Shallow Borehole Temperature Profiles in Permafrost Terrains

Dempster and Alaska Highways

1978

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SUMMARY

This report presents the first set of temperature profiles obtained in shallow boreholes along the proposed Alaska Highway and Dempster Highway pipeline routes. The boreholes were drilled in the summer of 1978 to conduct geophysical and geotechnical investigations of the soil and permafrost along the routes. The Dempster boreholes, averaging 2.2 m in depth, are situated between Inuvik and Fort McPherson, N.W.T.; the Alaska Highway boreholes, averaging 6.7 m, are between Champagne and Beaver Creek, Yukon.

Permafrost was present in all of the Dempster boreholes. August temperature logs recorded negative temperatures and negative temperature gradients. These gradients are only seasonal, varying due to the penetration of a 50 K annual air temperature variation into a medium of low thermal diffusivity. Temperature logs of the Alaska Highway boreholes, taken in late November, registered negative temperatures in most holes. Permafrost was encountered at all sites along and north of Kluane Lake; none was found in the holes south of the lake.

Monitoring of selected sites, preferably deepened to exceed the depth of zero annual amplitude, for a minimum of two years, is necessary to establish the detailed shallow ground thermal regime at present. Further temperature logs will enable the determination of the mean annual ground temperatures, the amplitude and depth of penetration of the annual variation of surface temperature, the thickness of the active layer, the temperatures within the permafrost and their proximity to $0^{o}C$.

1. INTRODUCTION

During the summer of 1978 several shallow boreholes were drilled along the proposed Dempster and Alaska Highway pipeline routes to conduct geotechnical and geophysical investigations of the adjacent terrain. The Geological Survey of Canada drilled hydraulically at 14 locations on the Dempster highway between Inuvik and Fort McPherson, a distance of 150 km. The drillholes were preserved for downhole geophysical and temperature logs by installing a black plastic PVC casing and filling it with diesel fuel. Foothills Pipe Line (South Yukon) Ltd. drilled about 100 holes in 1978 as part of their ongoing geotechnical program along the South-Yukon portion of their proposed Alaska Highway pipeline route. Twenty of these boreholes were similarly preserved, with plastic pipe filled with diesel fuel. The Foothills' boreholes lie between Champagne and Beaver Creek, Yukon, a distance of 400 km.

The studied sections of the Dempster and Alaska highways are indicated on the general location map (Fig. 1). The locations of the drill sites are shown in figures 2 and 3. Figure 1 includes the approximate position of the permafrost boundaries in the Yukon area. The Dempster boreholes fall within the continuous permafrost zone; the Alaska highway boreholes within the discontinuous zone. Shallow borehole temperature logs along these corridors should provide a greater understanding of the near-surface thermal regime: thickness of the active layer, amplitude of the annual wave, depth of annual wave penetration, proximity of soil temperature to $0^{\circ}C$, insulating characteristics of vegetation, and reference temperatures for other geophysical observations. The thermal regime is an important parameter in assessing the effects of the proposed pipelines on natural conditions and vice versa, e.g. the effect of frost heave, thaw subsidence and slope instability on the pipeline.

2. PREVIOUS WORK

2.1 Yukon Territory

A comprehensive report on permafrost investigations in the Southern Yukon was compiled by R.J.E. Brown (1967). Prior to the publication of this report permafrost occurrences had been noted and reported in the technical literature by industry and various government agencies - notably the Department of Public Works, the Geological Survey, the Department of National Defence and the Department of Indian and Northern Affairs.

Brown's investigations concerned only the discontinuous zone of the southern Yukon (below 65°N). Observations were made in the fall of 1964 at over 150 sites along the highway network. Information on depth to permafrost, thickness of permafrost, type and thickness of vegetation was gathered. Combining field observations with information on climate, air photos, vegetation and topography, Brown delineated the boundary between the widespread discontinuous zone and the southern fringe of permafrost zone (Fig. 1).

At the southern fringe of the discontinuous permafrost zone shown in Fig. 1, frozen ground is found as scattered thin patches in low lying areas, particularly in peat bogs and beneath north-facing slopes. Patches vary in extent from less than 30 m to several hundred meters wide, and in thickness from 0.5 m to 30 m. Active layer thickness is about 0.6 m. The occurrence of permafrost in this zone seems to be mainly restricted by terrain type. Mean annual air temperatures range from -1° to -4°C,, and ground temperatures are near the freezing point.

North of the -4°C mean annual air temperature isotherm, delineated as the southern boundary of the widespread discontinuous zone, permafrost becomes

increasingly widespread. Its occurrence is no longer restricted by terrain type; it is found in low and high areas, north and south facing slopes. Thicknesses range from more than 30 m in the south at Dawson to more than 150 m at the north end of the Dempster (which only extended 125 km northeast of Dawson in 1964).

The climate of the southern Yukon is continental with large differences between the summer and winter air temperatures. Air temperatures are recorded at half a dozen locations by the Atmospheric Environment Service (AES). Little data on ground temperatures are recorded. The AES station at Haines Junction measures ground temperatures to a depth of 150 cm; the mean annual ground temperature at 20 cm is $2^{\circ}C$ and the amplitude of the annual wave is 20°. Limited additional ground temperature and permafrost data has been collected by the Geothermal Service. Observations at Clinton Creek, north of Beaver Creek reveal 125 m of permafrost with a mean annual ground temperature of $-4^{\circ}C$. None of the temperature observations in the Whitehorse area have detected permafrost and mean ground temperatures have ranged from 0.7 to $3.0^{\circ}C$ although Whitehorse Copper Ltd. have reported permafrost high on north-facing slopes and Klassen (1979) has reported thermokarst features in the Takhini Valley north of Whitehorse. Similarly we have observed no permafrost on the Nisutlin Plateau in the vicinity of Atlin. Mean ground temperatures in four drillholes between 1400 and 1550 m a.s.l. ranged from 0.5 to $3^{\circ}C$. Tallman (1973) however inferred 15 to 20 m of permafrost in a peat bog at 1000 m elevation based on electrical resistivity measurements in the same area. Observations in drillholes to the east at Faro have revealed sporadic permafrost centred largely in areas of thick overburden. As yet too few observations have been made to determine if it is relic in nature. At a

site at 66°N in the Eagle Plains north of the 1964 extent of the Dempster highway a ground temperature of -4.2°C and permafrost thickness of 88 m has been observed (Judge, 1973).

2.2 Mackenzie Delta (Inuvik - Fort McPherson)

The reports on the thermal regime of the Mackenzie Valley (Judge, 1973 and 1975) provide the most extensive information on permafrost and ground temperatures in the Valley. Summaries of much of the previously published material, consisting mainly of townsite investigations by the National Research Council at Aklavik, Inuvik and Fort McPherson (e.g. Pihlainen, 1962; Brown, 1966), research on ground temperatures and permafrost distribution (e.g. Mackay, 1967; Brown et al., 1964) are included in the reports. A selected bibliography is available in Judge (1973). In addition to this previous work, data are presented from observations in over 30 new drill sites, both deep and shallow.

The following summarizes the information on the thermal regime in the Inuvik-Fort McPherson area; the area from which additional data was gathered for this project;

mean annual air temperatures:	from -7.5 to -10°C
mean annual ground temperatures:	from -2 to - 5°C
depth to zero annual amplitude:	average 10 m
permafrost thickness:	from 90 to 150 m
active layer thickness:	from 0.6 to 15 m along the valley

On the basis of the thermal conditions described in his reports, Judge (1975) has divided the Mackenzie Valley and Delta into thermal zones (Fig. 1). South of 67°N not all soils are frozen; permafrost is marginal, and

ranges in thickness from 50-80 m. North of 67° permafrost is continuous, thicker, and mean surface temperatures are in general below -4°C. Permafrost conditions in the recent delta are likened to those south of 67°. These thermal investigations have revealed an increase in surface temperature of several degrees over the last century and pointed out the importance of determining long term climatic effects. In areas of marginal permafrost small changes in ground temperature can have drastic effects on the properties of frozen soils.

3. FIELD METHODS

The Dempster sites were in general within 100 m of the highway and easily reached from the road by a short hike into the bush. Logging took place from August 1-4, 1978. The Alaska highway sites were reached both by helicopter and by truck. These boreholes were situated in a large area cleared of bush, generally several hundred meters from the highway. The long hikes through dense bush and the snow cover of 15 cm presented some difficulties in locating the sites. The southern Yukon boreholes were logged from November 19-26, 1978.

The standard borehole logging equipment and procedure of the Geothermal Service were employed for the logging (Judge, 1973). Temperature sensors were Fenwall glass bead thermistors, having an accuracy of 0.01 K.

4. DATA

The logged depth of the Dempster boreholes, Inuvik to Arctic Red River, averaged 2.2 m (maximum depth 4.3 m). In several areas boreholes were spaced only a few meters apart, e.g., at site 1 between Arctic Red River and Fort

McPherson 6 boreholes averaging 2.4 m in depth logged extend in line from the highway down towards a lake. Listings of the Dempster borehole temperature measurements and plots of the temperature profiles are provided in Appendix A. General information on all sites, such as location and depth drilled, is given in Table 1. Data were obtained at 11 of the 14 sites.

The average depth logged of the Foothills boreholes was 6.7 m (maximum depth 8.8 m). Of the 20 boreholes preserved for geophysical measurements 15 were successfully reached and logged. Appendix B contains temperature listings and plots of the temperature profiles of the Alaska highway sites. Table 2 summarizes several pertinent features of the boreholes, such as location, depth drilled, cased and logged and condition of the drillhole.

5. DISCUSSION

5.1 Temperatures

Negative temperatures were recorded in the Dempster holes - permafrost was present in all. Temperatures were recorded in early August when the active layer had probably not yet reached its maximum development. Active layer thickness at this time ranged from 0.2-1.5m. Temperature gradients in all boreholes were negative; however, this is a seasonal trend since the boreholes do not exceed the depth of penetration of the annual wave. Temperatures recorded at D-78-5 were anomalously high. The plastic casing at this site rose over 1m above the ground and was diesel filled. The heat absorbed during the warm summer days in the above ground section results in a high heat flux into the ground and thus in large negative temperature gradients.

The Foothills boreholes were logged in late November 1978 and although the active layer was frozen at this time, ground temperatures were still decreasing. Permafrost was encountered in most holes. However 78-A-71 and 78-A-72, the latter containing Foothills' temperature cable and last read in October 1978, registered positive temperatures. Boreholes 78-A-75 and 78-B-43 (except for the bottom hole temperature) gave positive temperature readings. These last two holes were dry, i.e. no diesel remained in the casing and readings are suspect. Air filled holes tend to be unstable, easily prone to convection, particularly when uncapped.

5.2 Preservation of Shallow Boreholes

The ideal procedure for monitoring the temperature of shallow boreholes would be:

1. immediately after completion of drilling to run all other geophysical logs.
2. install a multithermistor cable and backfill the hole.

Although this method might require permanent casing, diesel fuel would not be necessary and land use permits are simpler to obtain. Abandonment of the hole consists in removing the surface cable, plug, and wellhead. Several years of data can be obtained from the hole justifying the cost of the cable.

Although short multithermistor cables could have been prepared on short notice funds were not available to purchase them - the Energy R & D Northern

Transportation funds received late in 1978 had not yet been approved. In addition, the Geological Survey had neither the manpower nor the equipment available to run their geophysical logs immediately after drilling. Some uphole seismic logs were run in 1978. It is hoped that the remainder will be done in 1979 if funds and manpower allow.

To ensure multipurpose use of the boreholes, these holes were preserved by installing plastic casing and filling with diesel fuel. The GSC drilled and preserved the Dempster highway holes and provided the casing for the Alaska Highway holes. Foothills offered to preserve several of their Alaska highway boreholes by this method for our use. This is a quick and relatively inexpensive means of preservation, but not foolproof. Care must be taken, when capping and assembling the casing, to ensure that no diesel leakage occurs. Development of a more successful preservation scheme is constrained by budgetary restrictions. The use of diesel fuel is not generally favoured by the Yukon Land Use personnel and should be avoided for shallow thermal installations unless absolutely necessary.

5.3 Future Plans

Shallow borehole temperatures should ideally be monitored at monthly intervals over a minimum period of two years in order to determine the ground thermal regime. Ideally the boreholes should penetrate below the depth of zero annual amplitude. Thus several of the highway boreholes, particularly along the Dempster would have to be deepened to obtain a more complete data set. Manpower and budgetary restrictions prevent revisiting all sites at

frequent intervals for a two year period. A complete thermal profile along these sections of the Dempster and Alaska highways can therefore not be obtained. However a few sites close to settlements, selected on the basis of this initial data can be monitored.

In the summer of 1979, temperature logs will be repeated in several of the deeper holes immediately prior to other geophysical logs. Physical soil properties as determined from geophysical logs can then be related to the temperature. Foothills Pipe Lines Ltd. have made available this Spring 3 holes each 30m deep to be drilled at each of the northern compressor stations on the Alaska Highway right-of-way. Permanent multithermistor cables will be installed at these deeper sites, the holes will be backfilled and temperature will be monitored for several years. These cables will be monitored at fairly regular intervals of several months with the assistance of the Inuvik Research Lab, D.I.N.A., Inuvik for the Dempster holes and of Foothills Pipe Lines Ltd. and D.I.N.A. (Whitehorse) for the Alaska highway holes.

6. ACKNOWLEDGEMENTS

The Inuvik Research Lab, D.I.N.A. provided accommodation and assistance during the Dempster work. Jim Hunter of the GSC lent a four wheel drive truck for this field work. Mr. Cheng and Mr. Jao of the People's Republic of China, visiting scientists with the Geothermal Studies section of the Earth Physics Branch, assisted in the Dempster field work. Ted Harrison, GSC provided many helpful details concerning both highway logging trips.

The Whitehorse resident geologist's office of D.I.N.A. put a four wheel drive truck at our disposal during the Yukon field trip. For this and all their help we thank Mike Marchand and Jim Morin. John Elwood of Foothills Pipe Lines Ltd. provided us with air photos of the borehole sites and maps of the proposed routes. The project was partially funded by the Ministry of Transport through the Permafrost Research Programme - Energy Research and Development.

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BOREHOLE	LAT.	LONG.	TOTAL DEPTH DRILLED (m)	TOTAL DEPTH LOGGED (m)	COMMENTS
D-78-1	68 16.0	133 14.8	2.7	1.5	Ice Plug
D-78-2	68 17.5	133 16.8	5.2	2.4	Hole blocked at 2.4m
D-78-3A	68 08.8	133 26.5	2.4	2.1	
D-78-3B	68 08.8	133 26.5	4.4	4.3	
D-78-4A	68 05.0	133 29.3	2.4	2.2	
D-78-4B	68 05.0	133 29.3	2.7	1.8	
D-78-5	68 00.5	133 27.9	1.5	1.5	1.2m of diesel filled casing above ground level
D-78-6	67 50.6	133 41.8	2.3	2.1	0.8m of casing above ground
D-78-7	67 45.1	133 51.3	2.1	2.1	
D-78-8A	67 38.9	133 50.1	1.8	1.8	1.2m of casing above ground
D-78-8B	67 38.9	133 50.1	2.1	1.8	0.8m of casing above ground
D-78-9	67 33.4	133 47.5	2.3	2.1	
D-78-10	67 28.5	133 46.0	3.1	-	did not find site - 3 holes all 3.1m deep
D-78-11A	68 05.9	133 28.9	3.1	2.7	
D-78-11B	68 05.9	133 28.9	2.7	2.1	
Site 1	67 24.6	134 20.2	2.8	2.1	closest to highway
			2.7	2.4	
			2.1	2.7	
			2.6	2.4	
			1.6	1.8	
			2.7	2.7	furthest from highway
Site 2B	67 25.9	134 50.5	-	-	did not find site - 7 holes averaging 3.3m deep
Site 4	67 21.5	134 52.2	-	-	did not search for site - 5 holes averaging 3.3m deep

TABLE 1. BOREHOLES ALONG THE DEMPSTER HIGHWAY

BOREHOLE	LAT.	LONG.	TOTAL DEPTH DRILLED (m)	TOTAL DEPTH CASED (m)	TOTAL DEPTH LOGGED (m)	DEPTH DIESEL STARTS AT (m)	HEIGHT OF CASING ABOVE GROUND (cm)	CAP ON TOP (?)	TYPE OF CLEARING NATURAL, ARTIFICIAL	ACCESSIBILITY
78-A-2	62 32.3	140 57.9	7.0	6.8	-	-	-	-	N?	Brief unsuccessful attempt to locate from air.
78-A-3	62 31.6	140 56.9	6.9	6.3	6.1	0	60	Yes	A	Accessed by helicopter.
78-A-8	62 17.5	140 46.1	8.5	8.5	7.0	0.8	45	Yes	A	Accessed by helicopter.
78-A-9	62 17.2	140 45.8	5.6	1.8						No attempt to locate. Slumped in at 1.8m.
78-A-23	61 59.1	140 27.0	7.3	5.8	-	-	-	-	N?	No time (daylight) to search from air.
78-A-39	61 42.9	139 50.3	4.5	?	3.0	0	30	Yes	Old A	Accessed by truck. Beside old pipeline.
78-A-40	61 42.8	139 50.1	8.3	8.2	7.3	5	15	Yes	Old A	Accessed by truck. Enlarged pipeline clearing.
78-B-25	61 40.5	139 43.7	6.2	6.2	4.9	0	45	Yes	A	Accessed by truck.
78-A-46	61 35.6	139 27.3	9.0	7.3	-	-	-	-	N	Accessed by truck. Located general area of drill site; drillhole hidden by snow cover and could not be found.
78-B-28	61 35.6	139 27.1	8.2	6.1	5.5	0	60	Yes	A	Accessed by truck.
78-A-51	61 30.4	139 19.4	8.5	8.5	8.5	4.5	10	Yes	A	Accessed by truck.
78-A-55	61 26.7	139 14.0	9.1	7.3	7.9	1.5	60	Yes	Old A	Accessed by helicopter. Enlarged clearing at old pipeline.
78-A-57	61 24.8	139 11.1	6.6	2.7	-					No attempt to locate. Slumped in at 2.7m.
78-A-62	61 16.1	138 50.3	9.2	9.2	7.3	0	10	Yes	A	Accessed by truck.
78-A-63	61 14.9	138 47.7	5.9	4.6	4.6	3.5	60	No	A	Accessed by truck, driving up to site.
78-A-64	61 14.4	138 46.8	9.2	9.2	8.2	0	25	Yes	Old A	Accessed by truck, driving up to site.
78-A-71	60 54.9	137 52.3	9.2	9.2	8.8	1.5	15	Yes	A	Accessed by helicopter.
78-A-72	60 48.1	137 31.6	9.2	8.5	-	-	-	No	A	Foothills thermistor cable installed. Hole plugged.
78-B-43	60 50.9	136 59.2	7.8	7.3	7.3	Air	15	No	A	Accessed by helicopter.
78-A-75	60 48.9	136 41.9	9.3	6.1	6.4	Air	15	Yes	A	Accessed by truck.

TABLE 2 BOREHOLES ALONG THE PROPOSED ALCAN GAS PIPELINE

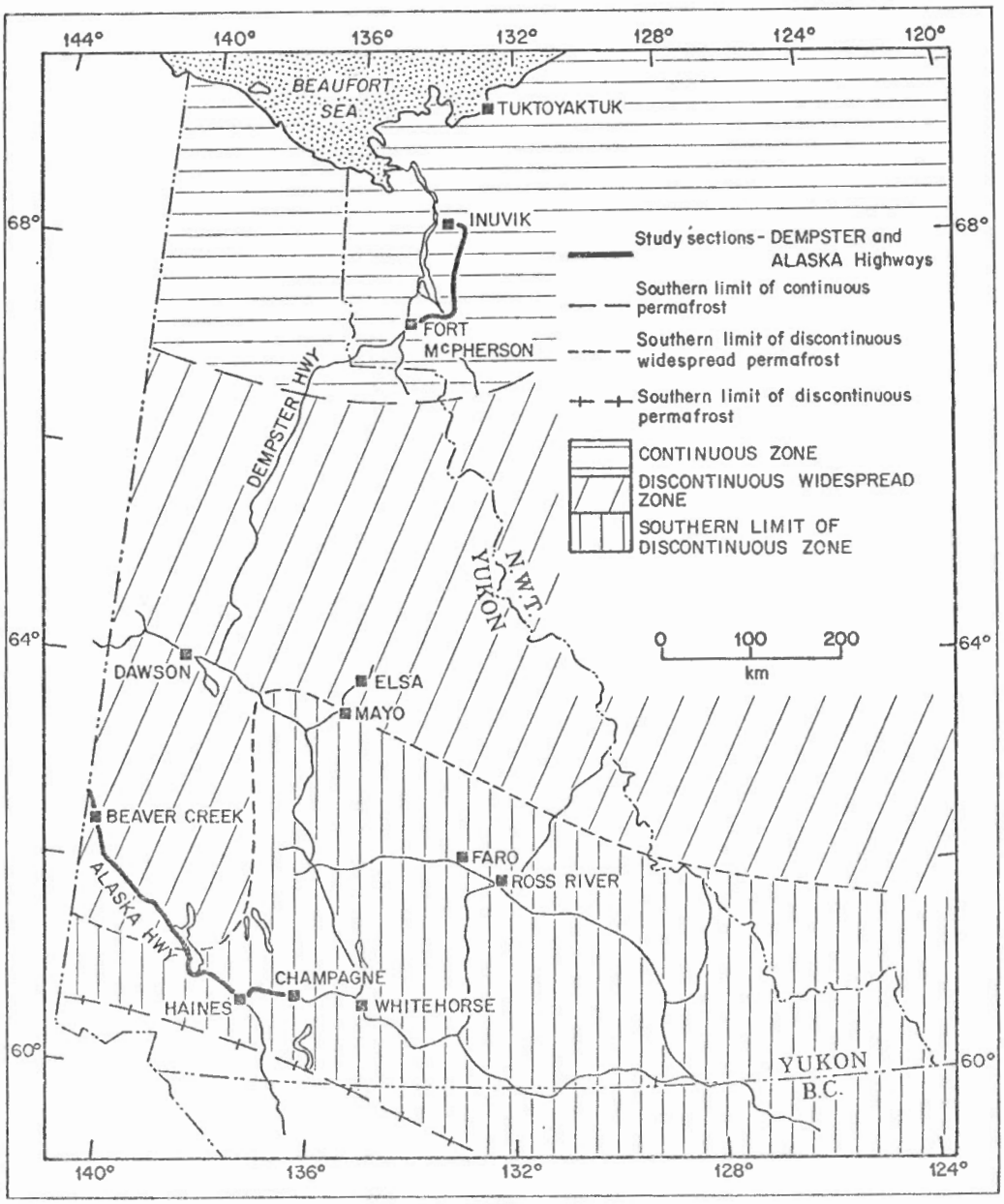


Figure 1. Location Map - Dempster and Alaska Highways. (Permafrost boundaries taken from Brown 1964, Judge 1975).

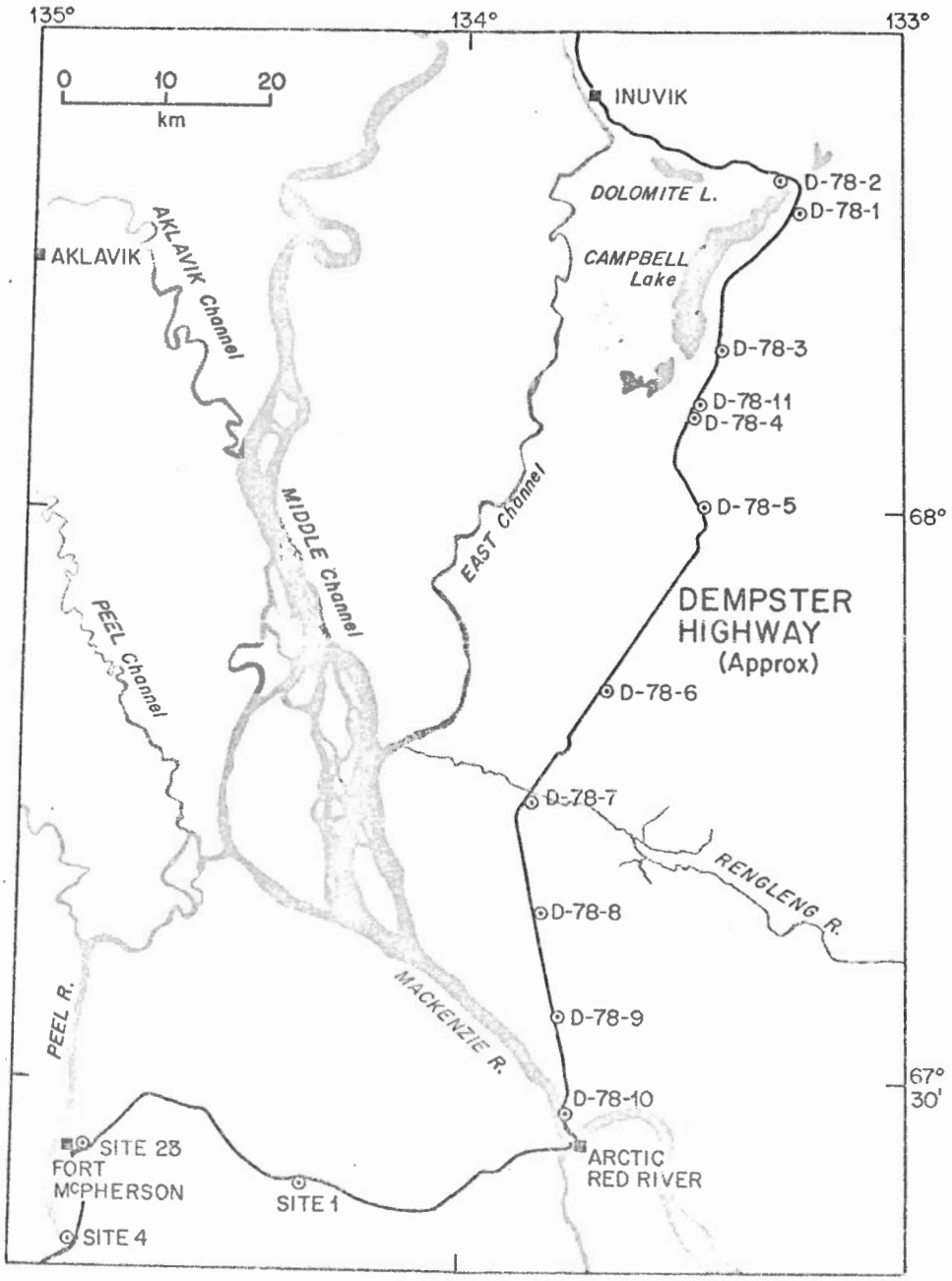


Figure 2. Dempster Highway Borehole Locations

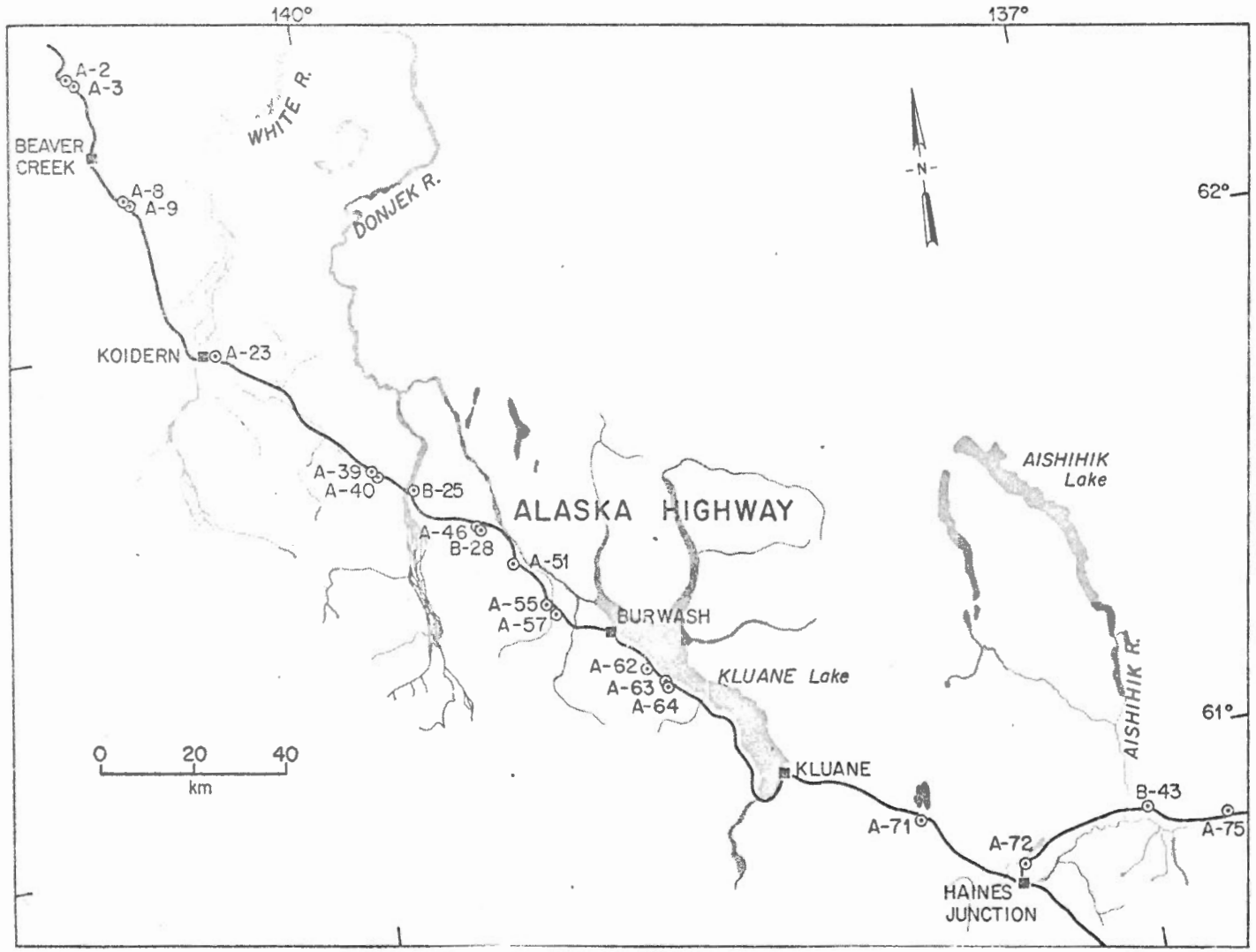


Figure 3. Alaska Highway - Foothills (South Yukon) 1978 Borehole Locations

APPENDIX A

DEMPSTER HIGHWAY BOREHOLE TEMPERATURE PROFILES & DATA LISTINGS

DEMPSTER HIGHWAY AUGUST 1973

BOREHOLE TEMPERATURE LOGS

D-78-1

DEPTH	TEMP.
0.9	.00
1.5	-1.05

D-78-2

DEPTH	TEMP.
0.6	-1.25
1.8	-2.63
2.4	-3.43

D-78-3A

DEPTH	TEMP.
0.3	.04
0.9	- .81
1.5	-1.69
2.1	-2.37

D-78-3B

DEPTH	TEMP.
0.3	.06
0.9	- .81
1.5	-1.81
2.1	-2.38
2.7	-2.78
3.4	-3.20
4.0	-3.51
4.3	-3.42

D-78-4A

DEPTH	TEMP.
0.3	- .20
0.9	- .89
1.5	-1.49
2.1	-1.84
2.2	-1.62

D-78-4B

DEPTH	TEMP.
0.3	- .02
0.9	-1.06
1.5	-1.44
1.8	-1.85

D-78-5

DEPTH	TEMP.
0.3	7.40
0.9	3.49
1.5	- .10

D-78-6

DEPTH	TEMP.
0.3	- .04
0.9	- .66
1.5	-1.27
2.1	- .93

D-78-7

DEPTH	TEMP.
0.3	3.60
0.9	.04
1.5	- .40
2.1	- .69

D-78-8A

DEPTH	TEMP.
0.3	5.22
0.9	.25
1.5	- .10
1.8	- .20

D-78-8B

DEPTH	TEMP.
0.3	5.43
0.9	.15
1.5	.01
1.8	- .08

D-78-9

DEPTH	TEMP.
0.3	3.62
0.9	- .19
1.5	- .91
2.1	-1.21

D-78-11A

DEPTH	TEMP.
0.3	- .27
0.9	- .78
1.5	-1.38
2.1	-1.83
2.7	-2.15

D-78-11B

DEPTH	TEMP.
0.3	+ .03
0.9	- .91
1.5	-1.47
2.1	-1.61

Note All depths are expressed in metres and all temperatures in °C.

FORT McPHERSON - ARCTIC RED RIVER SITE NO. 1
AUGUST, 1978

TEMPERATURE LOGS

1A

DEPTH	TEMP.
0.3	4.23
0.9	-1.47
1.5	-2.46
2.1	-3.32

1B

DEPTH	TEMP.
0.3	2.39
0.9	-1.19
1.5	-2.33
2.1	-2.48
2.4	-2.66

1C

DEPTH	TEMP.
1.5	-2.48
2.1	-2.13
2.7	-1.50

1D

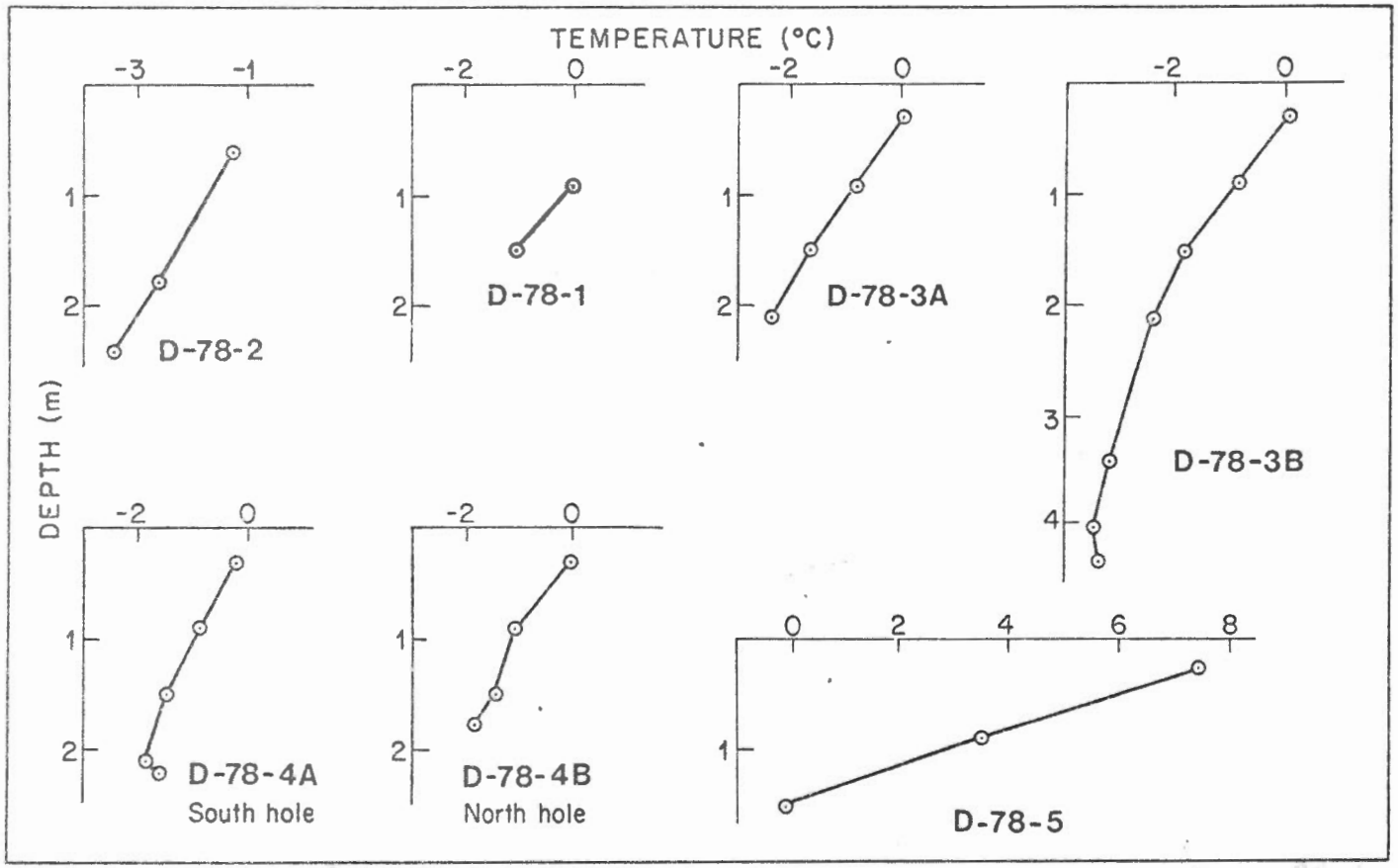
DEPTH	TEMP.
0.3	5.19
0.9	-1.09
1.5	-2.12
2.1	-2.85
2.4	-3.25

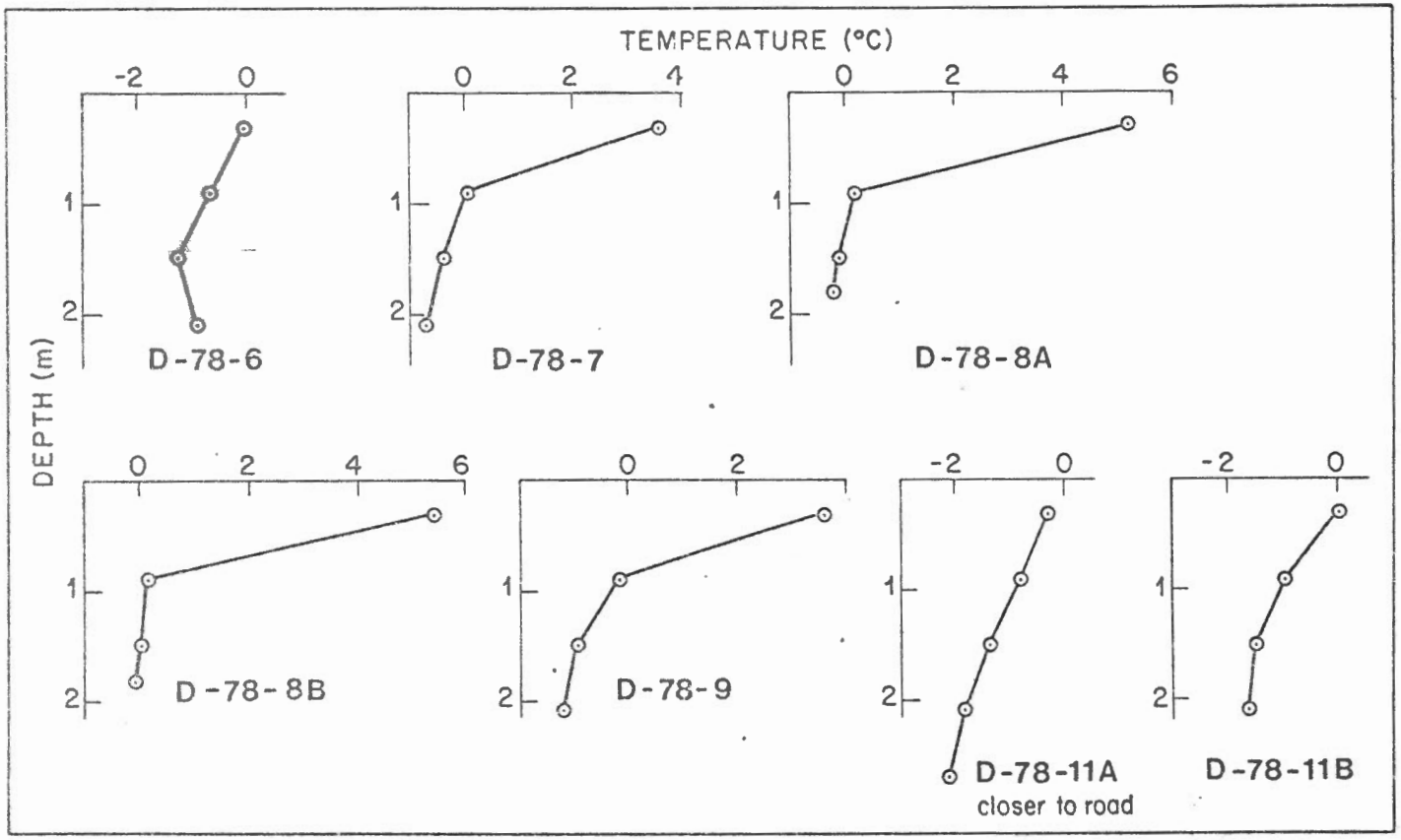
1E

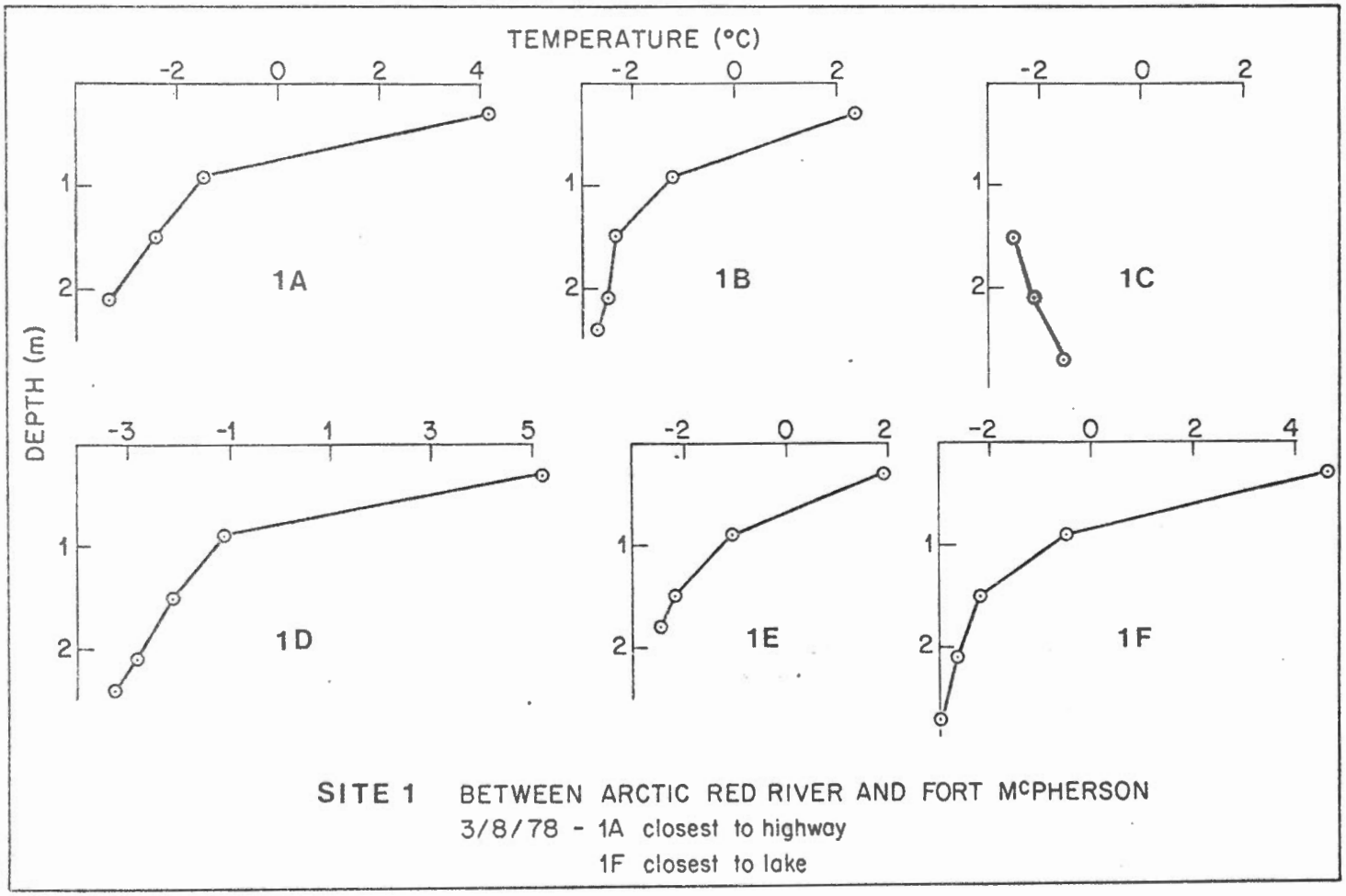
DEPTH	TEMP.
0.3	1.94
0.9	-1.07
1.5	-2.18
1.8	-2.46

1F

DEPTH	TEMP.
0.3	4.67
0.9	-.98
1.5	-2.18
2.1	-2.66
2.7	-2.94


TEMPERATURE (°C)
DEPTH (m)
D-78-2
D-78-1
D-78-3A
D-78-3B
D-78-4A
South hole
D-78-4B
North hole
D-78-5


TEMPERATURE (°C)
DEPTH (m)
-2
0
2
4
6
1
2
D-78-6
D-78-7
D-78-8A
D-78-8B
D-78-9
D-78-11A
closer to road
D-78-11B



SITE 1 BETWEEN ARCTIC RED RIVER AND FORT McPHERSON

3/8/78 - 1A closest to highway

1F closest to lake

APPENDIX B

FOOTHILLS PIPE LINES LTD.
BOREHOLE TEMPERATURE
PROFILES & DATA LISTINGS

FOOTHILLS PIPE LINES LTD. BOREHOLES

NOVEMBER 1978 TEMPERATURE LOGS

78-A-3

DEPTH	TEMP.
0.6	-1.72 D
1.5	-1.22 D
3.0	-1.46 D
4.6	-2.10 D
6.1	-2.48 D

78-A-8

DEPTH	TEMP.
1.5	-2.39 D
3.0	-1.77 D
4.6	-1.63 D
6.1	-1.79 D
7.0	-1.88 D

78-A-39

DEPTH	TEMP.
1.5	-1.46 D
3.0	- .90 D

78-A-40

DEPTH	TEMP.
1.5	- .51 A
3.0	- .61 A
4.6	- .61 A
6.1	- .98 D
7.3	-1.47 D

78-B-25

DEPTH	TEMP.
1.5	-1.74 D
3.0	-1.23 D
4.6	-1.02 D
4.9	-1.02 D

78-B-28

DEPTH	TEMP.
0.3	-2.04 D
1.5	-1.41 D
3.0	-1.45 D
4.6	-1.69 D
5.5	-1.73 D

78-A-51

DEPTH	TEMP.
1.5	- .89 A
3.0	- .89 A
5.5	-2.65 D
7.3	-2.27 D
8.5	-1.91 D

78-A-55

DEPTH	TEMP.
1.5	- .35 D
3.0	- .60 D
4.6	- .74 D
6.1	- .76 D
7.6	- .74 D
7.9	- .72 D

78-A-62

DEPTH	TEMP.
1.5	-1.32 D
3.0	-1.23 D
4.6	-1.43 D
6.1	-1.57 D
7.3	-1.63 D

78-A-63

DEPTH	TEMP.
0.3	- .77 A
1.5	- .23 A
3.0	- .59 A
4.0	-1.43 D
4.6	-1.51 D

78-A-64

DEPTH	TEMP.
1.5	-1.53 D
3.0	-1.16 D
4.6	- .93 D
6.1	- .89 D
7.6	- .86 D
8.2	- .71 D

78-A-71

DEPTH	TEMP.
1.5	.23 D
3.0	.16 D
4.6	.17 D
6.1	.15 D
7.6	.16 D
8.8	.01 D

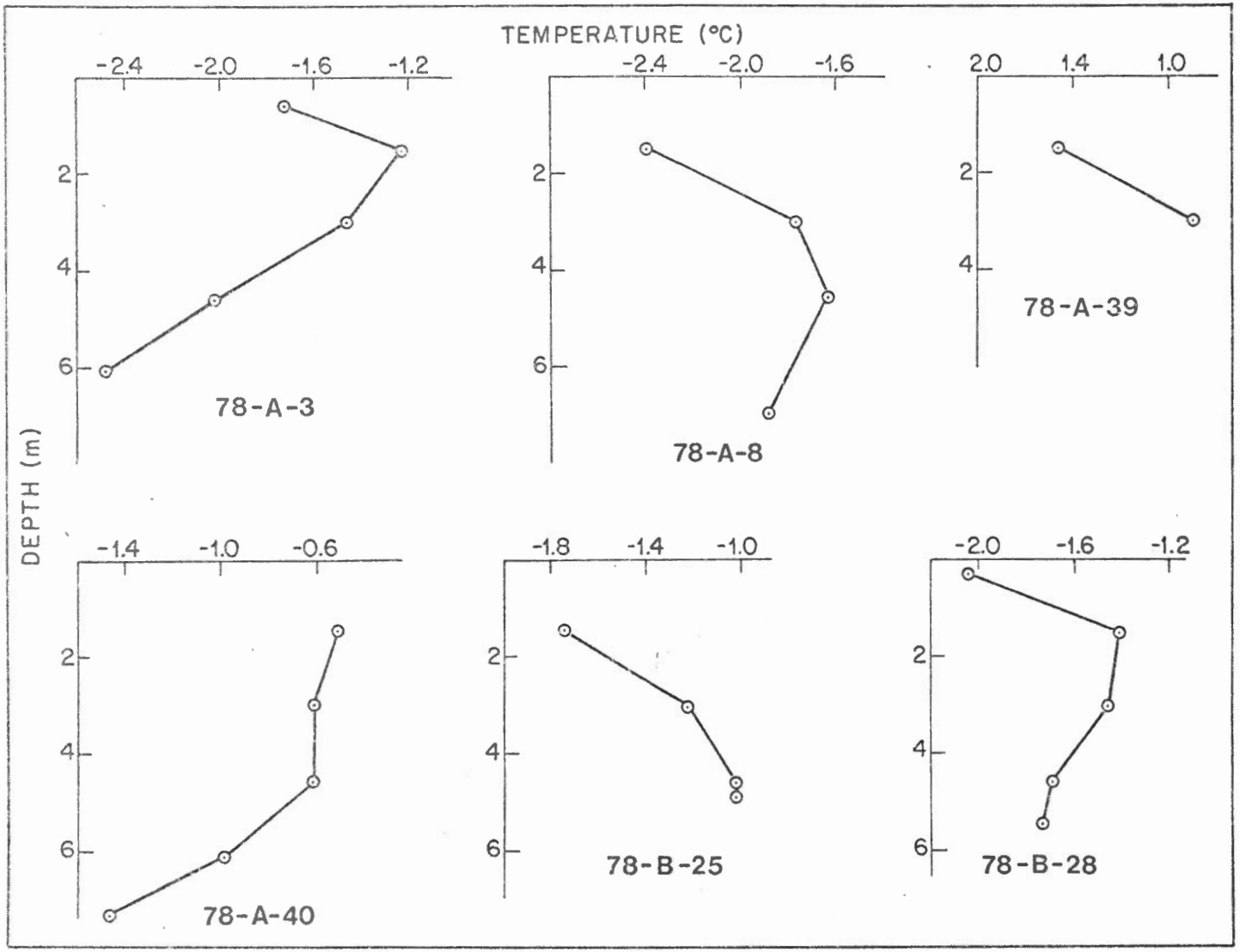
78-B-43

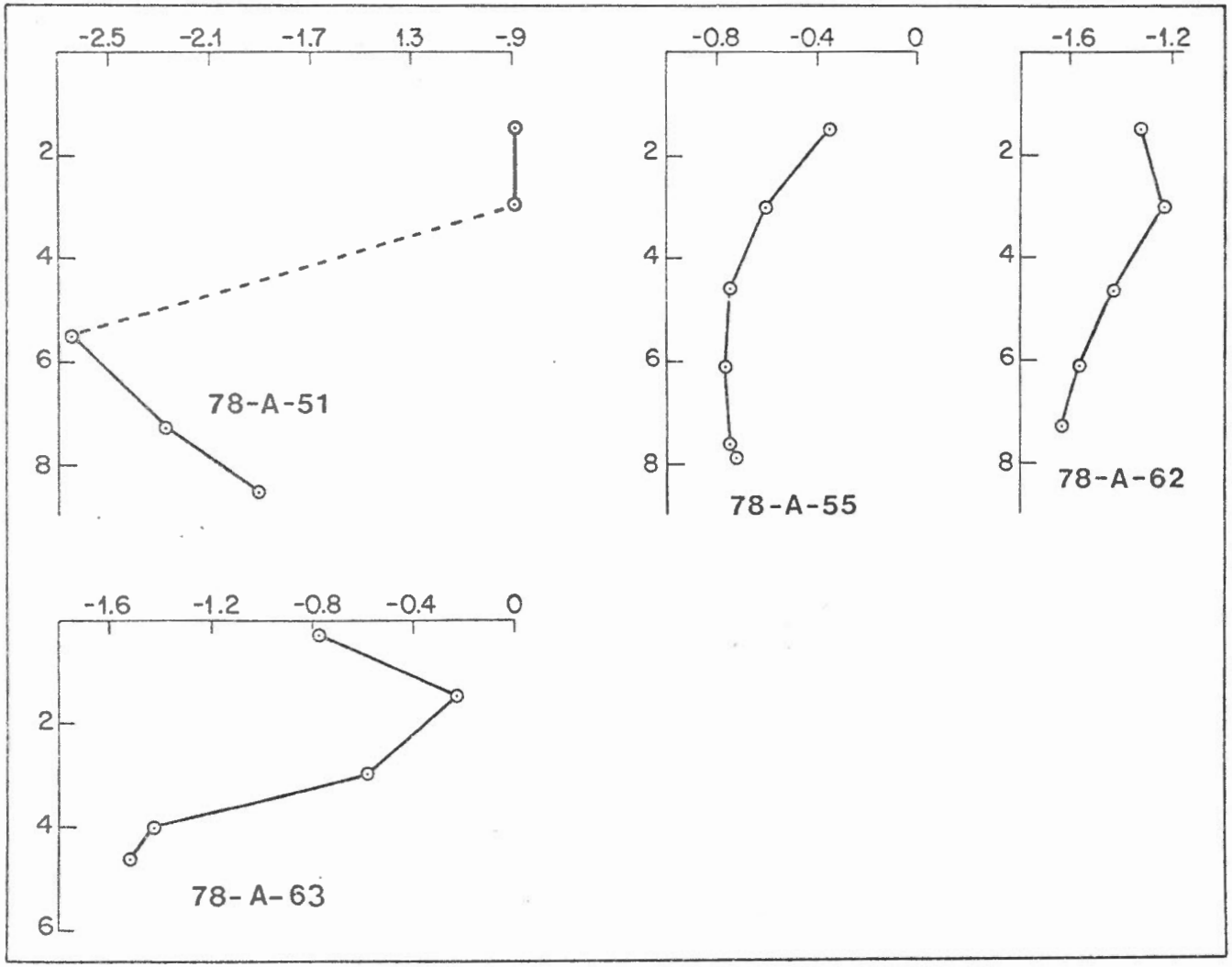
DEPTH	TEMP.
1.8	1.24 A
3.0	1.53 A
4.6	1.52 A
6.1	1.51 A
7.3	- .12 A

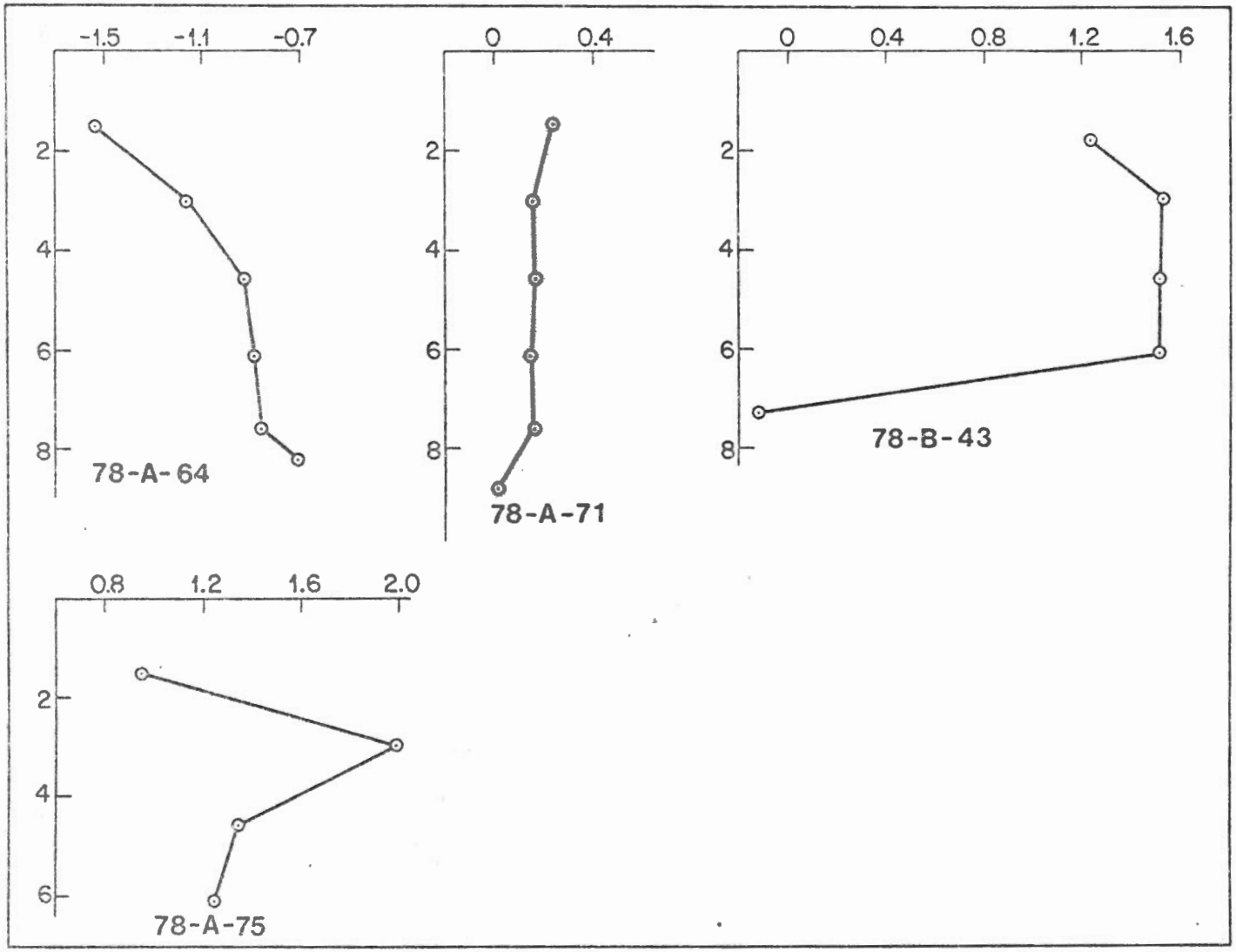
78-A-75

DEPTH	TEMP.
0.3	-6.84 A
1.5	- .95 A
3.0	1.99 A
4.6	1.34 A
6.1	1.25 A

Note: A - reading in air; D - reading in diesel fuel


TEMPERATURE (°C)
DEPTH (m)
-2.4
-2.0
-1.6
-1.2
2
4
6
78-A-3
-2.4
-2.0
-1.6
78-A-8
2.0
1.4
1.0
78-A-39
-1.4
-1.0
-0.6
78-A-40
-1.8
-1.4
-1.0
78-B-25
-2.0
-1.6
-1.2
78-B-28


-2.5
-2.1
-1.7
1.3
-.9
2
4
6
8
78-A-51
-0.8
-0.4
0
2
4
6
8
78-A-55
-1.6
-1.2
2
4
6
8
78-A-62
-1.6
-1.2
-0.8
-0.4
0
2
4
6
78-A-63


-1.5
-1.1
-0.7
2
4
6
8
78-A-64
0
0.4
2
4
6
8
78-A-71
0
0.4
0.8
1.2
1.6
2
4
6
8
78-B-43
0.8
1.2
1.6
2.0
2
4
6
78-A-75