made to carry out a detailed statistical analysis of these data; however, several trends are apparent when comparing data for the period from 1976 to 1982 to the averages for the full 33 year period. The average mean annual air temperature for the 1976 to 1982 period was consistently higher for most stations when compared to the average for the 1949 to 1982 period. Snowfall was less in more than half the stations during this seven year period but higher in at least seven stations when compared to the long-term average. There were a smaller number of freezing degree days and a larger number of thawing degree days for most of the stations during this seven year period compared to the long-term average. For the Fairbanks station, the mean annual air temperature from 1977 to the present time has continued to be warmer than the long-term mean .

These apparent recent trends need to be confirmed by rigorous statistical analyses of all the available data. It is important to carry out such an investigation, not only for scientific interest, but also because engineering design criteria are often based on permafrost temperatures which are sensitive to changes in climate.

#### DISCUSSION

The preliminary analysis and interpretation given above are based on limited temperature data available from shallow drill

holes. When these data are combined with data from other holes that we have developed (Osterkamp et al., 1985), the following general but tentative picture emerges for the north-south transect of the state along the oil pipeline.

The permafrost in the coastal areas of the North Slope has undergone a warming of about 1.5 to 3 °C during the last century but has cooled slightly since 1983. Data from ANWR is consistent with these results. In the area from the Yukon River north through the Brooks Range, the warming of the permafrost has been small or non-existent. The permafrost in areas south of the Yukon River to the Copper River basin has undergone a warming which still continues today but it has not been possible to obtain accurate estimates of the duration and magnitude of this warming. However, the permafrost in this area is generally within a few degrees of thawing, and some of this permafrost is presently thawing!

It must be emphasized that these conclusions are based on sparse data. Continued monitoring of existing holes and additional holes in permafrost are needed to verify them. A follow-on proposal to conduct detailed analyses of the data and to obtain additional data, as noted in the work plan for the original proposal, has not been funded. If additional funding is not obtained, the large investment (\$134,970) in drilling the existing holes will be lost.

#### SUMMARY

Twenty one holes have been drilled in permafrost for the purpose of developing a program to determine the thermal regime

of permafrost in Alaska and, insofar as possible, its relation to climate. The holes were cased so that repeated temperature measurements can be made. A preliminary analysis of the data, when coupled with data obtained from our other holes in the state (Osterkamp et al., 1985), has allowed a tentative model of the thermal regime of the permafrost along the oil pipeline to be developed. The results show that the permafrost in the coastal areas of the North Slope has undergone a warming of about 1.5 to 3 °C during the last century but has cooled slightly, a few tenths of a degree, since 1983. Data from ANWR is consistent with these results. In the area from the Yukon River north through the Brooks Range, the permafrost warming has been small or non-existent. The permafrost in areas south of the Yukon River to the Copper River basin near Glennallen has undergone a warming which still continues today but it has not been possible to obtain accurate estimates of the duration and magnitude of this warming. However, the permafrost in this area is generally within a few degrees of thawing, and some of this permafrost is presently thawing!

#### RECOMMENDATIONS

While the data are sparse, it is clear that most of the permafrost south of the Yukon River, and including the Seward Peninsula, is within 2 °C of thawing. Current climate models predict, by the middle of the next century, a climate warming associated with the "greenhouse gases" of several degrees Celsius or more in polar regions (National Research Council, 1982). Most of Alaska has been experiencing warmer than normal

temperatures for about the last twelve years. Some permafrost in the Fairbanks area is presently thawing. Where permafrost is ice-rich or contains massive ground ice, thaw settlement with its attendant problems may be expected to occur. Additional problems, such as those noted by Osterkamp (1983), may also be expected to plague engineering efforts. Therefore, the following recommendations are made.

1. Conduct rigorous statistical analyses of available climatological data (air temperature, snowfall, precipitation, freezing and thawing degree days) in Alaska to determine past trends.

2. Establish a systematic program to define and monitor the the thermal regime of the permafrost in Alaska.

The current data are sparse, as noted above, and much better coverage of the state is needed, particularly south of the Yukon River and on the Seward Peninsula. Current permafrost temperature data and data on warming trends would allow engineering designs for construction projects to be based on real numbers rather than guesses.

3. Create new and innovative construction methodologies for projects sited on very warm permafrost that may begin to thaw.

The primary concern is for ice-rich permafrost or permafrost that contains massive ice although other problems may have to be addressed (Osterkamp, 1983). The construction methodologies must contain at least two components:

- a. Identification and delineation of permafrost that is ice-rich or contains massive ground ice.

b. The use of special construction techniques or pre-thawing methods for construction on permafrost that is ice-rich or contains massive ground ice. We recommend pre-thawing methods over special construction techniques.

If the above recommendations are implemented, it will be possible to develop rational designs for construction projects on warm permafrost in Alaska. If they are not implemented and the current warming trend continues, then the State of Alaska will be faced with costly ad hoc solutions to engineering design failures in warm or thawing permafrost.

#### ACKNOWLEDGEMENTS

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#### FIGURES

Figure 1. Map of Alaska showing the location of the drill holes.

Figure 2. Measured permafrost temperatures in shallow drill holes in the Arctic National Wildlife Refuge. Depth was measured from the ground surface. Hole A was closest to the coast and hole K was farthest from the coast.

Figure 3. Temperature profile at Galbraith Lake.

Figure 4. Temperature profile at Hogan's Hill.

Figure 5. Daily maximum, minimum and mean ground surface temperatures at Sheep Creek.

# STATE of ALASKA

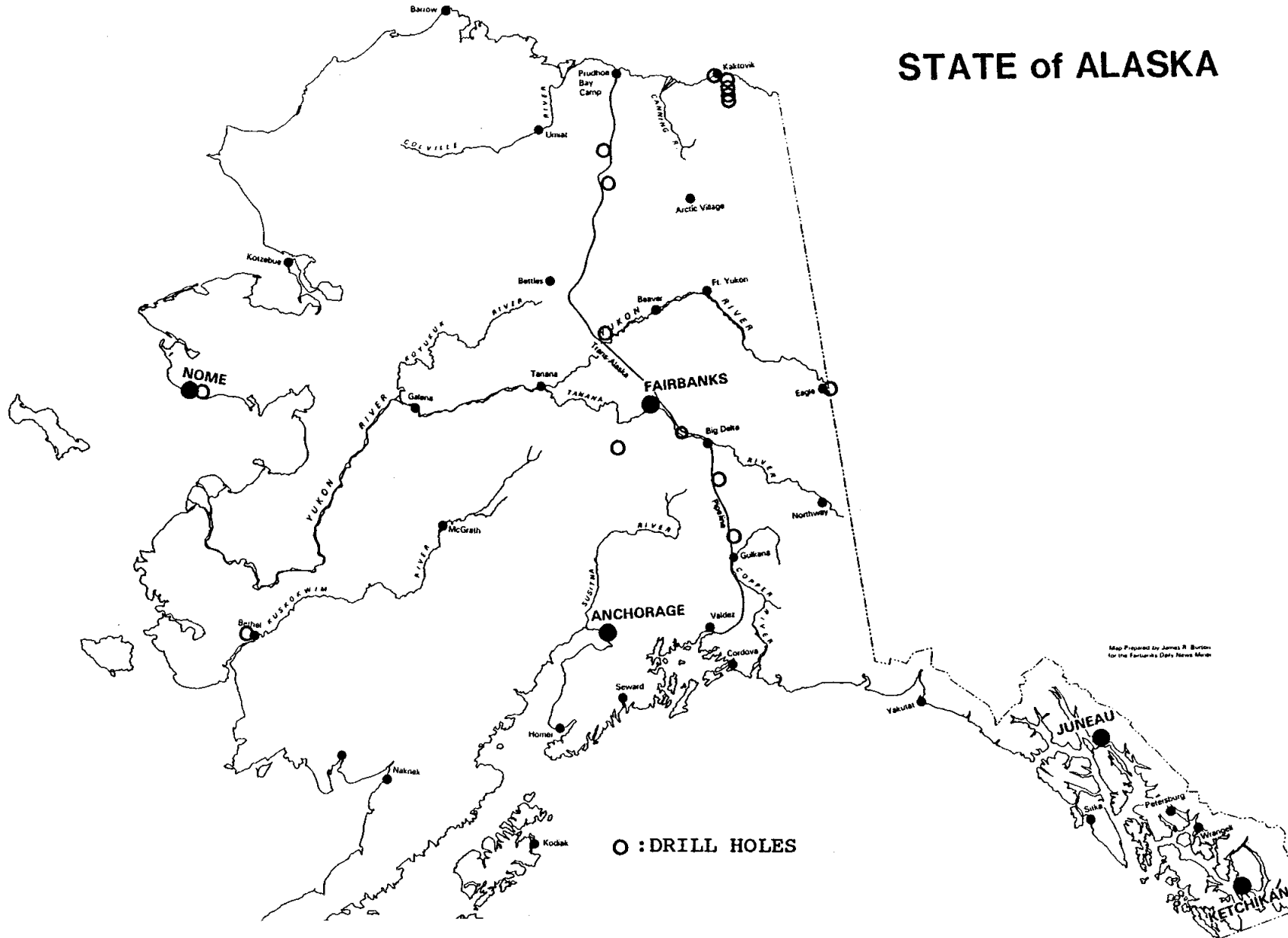


Figure 1. Map of Alaska showing the location of the drill holes.

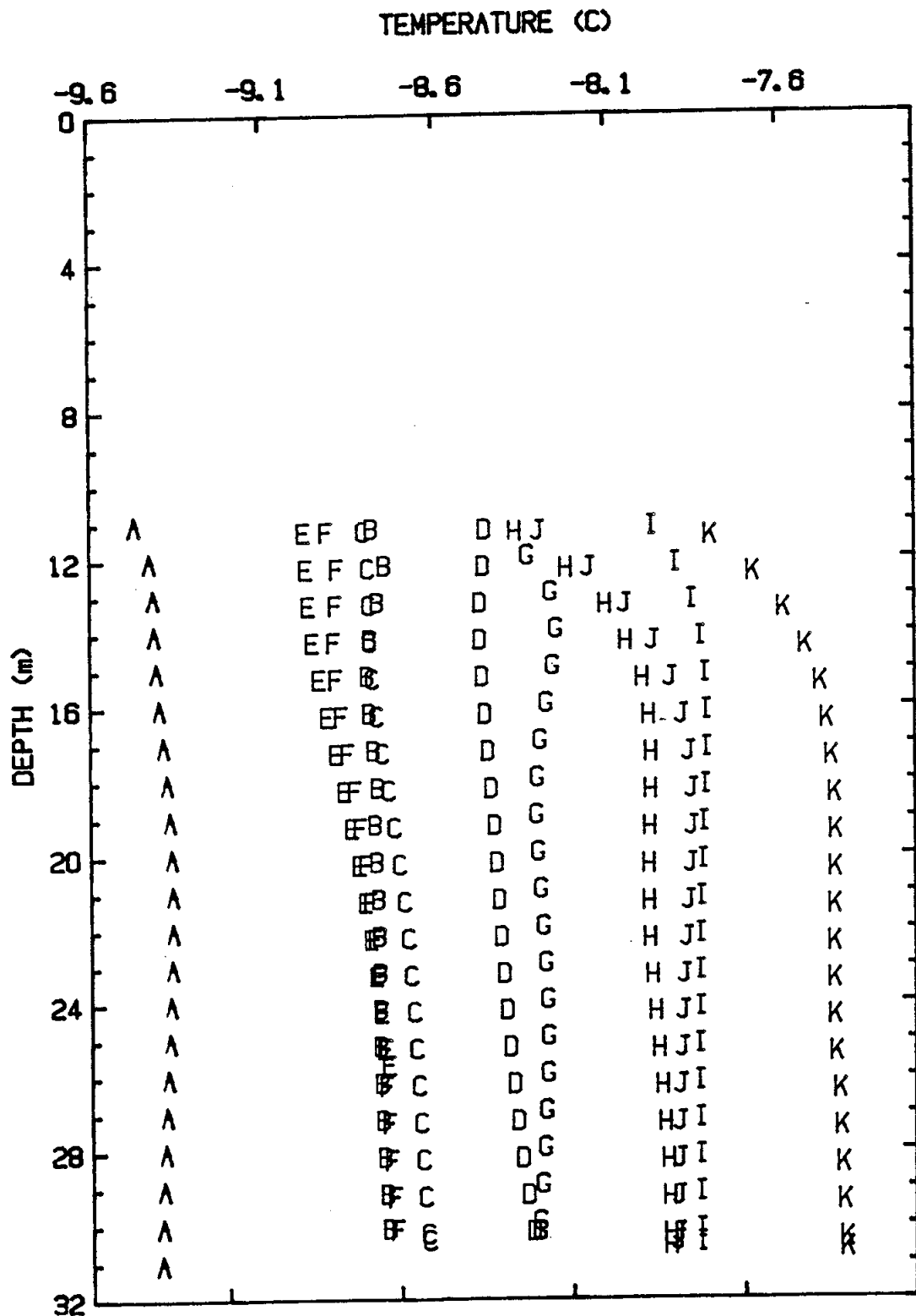


Figure 2. Measured permafrost temperatures in shallow drill holes in the Arctic National Wildlife Refuge. Depth was measured from the ground surface. Hole A was closest to the coast and hole K was farthest from the coast.

GALBRAITH LAKE

GALBRC

870624

TEMPERATURE (C)

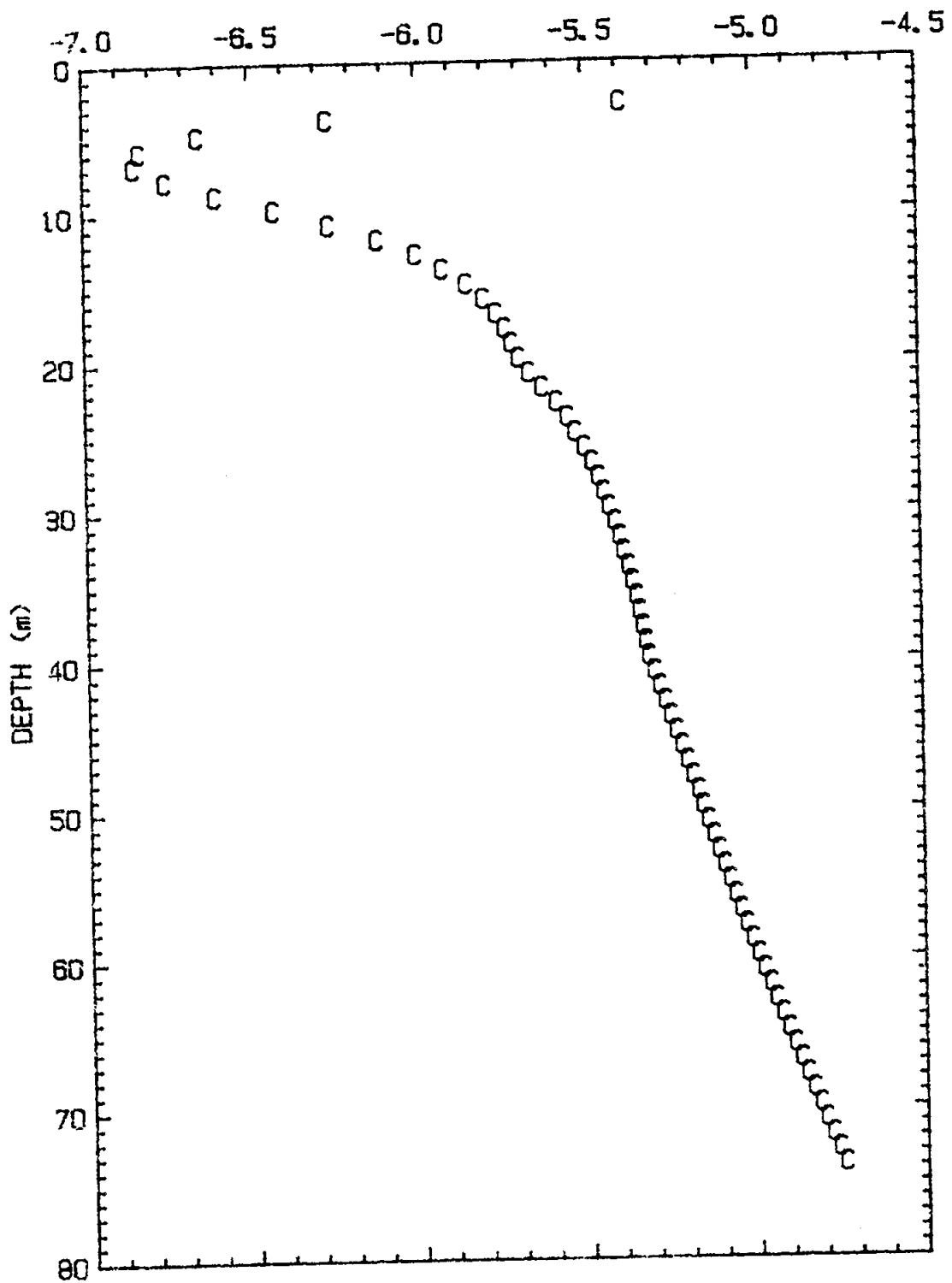


Figure 3. Temperature profile at Galbraith Lake.

SOURDOUGH

HOGAN'S HILL

850813

TEMPERATURE (C)

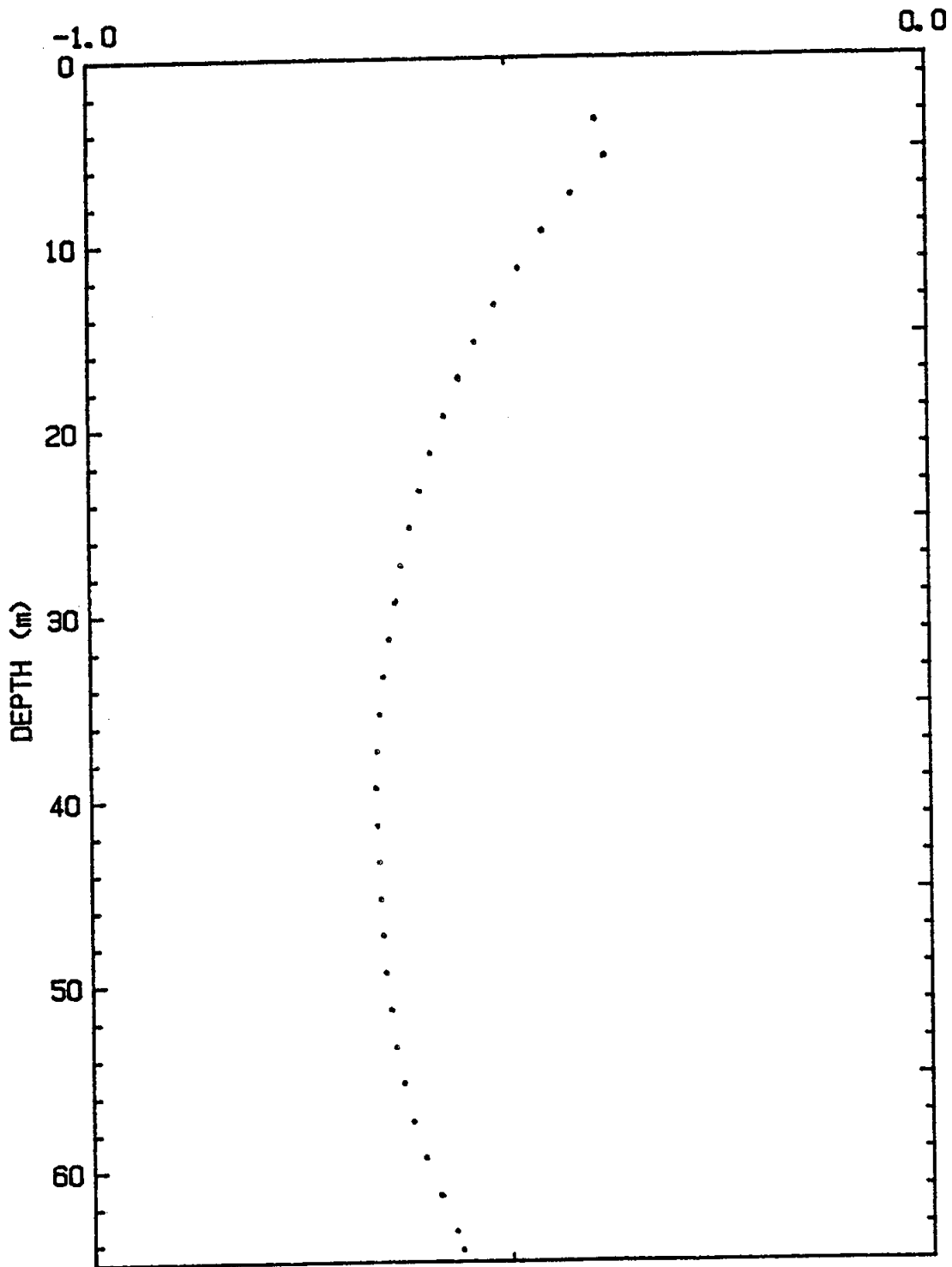


Figure 4. Temperature profile at Hogan's Hill.

# GROUND SURFACE TEMPERATURE FOR SHEEP CREEK

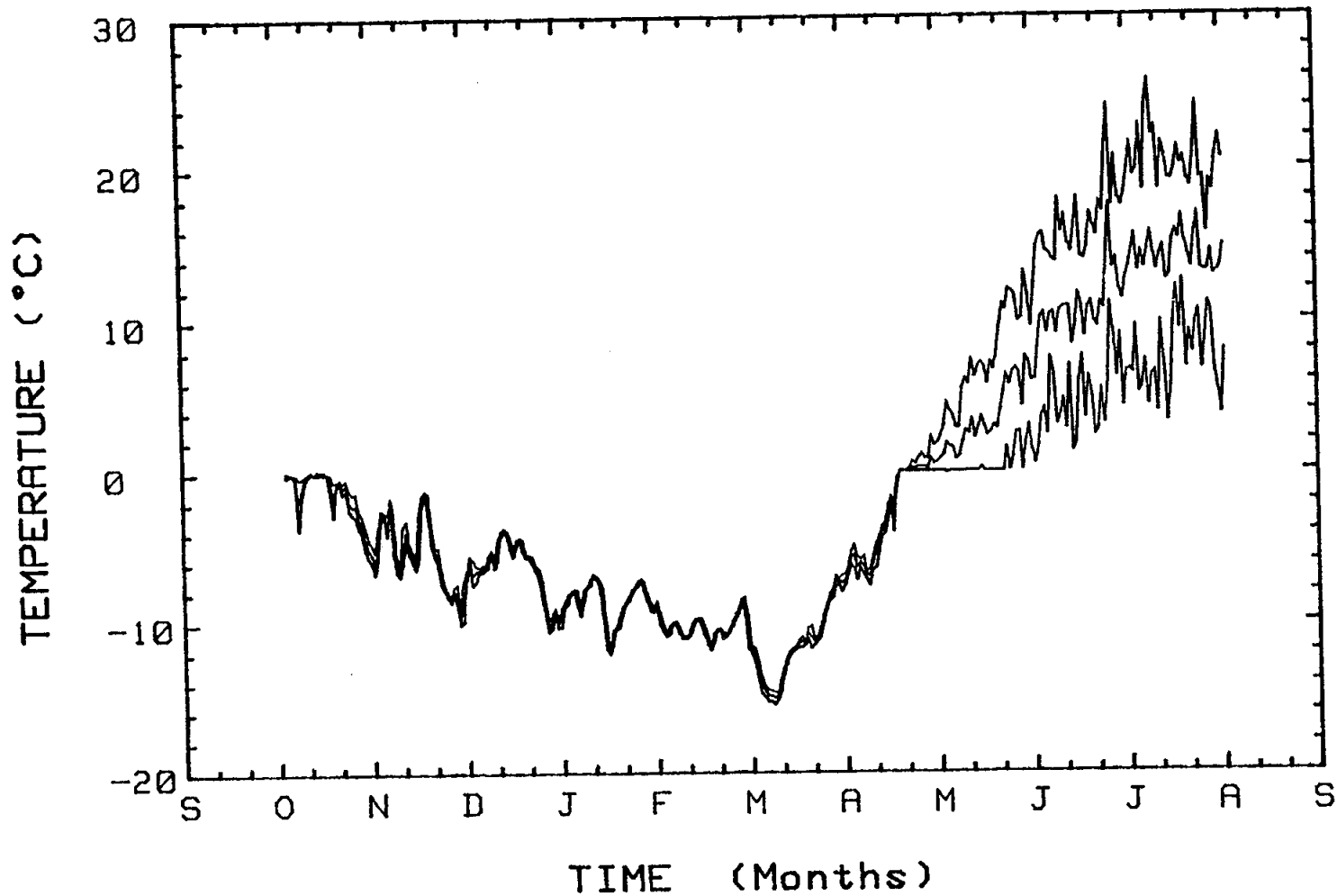


Figure 5. Daily maximum, minimum and mean ground surface temperatures at Sheep Creek.