United States Department of Agriculture

Soil Conservation Service

Northeast NTC
160 East 7th Street
Chester, PA 19013

Subject: Summary of GPR field studies in Bethel, Alaska; July 18 - August 3, 1988

Date: August 26, 1988

To: Mike Gross
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Mike,

As requested during our phone conversation of 11 August 1988, I have hastily composed a summary of our work in Bethel, AK. The enclosed figures are examples of graphs and radar profiles which will be prepared to explain variations in the depth to permafrost observed at each site. As the active layer was deepening at the time of these observations, I prefer to use the term "active layer/frozen ground interface" rather than "permafrost table."

The ground-penetrating radar system used was the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems Inc. The SIR System-8 consists of a control unit with microprocessor, an ADTEK SR 8004H graphic recorder, an ADTEK DT 6000 tape recorder, and a power distribution unit. The microprocessor, which has programs to enhance and amplify weak signals and remove background noise was not used in this study. The tape recorder malfunctioned and was not used. The system was powered by two 12-volt marine batteries.

Two antennas (120 and 500 MHz) were available for this study. The higher frequency 500 MHz antenna provided adequate depth of penetration and was used at most sites. This antenna has a shorter pulse width and greater powers of resolution. The lower frequency 120 MHz antenna was used to trace the unfrozen/frozen ground interface beneath Chaos Lake. This antenna has a longer pulse width, greater radiation powers, and emits signals that are less rapidly attenuated by earthen materials.

Seven areas representing a wide variety of topographic positions and expressions were selected for investigations. Twenty-four transects were established within these study areas. Transects ranged in length from 33 to 230 meters and totalled 1593 meters. Though the GPR provides a continuous profile of subsurface conditions, observation site were established at 3, 5, or 10 meter intervals along transect lines. Measurements of relative surface elevations and some ground-truth soil profile observations were

collected at these sites. Soil type, surface roughness, and slope aspect and gradients were also determined.

Figure 1 is a representative example of a GPR profile. This profile is from transect A at site 3. The active layer/frozen ground interface is represented by the dark bands across the profile. This interface was confirmed by ground-truth soil probing. Though variable in expression across this profile, the active layer/frozen ground interface ranges in depth from 30 and 120 cm. Variations in the expression of this interface are attributable to variations in ice crystal contents, the presence of closely spaced organic or mineral soil horizons, or layers differing in soil moisture contents or bulk densities.

Figure 2 is a graph of the permafrost-landscape relationships at site 3A. In this graph the relative elevation of the ground surface has been plotted and the relative depth to the active layer/frozen ground interface (from the GPR profile) reconstructed. Variations in the depth to permafrost with soil-landscape positions are evident on this graph. Variations in the depth to the active layer/frozen ground interface will be statistically analyzed and summarized. Variations in the depth to frozen ground can be explained by variations in the thickness of organic mat, slope aspect or gradient, and soil texture, moisture, and drainage. Similar graphs will be constructed for each site to help explain the permafrost-landscape relationships near Bethel, Alaska.

Please keep me informed of deadlines for submitting my research to you or of any planned BREW conferences. With kind regards.

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cc:
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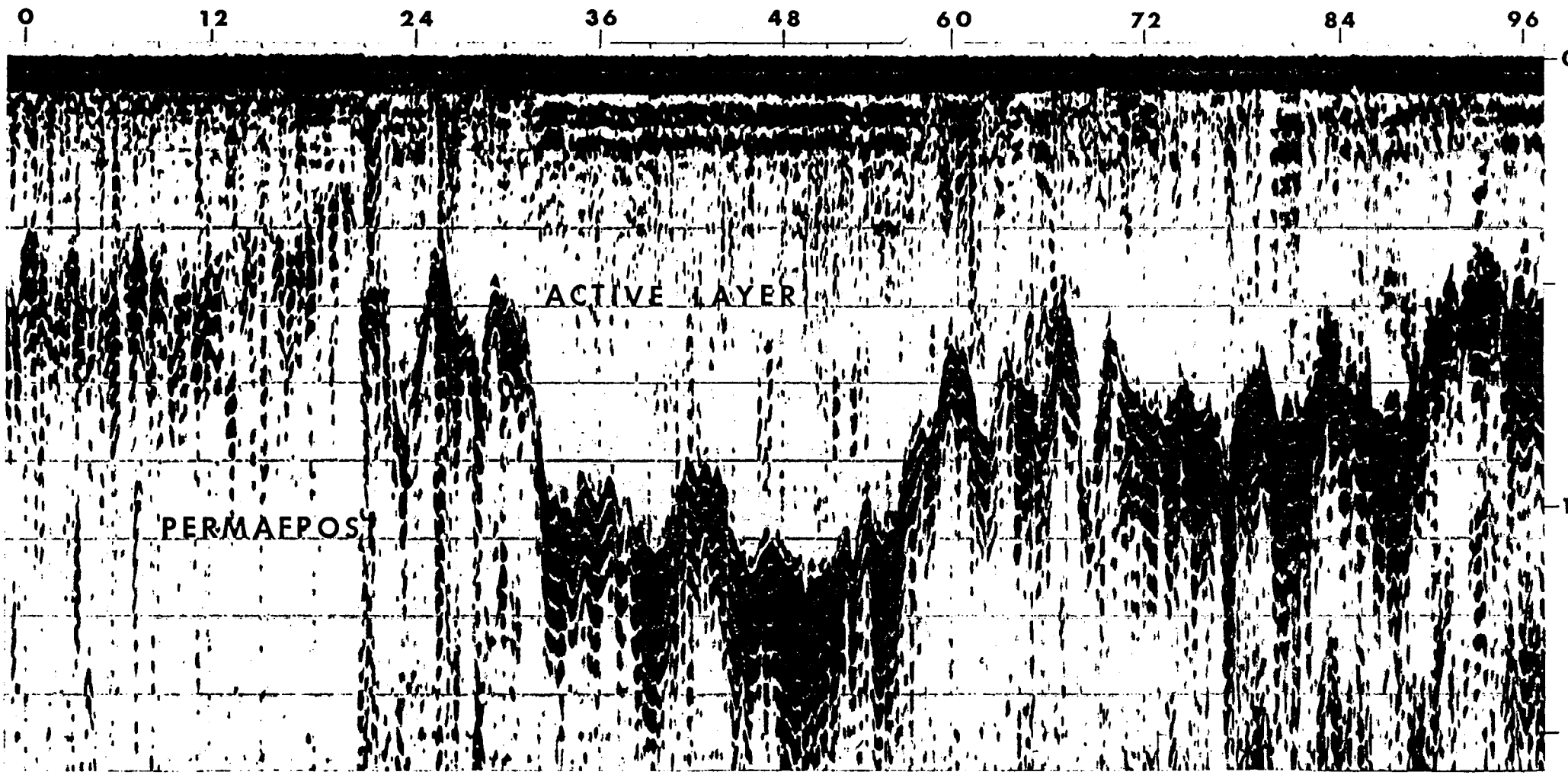
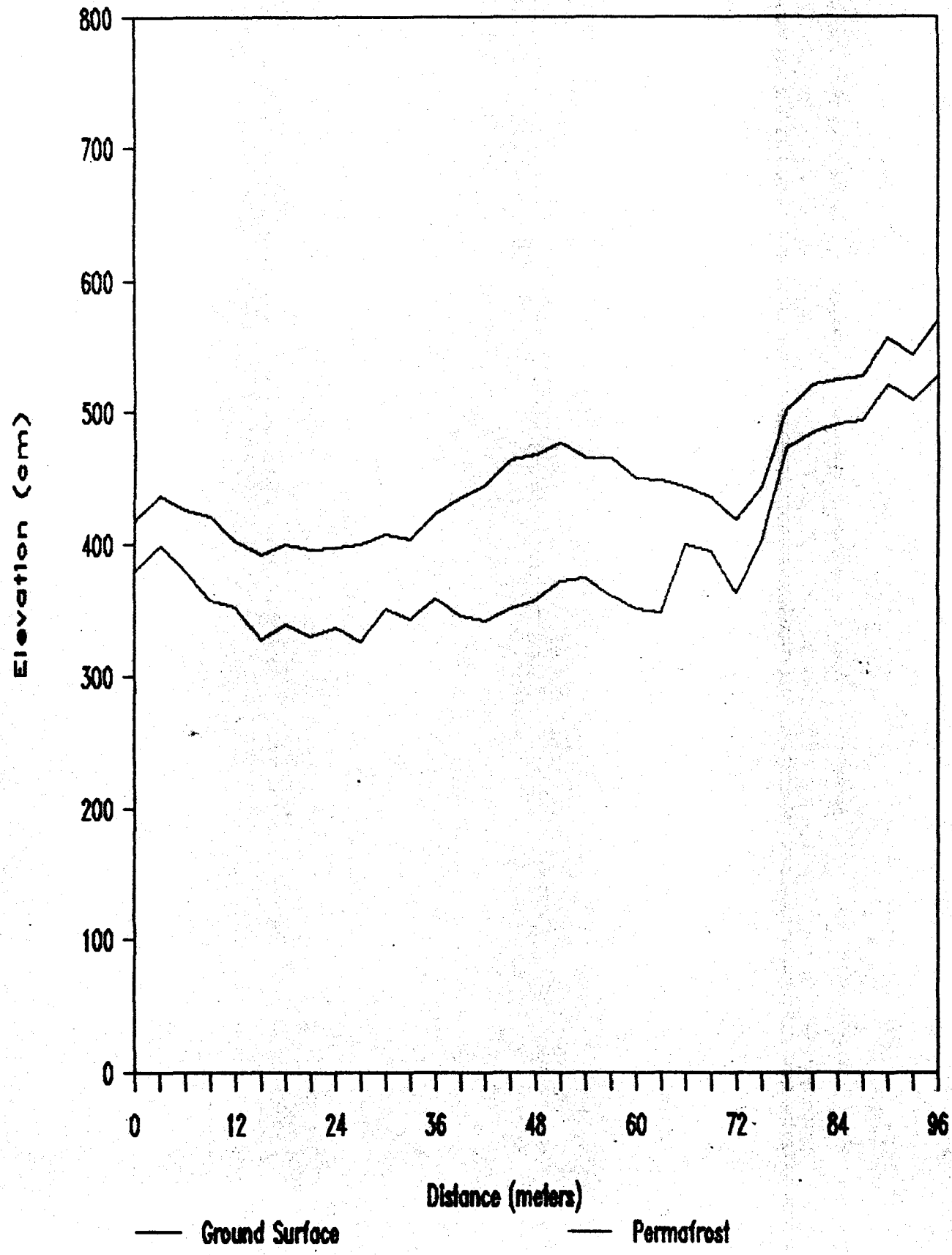


DEPTH TO PERMAFROST

IN METERS

PERMAFROST-LANDSCAPE RELATIONSHIPS

SITE 3A BETHEL, AK



BREW STUDIES AT BETHEL, ALASKA, JULY 21-29, 1988

Permafrost or perennially frozen ground is earthen material which, according to Brown (1969), "freezes in one winter, remains frozen through the following summer and into the next winter." Climate is the most influential factor determining the formation and occurrence of permafrost (Brown, 1970 and 1971). However, local variations in the occurrence and distribution of permafrost and the thickness of the active layer are determined by differences in vegetation, topography, drainage, soil type, and snow cover (Brown, 1969, 1970, and 1971; Dingman and Koutz 1974; and Hopkins et al., 1955). These factors have been collectively referred to as "terrain factors" by Brown (1970).

While many permafrost investigations have been conducted in arctic and subarctic environments, few systematic studies have been reported comparing the thickness of the active layer or the depth to frozen ground with these terrain factors (Brown, 1971). The purpose of this study was to assess variations in the depth to frozen ground (i) among three tundra landscape components in western Alaska, (ii) and with variations in selected terrain factors on upland components.

The study area is located to the northeast of Bethel, in west-central Alaska. The study area adjoins the Kuskokwim River flood plain and is located within the Kuskokwim Delta area. This area is underlain by a moderately thick to thin zone of permafrost except beneath large bodies of water where it is absent (Ferrians, 1965). The Delta is characterized by stratified silty and sandy deposits of alluvial and eolian origins. Numerous ponds and lakes dot the Kuskokwim Delta. The mean annual precipitation is about 43 cm. The mean annual temperature is 29 C.

VEGETATION

The artic tundra vegetation forms a low, dense, continuous ground cover. Principal species include dwarf arctic birch (Betula nana), alpine bearberry (Arctostaphylos alpina), alpine blueberry (Vaccinium uliginosum), black crowberry (Empetrum nigrum), cotton grass (Eriophorum vaginatum), Labrador tea (Ledum palustris), mountain cranberry (Vaccinium vitis-idaea), and sedge (Carex lugens).

SOILS

Soils of the Bethel area have permafost at relatively shallow depths. In most areas, the soils have a thin mantle of silty loess. Underlying the loess are stratified silty and sandy deposits of alluvial origin (Hinton and Girdner, 1966). These soils commonly have an irregular decrease in

organic matter content with depth which has been ascribed to solifluction and other processes of cryoturbation (Douglas and Tedrow, 1960; Tedrow, 1965).

Study sites 1, 2, and 3 were located on uplands in an area of Kuskokwim silt loam, 0 to 3 percent slopes (Hinton and Girdner, 1966). The Kuskokwim series (loamy, mixed, acid Histic Pergelic Cryaquepts) is the most extensively mapped soil on the tundra surrounding Bethel. However, Kuskokwim has been not extensively recognized in Alaska and remains a tentative soil series. Study sites 4 and 5 were located along the escarpment which separates the upland tundra from the floodplain of the Kuskokwim River. These sites are in an area of Kuskokwin-Kwethluk Complex, 12 to 20 percent slopes. The Kwethluk series (sandy mixed Pergelic Cryopsamments) has not been recognized as a soil series.

The thickness of the insulating organic mat influences the depth of seasonal thaw and is a critical factor determining the classification of soils. Thickness of the organic mat ranged from 10 to 46 cm. The average thickness of the organic mat were 15.2 cm on sandy upland tundra sites, 18.3 cm on silty upland tundra sites, and 40.6 cm within the drainageway.

Based on the thickness of the organic mat, the upland tundra sites are 65 percent Pergelic Cryaquepts (< 20 cm thick), 27 percent Histic Pergelic Cryaquepts (20 to 60 cm thick), and 7 percent Pergelic Cryofibrists (>60 cm thick).

Pergelic Cryaquepts:

Silty Upland Sites:

On a convex surface of a frost mound.

Oi1...6 to 4 inches; brown (7.5YR 4/4) and pale brown (10YR 6/3) peat moss; abrupt smooth boundary.

Oi2...4 to 0 inches; dark reddish brown (5YR 2/2) coarse fibrous peat; clear smooth boundary.

A1...0 to 2 inches; black (5YR 2/1) silt loam intermixed with laminated organic matter; moderate medium platy structure; nonsticky and nonplastic; many very fine roots; clear smooth boundary.

A2...2 to 12 inches; dark brown (7.5YR 3/2) silt loam intermixed with laminated organic matter; moderate medium platy structure, nonsticky and nonplastic; very

thin strata of black (5YR 2/1) material in upper part; common very fine roots; abrupt smooth boundary.

C...12 to 13 inches; very dark grayish brown (10YR 3/2) silt loam; massive; common very fine roots; abrupt smooth boundary. Frozen below.

The O horizon ranges from 4 to 7 inches thick. The depth to frozen layers (at the time of this survey - July 21 to 29, 1988) ranged from 14 to 18 inches from the surface.

The O horizon has a hue of 5YR to 10YR, value of 3 to 6, and chroma of 1 to 4.

The A horizon, where present, has a hue of 5YR to 10YR, value of 2 or 3, and chroma of 1 to 3, or is N 2/0. It ranges in thickness from 0 to 8 inches. Texture is silt loam or silt loam intermixed with laminated organic matter.

The C horizon has a hue of 10 YR to 5Y, value of 3 to 5, and chroma of 1 or 2.

Pergelic Cryaquepts:

Sandy Sites:

On a convex slope between two drainageways.

Oi...2 to 0 inches; brown (7.5YR 4/4) and white (10YR 8/2) coarse fibrous lichen and moss peat; abrupt smooth boundary.

A...0 to 3 inches; dark brown (7.5YR 3/2) silt loam; moderate coarse platy structure; nonsticky and slightly plastic; common very fine roots; abrupt irregular boundary.

C1...3 to 13 inches; dark gray (10YR 4/1) sandy loam; weak medium platy structure; thin very dark grayish brown (2.5Y 3/2) strata; nonsticky and slightly plastic; common very fine roots; clear wavy boundary.

Cg2...13 to 44 inches; dark gray (N4/0) loamy sand; single grain; nonsticky and nonplastic; smell of sulfides on freshly broken surfaces; few very fine roots; abrupt smooth boundary. Frozen below.

Histic Pergelic Cryaquepts:

On a plane smooth backslope.

Oi1...9 to 3 inches; dark brown (7.5YR 3/4) and pale brown (10YR 6/3) coarse fibrous lichen and peat moss; abrupt smooth boundary.

Oe2...3 to 2 inches; black (5YR 2/1) moderately decomposed organic matter; clear smooth boundary.

Oe3...2 to 0 inches; very dark brown (10YR 2/2) moderately decomposed organic matter; abrupt smooth boundary.

Clg...0 to 7 inches; very dark grayish brown (10YR 3/2) silt loam; moderate medium platy structure; nonsticky and slightly plastic; abrupt smooth boundary. Frozen below.

The Histic epipedon ranges from 8 to 16 inches thick and, where present, includes part of the A horizon. The depth to frozen layers (at the time of this survey - July 21 to 29, 1988) ranged from 12 to 16 inches from the surface.

The O horizon has a hue of 5YR to 10YR, value of 2 to 6, and chroma of 1 to 4.

The A horizon, where present, has a hue of 10YR to 5Y, value of 2 or 3, and chroma of 1 to 3, or is N 2/0. It ranges in thickness from 0 to 8 inches. Texture is silt loam or mucky silt loam.

Pergelic Cryofibrists:

Drainageway Site:

In an area of sedge tussocks and cotton grass along a drainageway.

Oi1...18 to 14 inches; dark brown (7.5YR 3/2) coarse fibrous peat; clear smooth boundary.

Oi2...14 to 6 inches; dark brown (7.5YR 3/4) coarse fibrous peat; gradual smooth boundary.

Oe3...6 to 0 inches; very dark grayish brown (10YR 2/2) moderately decomposed organic matter; abrupt smooth boundary.

A...0 to 2 inches; very dark grayish brown (10YR3/2) silt loam intermixed with laminated organic matter; moderate coarse platy structure; about 10 percent peat; common very fine roots; abrupt smooth boundary. Frozen below.

GROUND-PENETRATING RADAR

Ground-penetrating radar (GPR) techniques have been used to measure the dielectric properties of perennially frozen ground (Annan and Davis, 1975; and Arcone and Delaney, 1982 and 1984; Davis et al., 1976); to identify and map areas of massive ground ice and the internal structure of permafrost (Arcone et al., 1982; Dallimore and Davis, 1987; Kovacs and Morey, 1979; Scott et al., 1973) and to study spatial and temporal variations in the thickness of the active layer and the depth to the permafrost table (Annan and Davis, 1978; Pilon et al., 1979 and 1985; and Wong et al., 1979).

The GPR system used in this study is the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc. (*) Principles of operation have been described in detail by Olson and Doolittle (1985) and Shih and Doolittle (1984). Components used in this study included the model 4800 control unit, ADTEK SR 8004H graphic recorder, ADTEK DT 6000 tape recorder, power distribution unit, and the 120 and 500 MHz antennas. The system was powered by two 12-volt batteries.

FIELD METHODS

The study area was located northeast of Bethel, Alaska, and defined by the coordinates of N60 40'13" to N60 48'47" and W161 43'49" to W161 45'11". Five sites (sites 1 to 5) were selected in the NE1/4 Sec. 4, T. 8 N., R. 71 W. and one site (site 6) was selected in the NW 1/4 Sec. 3, T. 8 N., R. 71 W. The five study sites located in section 4 are representative of areas of tundra on nearly level uplands and gently sloping to moderately steep escarpments to the Kuskokwim River flood plain. Site 6 is an extremely small, oval, shallow thaw lake, Chaos Lake, which has an area of about 4.0 hectares.

At each site, transects were established with the aid of Brunton compass, measuring tape, transit, and surveying flags. Observation points were established and flagged at intervals of 5 (sites 1 and 2), 3 (sites 3, 4, and 5) and 10 (site 6) meters along twenty-two transect lines.

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1. Use of trade names is for identification purposes and does not constitute endorsement.

(*) Use of trade names in this report is for identification purposes only and does not constitute endorsement.

The six study sites provided a total of 356 observation points. At each observation point the elevation, aspect, slope gradient, slope type, and depth to frozen layer was determined. A transect was used to determine surface elevations. Elevations were not tied into a benchmark. The lowest point within study site 5 was assumed to approximate the 9.14 m (30 foot) contour and all elevations for sites 1 through 5 were tied to this approximation. The elevation of the surface of Chaos Lake was assumed to be 6.12 meters (20 feet). Slope aspect was determined with the aid of a Brunton compass. Slope gradient was calculated for each observation point from changes in elevation for the slope segment spanning between the two adjacent observation points. Slope type was described at each site as being (1) concave, (2) linear, or (3) convex. The depth to frozen layer was scaled from the radar profiles.

This study was conducted and reflects conditions measured during the period of July 21-29, 1988. These measurements were collected prior to the end of the ground thawing seasons and do not necessarily reflect the maximum or average depth of thawing.

ANALYSIS OF TRANSECT DATA

Data from twenty-two transects were grouped into three basic landscape components: uplands, drainageway, and lake. Figure 1 illustrates the distribution of depths to frozen ground for the 356 observation points as distributed within the three landscape components. The distributions of depths to frozen layers are significantly different between these three landscape components. The basis statistics for the depth to frozen ground within each of these landscape components is summarized in Tables 1 and 2. In these tables, upland sites have been subdivided into silty and sandy sites based on observed differences in soil texture.

TABLE 1

DEPTH TO FROZEN GROUND ON THREE TUNDRA LANDSCAPE COMPONENTS
BETHEL, ALASKA; JULY 21-29, 1988*

LANDSCAPE	NUMBER	MEAN	MINIMUM	MAXIMUM	STANDARD DEVIATION
UPLANDS					
SILTY SITES	251	37.80	17.00	63.00	7.46
SANDY SITES	7	102.71	90.00	112.00	7.36
DRAINAGEWAY	50	64.30	29.00	142.00	24.93

LAKE	48	241.56	30.00	303.00	45.64

*All measurements in centimeters.

TABLE 2

DEPTH TO FROZEN GROUND ON THREE TUNDRA LANDSCAPE COMPONENTS
BETHEL, ALASKA; JULY 21-29, 1988*

LANDSCAPE COMPONENT	MEAN	STANDARD DEVIATION	QUARTILES 1st	MEDIAN	3rd
UPLANDS					
SILTY SITES	37.80	7.46	34.00	38.00	42.00
SANDY SITES	102.71	7.36	71.00	100.00	107.00
DRAINAGEWAY	64.30	24.93	48.00	60.00	82.00
LAKE	241.56	45.64	220.00	228.00	255.00

* All measurements in centimeters.

CHAOS LAKE STUDY SITE

Chaos Lake is an extremely small, oval, shallow lake with a width of about 230 meters and an area of about 4.0 hectares. Two transects of similar lengths crossed Chaos Lake in a east-west direction and provided 48 observation points. At the time of this study, the average depth of the water within the lake was 15.28 cm with a range of 0.0 to 50.3 cm. The average depth to frozen layers was 242 cm. Depths to frozen layers ranged from 30 to 303 cm. The median depth to frozen layers is 228 cm. The lower quartile was 220 cm and the upper quartile was 255 cm. One-half of the observations had depths to frozen layers between 220 and 255 cm.

BREW DRAINAGEWAY

One drainageway was selected for study. Segments of ten transects within sites 3, 4, and 5 crossed portions of this drainageway and provided 50 observation points. The drainageway is a very poorly drained meadow tundra site which drains a portion of the upland and crosses the escarpment to the Kuskokwim River flood plain. The average depth to frozen layers within the drainageway was 64.3 cm. Depths to frozen layers ranged from 29 to 142 cm. The median depth to frozen layers is 60 cm. The lower quartile was 48 cm and the upper quartile was 82 cm. One-half of the

observations had depths to frozen layers between 48 and 82 cm.

UPLAND TUNDRA STUDY SITES

A small included area of sandy soils was crossed in Site 3 along transect A. This was the only area of deep, sandy soils encountered in the study. A total of seven observations sites were included in this area. The average depth to frozen layers within the sandy upland site was 103 cm. Depths to frozen layers ranged from 90 to 112 cm. The median depth to frozen layers is 100 cm. The lower quartile was 71 cm and the upper quartile was 107 cm. One-half of the observations had depths to frozen layers between 71 and 107 cm.

The majority of the upland sites were underlain by silty loessial or alluvial deposits. A total of 251 observations sites were established in silty upland tundra areas. The average depth to frozen layers within these areas was 38 cm with a standard deviation of 7.5. Depths to frozen layers ranged from 17 to 63 cm. The median depth to frozen layers is 38 cm and is identical to the mean. The lower quartile was 34 cm and the upper quartile was 42 cm. One-half of the observations had depths to frozen layers between 34 and 42 cm.

ANALYSIS OF SILTY UPLAND TUNDRA SITES

The distribution of depths to frozen layers on silty upland tundra sites approximates a normal population. In Figure 1 and 2, there is slight evidence of skewness and peakedness in the population. Tests for skewness (0.623) and kurtosis (1.707) indicate a significant departure from normality (.001% level) for this distribution. However, in the following analysis, normality of this distribution has been assumed.

A further analysis of the 251 silty upland tundra sites was conducted to determine whether the depth to frozen layers could be predicted from the landscape elements of aspect, slope gradient, or slope type. As evident in Tables 3 and 4, these variables are weakly correlated with and account for little of the variation observed in the depth to frozen layers.

TABLE 3

SIMPLE CORRELATION COEFFICIENTS

	ASPECT	SLOPE GR.	SLOPE TYPE
ASPECT			
SLOPE GRADIENT	0.123		
SLOPE TYPE	-0.017	0.005	
DEPTH TO FROZEN LAYER	-0.101	-0.191	-0.131

TABLE 4

RESULTS OF MULTIPLE CORRELATION AND REGRESSION ANALYSIS

VARIABLE	PARTIAL REGRESSION COEF	T-VALUE	SIGNIFICANT
ASPECT	-0.0811	-1.305	NO
SLOPE GRADIENT	-0.1806	-2.905	YES*
SLOPE TYPE	-0.1310	-2.124	YES**

* .001 level; ** .005 level
COEFFICIENT OF DETERMINATION = 0.060
MULTIPLE R = 0.245

Analyses of variance were performed on the data to test assumptions that depth to frozen layers were not significantly different among slope aspects, slope types, and slope gradients. As shown in Table 5, variations in the depth to frozen layers were not significantly different among the slope aspect and slope type groups. However, the average depths to frozen layers were significantly different between slope groupings of 0 to 9 percent, 9 to 15 percent, and >15 percent slopes. As shown in Table 6, the depth to frozen layers decrease with increasing slope gradient.

TABLE 5

ANOVA

	DF	SUM OF SQUARES	ERROR MEAN SQUARE	F-VALUE	PROB.
ASPECT					
BETWEEN	3	261.7588	87.25	1.57	0.198
WITHIN	246	13710.2412	55.73		
TOTAL	249	13972.0000			
SLOPE TYPES					
BETWEEN	2	238.1016	119.05	2.15	0.118
WITHIN	248	13735.3327	55.38		
SLOPE GRADIENTS					

BETWEEN	2	238.1016	275.55	5.09	0.006
WITHIN	248	13735.3327	54.12		
TOTAL	250	13973.4343			

TABLE 6

VARIATIONS IN AVERAGE DEPTHS TO FROZEN LAYER WITH SLOPE GRADIENT

GRADIENT	OBSERVATIONS	DEPTH	SD
0 TO 9 %	181	38.70	7.04
9 TO 15 %	32	36.19	7.91
> 15 %	38	34.89	8.32

Generalizations can be made from the apparent differences that exist in the average depth to frozen layers with slope types. The majority of the slopes within the study area have linear slopes. As shown in Table 7, the depth to frozen layers appears to increase as slope gradients decrease downslope per unit length (increasing concavity) and water is allowed to collect in these concavities.

TABLE 7

VARIATIONS IN AVERAGE DEPTHS TO FROZEN LAYER WITH SLOPE TYPE

SLOPE TYPE	OBSERVATIONS	DEPTH	SD
CONCAVE	72	39.08	8.93
LINEAR	113	37.78	6.11
CONVEX	66	36.45	7.73

The average depths to frozen layers do not vary significantly among northeast-, southeast-, southwest-, and northwest-facing slopes. As shown in Table 8, the average depth to frozen layers is similar among northeast-, southeast-, and southwest-facing slopes. However, northwest-facing slopes had the shallowest and southwestern-facing slopes had the deepest and most variable depth to frozen layers.

TABLE 8

VARIATIONS IN AVERAGE DEPTHS TO FROZEN LAYER WITH ASPECT

ASPECT	OBSERVATIONS	DEPTH	SD
NORTHEAST	120	38.25	7.53
SOUTHEAST	58	37.98	4.79
SOUTHWEST	41	38.27	10.23
NORTHWEST	32	35.10	6.99

The data set was regrouped an analyses of variance conducted on north- and south-facing slopes. No significant difference was found to exist between the average depths to the frozen layer on north- and south-facing slopes (see Table 9). However, north-facing slopes displayed greater average depths to frozen layers (38.17 vs 36.92 cm) than south-facing slopes. It should be noted that north-facing slopes were less steep (6.71 %) than south-facing slopes (9.08 %) and this difference was significant at the .035 probability level (F-value 4.49).

TABLE 9

ANOVA

	DF	SUM OF SQUARES	ERROR MEAN SQUARE	F-VALUE	PROB.
NORTH-SOUTH ASPECTS					
BETWEEN	1	80.9836	80.98	1.45	0.229
WITHIN	249	13892.4507	55.79		
TOTAL	250	13973.4343			

References

Annan, A. P. and J. L. Davis. 1976. Impulse radar sounding in permafrost. Radio Science Vol. II (4): 383-394.

Annan, A. P. and J. L. Davis. 1978. High frequency electrical methods for the detection of the freeze-thaw interface. Proc. Third International Conf. on Permafrost. Edmonton. p. 495-500.

Annan, A. P., J. L. Davis, and W. J. Scott. 1975. Impulse radar wide angle reflection and refraction sounding in permafrost. Geol. Surv. Canada Paper 75-1C. p. 335-341.

Arcone, S. A. and A. J. Delaney. 1984. Radar investigations above the Trans-Alaskan Pipeline near Fairbanks. USA CRREL Report 84-27. Hanover, New Hampshire. pp.15.

Arcone, S. A., P. V. Sellmann, and A. J. Delaney. 1982. Radar detection of ice wedges in Alaska. USA CRREL Report 82-43. Hanover, New Hampshire. pp. 15.

Brown, R. J. E. 1969. Factors influencing discontinuous permafrost in Canada. IN: T. L. Pewe [ed.] The periglacial environment, past and present. INQUA, 7th Congr., Alaska, 1965. McGill-Queens University Press, Montreal.

Brown, R. J. E. 1970. Permafrost as an ecological factor in the Subarctic. IN: Ecology of subarctic regions. UNESCO, Paris. p. 129-140.

Brown, R. J. E. 1971. Characteristics of the active layer in the permafrost region of Canada. NRC Assoc. Committee on Geotech. Res. Tech. Mem. 103. p. 1-7.

Dallimore, S. R. and J. L. Davis. 1987. Ground probing radar investigations of massive ground ice and near surface geology in continuous permafrost. IN Current Research, Part A, Geol. Surv. Canada Paper 87-1A. p. 913-918.

Dingman, S. L. and F. R. Koutz. 1974. Relations among vegetation, permafrost, and potential insolation in central Alaska. Arctic and Alpine Res. 6(1):37-42.

Davis, J. L., W. J. Scott, R. M. Morey, and A. P. Annan. 1976. Impulse radar experiment on permafrost near Tuktoyaktuk, Northwest Territories. Canadian J. Earth Sci. 13:1584-1590.

Douglas, L. A. and J. C. F. Tedrow. 1960. Tundra soils of arctic Alaska. 7th Intern. Congr. of Soil Sci., Madison Wisconsin. 4:291-302.

Ferrians, O. J. 1965. Permafrost map of Alaska. USGS Misc. Geol. Inv. Map I-445. scale 1:2,500,000.

Hinton, R. B. and C. L. Girdner. 1966. Soils of the Bethel Area, Alaska. USDA-Soil Conservation Service. pp.28.

Hopkins, D. M., T. N. V. Karlstrom, R. F. Black, J. R. Williams, T. L. Pewe, A. T. Fernald, and E. H. Muller. 1955. Permafrost and ground water in Alaska. U. S. Geol. Surv. Prof. Paper 264-f p. 113-146.

Kovacs, A. and R. M. Morey. 1979. Remote detection of massive ice in permafrost along the Alyeska pipeline and the pump station feeder gas pipeline. Proceedings of the Speciality Conference on Pipelines in Adverse Environments. ASCE. New Orleans. 15-17 January 1979. p. 268-279.

Kovacs, A. and R. M. Morey. 1985. Impulse radar sounding of frozen ground. p. 28-40. IN J. Brown et al.(ed.) Workshop on permafrost geophysics, Golden Colorado, 23-24 October 1984. USA CRREL Special Report 85-5. Hanover, New Hampshire.

Olson, C. G. and J. A. Doolittle 1985. Geophysical techniques for reconnaissance investigations of soils and surficial deposits in mountaionous terrain. Soil Sci. Soc. Am. J. 49:1490-1498.

Pilon, J. A., A. P. Annan, J. L. Davis, and J. T. Gray. 1979. Comparison of thermal and radar active layer measurements in the Leaf Bay Area, Nouveau-Quebec. Geogr. Phys. Quat. 23(3-4):317-326.

Pilon, J. A., A. P. Annan, and J. L. Davis. 1985. Monitoring permafrost ground conditions with ground probing radar (G.P.R.) p. 71-73. IN J. Brown et al.(ed.) Workshop on permafrost geophysics, Golden Colorado, 23-24 October 1984. USA CRREL Special Report 85-5. Hanover, New Hampshire.

Scott, W. J., K. J. Campbell, and A. S. Orange. 1974. EM pulse survey method in permafrost. Proc. Symp. Permafrost Geophysics. 27-28 February 1974. Nat'l. Res Council Can Tech. Memo 113. Ottawa, Canada. P 92-96.

Shih, S. F. and J. A. Doolittle. 1984. Using radar to investigate organic soil thickness in the Florida Everglades. Soil Sci. Soc. Am. J. 48: 651-656.

Tedrow, J. C. F. 1965. Concerning genesis of the buried organic matter in tundra soil. Soil Sci. Soc. Proc. 29(1):89-90.

Wong, J., J. R. Rossiter, G. R. Olhoeft, and D. W. Strangway. 1977. Permafrost: electrical properties of the active layer in situ. Canadian J. Earth Sci. 14(4):582-586.