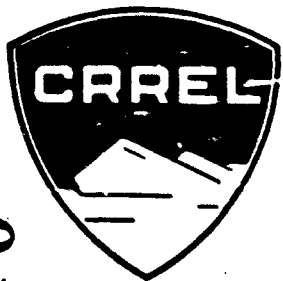


TR 199



AD 660310

Technical Report 199
GEOLOGY OF THE
USA CRREL PERMAFROST TUNNEL
FAIRBANKS, ALASKA

by
Paul V. Sellmann

JULY 1967

U.S. ARMY MATERIEL COMMAND
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE



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PREFACE

This geological study was undertaken to provide the pertinent regional and historical geology of the tunnel site and immediate surroundings, as well as data on the index properties of the material through which the tunnel passes. It is a supplemental study to USA CRREL Project 6.1, Rapid Tunneling Techniques in Frozen Ground, which was responsible for excavating the tunnel in permafrost near Fairbanks, Alaska. The planning, objectives, and construction phases of the tunneling operation are reported on by F. Russell (1963), J.E. McCoy (1964), and G. K. Swinżow (in preparation).

The author acknowledges the support provided by the USA CRREL Alaska Field Station and wishes to thank Mr. Otto Engelberth for his enthusiasm and highly capable assistance during all phases of the study. Thanks are extended to Dr. J. Brown, Dr. T.L. Péwé, Mr. L. S. Dingman and Dr. G. E. H. Ballard for reviewing and providing constructive comments and suggestions on the manuscript and work in general.

This report was prepared by Mr. Paul V. Sellmann, Geologist, of the Applied Research Branch (Mr. A. F. Wuori, Chief), Experimental Engineering Division (Mr. K. A. Linell, Chief), USA CRREL.

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SUMMARY

The age and sedimentary environment of a perennially frozen Quaternary silt section in the USA CRREL permafrost tunnel near Fairbanks, Alaska, were established by radiocarbon dating and stratigraphy, and substantiated by a study of the chemical gradient and massive ground ice structures. Data on the index properties and seismic velocities of material through which the tunnel passes were also gathered.

The section proved to be Late Wisconsin in age, with the maximum determined date of 33,700 (+2500, -1000) years. Ice wedges occur throughout the section. The large forms, exceeding a meter in width, are found only below 12 meters. Scattered vertical distribution, truncated flat tops, and second cycle growth of wedges suggest changing depositional and/or climatic conditions during their formation.

Two distinct breaks, "unconformities," are noted in the section. The lower break at a depth of approximately 12 meters is indicated by: radiocarbon dates jumping from approximately 14,000 to 30,000 years; total ion concentration showing in excess of a five-fold increase; and sudden occurrence of large wedge structures, some of which exhibit second cycle growth. The upper break at the depth of 3 meters is suggested by radiocarbon dates and a small truncated ice wedge and may indicate a warming period during late Wisconsin time. Lower total ion concentrations and smaller ice wedges in the 13-meter section suggest that during or shortly after deposition the unit was subjected to warmer climatic influences, and possibly deeper thaw, than accompanied formation of the lower unit.

GEOLOGY OF THE USA CRREL PERMAFROST TUNNEL FAIRBANKS, ALASKA

by

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INTRODUCTION

The USA CRREL tunnel is at Fox, Alaska, in the Glenn Creek Valley, approximately 10 miles north of Fairbanks on the Steese Highway (64°57'N, 147°37'W). It was excavated in perennially frozen silts of Pleistocene age. These silts have been of scientific and economic interest in the Fairbanks area since the turn of the century because of the need to economically remove thick sections of the material to expose the underlying gold-bearing gravels. The frozen sediments also preserved large floral and faunal assemblages, thereby retaining a record of plant and animal life and of the changing environmental conditions during late Quaternary time.

Physiographically the tunnel area is near the southern limit of the Yukon-Tanana Upland of interior Alaska. The upland consists primarily of rolling hills separated by broad alluvial- and colluvial-filled valleys. Spruce, aspen, birch and willow are the common trees. The ground cover is mainly mosses, sedges, Labrador tea, dwarf willow and various berry-producing bushes and dwarf-tree forms.

The tunnel portal was excavated into a near-vertical silt escarpment formed by a placer mining operation (Fig. 1). USA CRREL Project 6.1 personnel constructed the 360-ft tunnel during the winters of 1963-64, 1964-65 and 1965-66 using an Alkirk mining machine and a modified blasting technique. Sections in the blasted area are irregular and fractured, in contrast to the milled and nearly polished machine-made exposures. A vertical shaft 45 ft deep and 4 ft in diameter was augered in 1966 for ventilation.

The excavation provides unique exposures of the frozen sediments and an opportunity to study in detail the local stratigraphy and complex ground ice structures. Information on the index properties of the material through which the tunnel and vertical ventilation shaft pass was obtained from analysis of more than 60 samples. The late Quaternary history was interpreted with the aid of radiocarbon dates, stratigraphy, chemical profiles, and a study of the ground ice structures.

GENERAL GEOLOGY

The bedrock in the area consists chiefly of the Birch Creek schist of Precambrian age which underlies most of the Yukon-Tanana Upland. It is a gray to brownish graphite-quartz-calcite schist or quartz-mica schist. Inclusions of low grade marble are found near the tunnel site. These metamorphic rocks are intruded by quartz diorites, granite, and dike rocks of Mesozoic age (Mertie, 1937).

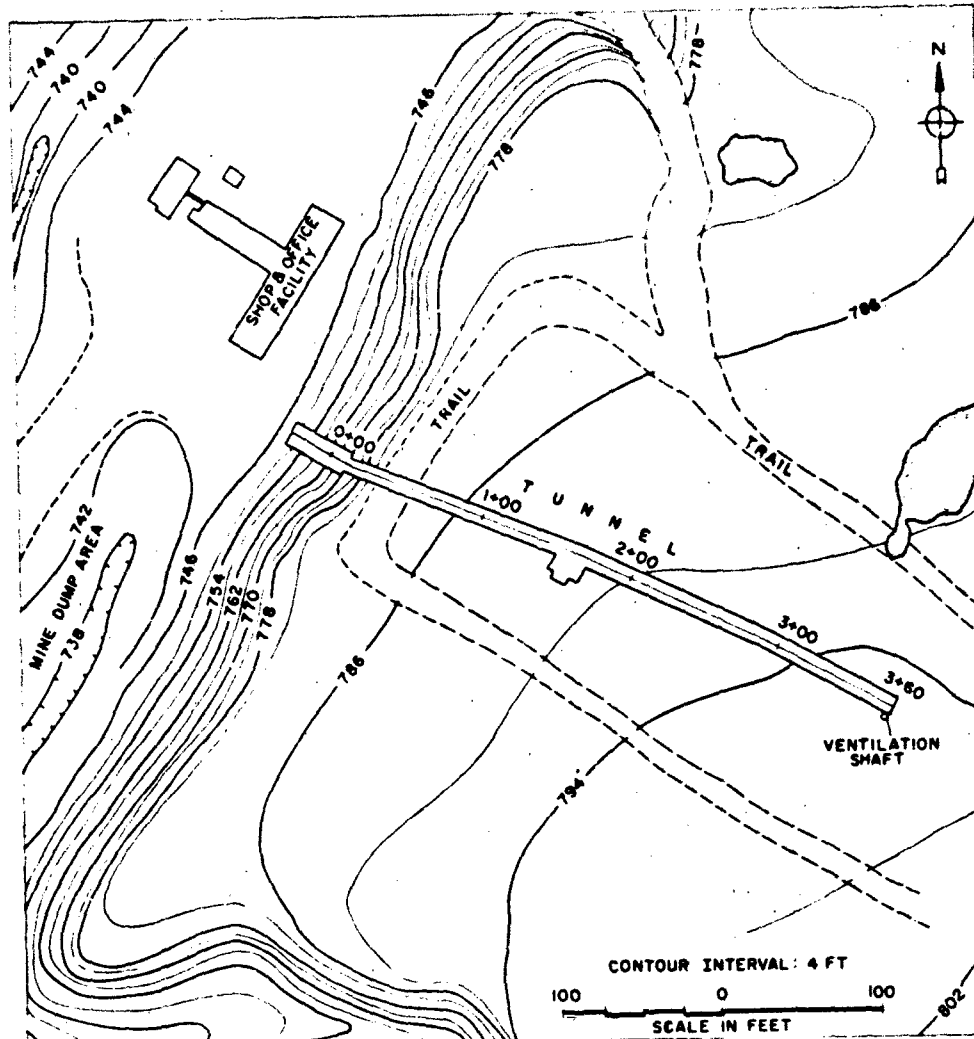


Figure 1. Topographic map of tunnel site with superimposed tunnel section.

The bedrock units are mantled by unconsolidated, largely ice-cemented silts and gravels of Pleistocene age. Immediately overlying the bedrock in the valleys are early Pleistocene gravel deposits, possibly Nebraskan and Kansan in age, which contained the placer gold deposits (Péwé *et al.*, 1965a) (Fig. 2). These gold-bearing gravels are capped by thick retransported silt sections that are thought to range in age from Illinoian to Recent.

The Illinoian deposits contain considerably less ground ice and organic material than the younger units. It is believed that ice originally in the Illinoian section melted during Sangamon interglacial time (Péwé, 1952, 1958, 1965a). The overlying silt of Wisconsin age is characterized by large ice wedges and

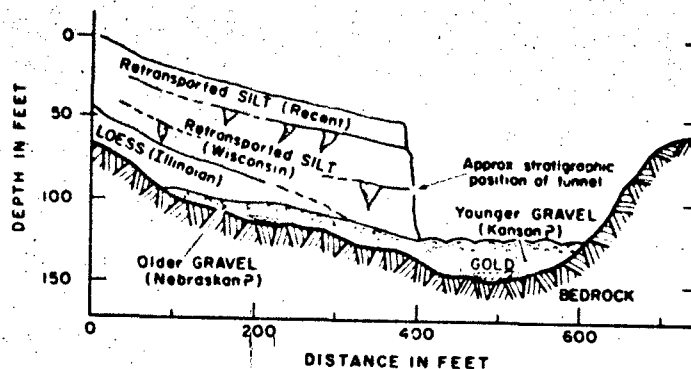


Figure 2. Diagrammatic cross section of Quaternary sediments in creek valley of central Alaska, showing stratigraphic position of tunnel section in relation to entire range of Pleistocene sediments (after Péwé *et al.*, 1965a).

high organic content. Horizontal bedding and sedimentary structures are not particularly abundant in this massive, amorphous material. Convolute and distorted gravel zones, possible bedding, and swirls of sediments constitute the most common megascopic structures. Bones of large extinct vertebrates, such as the bison and mammoth, are commonly found. The presence of fresh water pelecypods suggests that small ponds existed in the valley bottoms.

The origin of these silts has been a subject of some controversy and has been discussed by Taber (1943, 1953, 1958), Black (1951) and Péwé (1955). It is generally accepted that the silts are eolian in origin. They can be divided into two groups based on their subsequent history: (1) the primary eolian silts found mantling the hilltops along the southern margin of the Yukon-Tanana Upland, and (2) the valley bottom silts, a product of retransport of the hilltop material by slope wash, solifluction and normal fluvial activity. The source of the wind-blown silts in the Fairbanks area is the stream-transported glacial material originating from the glaciers of the Alaska Range and deposited on the broad, braided flood plain of the Tanana River. Rigorous climates during glacial times were responsible for a decrease in stream discharge and an increased load, forming the broad, braided, treeless flood plain, and providing large areas of fine-grained sediments for windborne transport. The tan to buff-colored sections of silt are well-sorted and structureless (Taber, 1953; Péwé, 1955). These same eolian processes are taking place today but on a smaller scale. Details concerning the mineralogy have been reported by Péwé (1955).

PERMAFROST CONDITIONS

The tunnel at Fox is in the center of the zone of discontinuous perennially frozen ground (permafrost). South-facing slopes and those parts of the valley bottoms containing coarse-grained sediment with correspondingly high permeability and well-developed internal drainage are usually free of perennially frozen ground. The maximum thickness of the perennially frozen ground in the

Fairbanks area has been reported to be greater than 265 ft (Péwé, 1958). The thickness of the active layer in the undisturbed, moss-covered wooded areas of the Glenn Creek Valley about 200 yards southeast of the tunnel site is approximately 28 in. (Dingman, 1966). The differences in the ground ice volume incorporated in the sediment in the vertical shaft indicate that maximum depth of the active layer in recent times is 30 in. The active layer is relatively free of visible ice lenses and the moisture content is generally much lower than in any other parts of the section.

The ground temperatures adjacent to the tunnel, measured along several profiles during and after tunnel construction, ranged from a minimum of 28 to a maximum of 31F (Swinzow, personal communication, 1965). Air circulation through the tunnel from January through March 1966, caused by natural convection induced by the newly constructed ventilation shaft, allowed ground temperatures of the sediments to be lowered as much as 20 and 14F, 2 ft and 8 ft from the tunnel wall, respectively, in the vicinity of station 1+50 * (McAnerney, personal communication, 1966).

Since the thickness of the frozen zone is extremely variable in areas of discontinuous permafrost, thawed zones within or below the frozen sediment could create severe construction problems, particularly if the tunnel were to intersect an unfrozen zone acting as an aquifer. The tunnel may also upset the thermal regime by warming the frozen ground adjacent to it, causing back-thaw which may result in wall failure or inflow of water. The high probability of the existence of thawed zones is indicated by cases in Siberia (Tsy-tovich and Sumgin, 1937) and the Fairbanks area (Péwé, 1958). The problem of encountering thawed zones in the present excavation would become more critical if the tunnel were to be advanced toward the ridge to the east, since permafrost commonly grades out locally as the ridge tops are approached.

TUNNEL GEOLOGY

Bedrock

Bore hole data. To determine the thickness of the ice indurated sediments over bedrock, positive bore hole information for the sediments in the immediate vicinity of the tunnel was obtained from the records of the United States Smelting, Mining and Refining Co. The records indicate that depth to bedrock along the tunnel section is around 60 ft (Fig. 3). These data were used as control for refraction seismic measurements made along the tunnel centerline to extend the profile well up onto the ridge to the east.

Seismic study. A 2500-ft line was run from the portal uphill along the proposed tunnel centerline. Ten overlapping seismic spreads with various phone spacings were placed along the line. This provided reasonable data for the projection of seven vertical profiles. A plot of the seismic data is shown in Figure 4.

The seismic information was gathered with a small portable 12-channel recording seismograph. The location and intensity of the energy source varied depending on the attenuation of the energy along any one line. The maximum charge used was 1/2 pound of dynamite. The organic mat was stripped to the base of the thaw layer and the geophones were placed directly in the frozen material. The charges were placed in holes drilled at least 2 ft into the frozen ground.

* Tunnel station designations are in feet from the portal (1+50 - 150 ft).

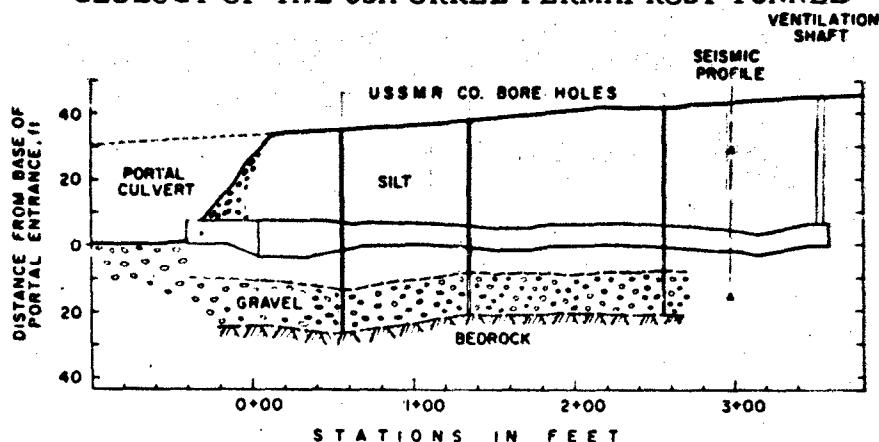


Figure 3. Tunnel site section. Depth to gravel and bedrock based on USSMR Co. bore hole records.

The records produced were of excellent quality, although velocities in the various media were quite similar, and it proved somewhat difficult to determine the exact position of subtle velocity breaks. The velocities for any one layer were determined from separate lines. Velocities within the upper medium varied from 7700 to 11,000 ft/sec. These variations are probably caused by the difficulty in constructing the precise slope for the time-distance data. The mean velocity for the upper unit (the frozen silts) is 9400 ft/sec. The calculated values for the depth to bedrock from the seismic data agreed well with the depth observed at the logged drill holes. The profile data for the bedrock-colluvium interface are reasonable, with the exception of two questionable points (Fig. 4). Four of the profiles suggest a low velocity medium in the upper part of the silt unit. This zone is restricted to the upper 9-15 ft, and has average velocities of 6200 ft/sec. These low velocities may reflect a decrease in the organic content with depth or a temperature controlled factor. Information from the vertical shaft suggests that the moisture content is slightly lower in the upper zone, which may also account for the lower velocities.

The final break in all records is assumed to indicate the depth to bedrock. The velocities in the lower medium average around 14,500 ft/sec. The break probably represents the bedrock-colluvium interface rather than the silt-gravel interface. This is based on the assumption that the gravel pinches out toward the valley side at approximately 800 ft from the portal along the proposed tunnel centerline, and on the configuration of the bedrock profile.

Even though the velocities in the frozen silt seem somewhat low, comparison of the seismic data with the test borings indicates that they are in reasonable agreement. This is also substantiated by the reasonable configuration of the measured bedrock surface.

The break between the silt or gravel and the bedrock is probably somewhat transitional. Small fragments of bedrock become more abundant toward the silt/gravel-bedrock interface. The bedrock, particularly the schistose rock, is often deeply weathered and frost-shattered as shown in other exposures in the Fairbanks area.

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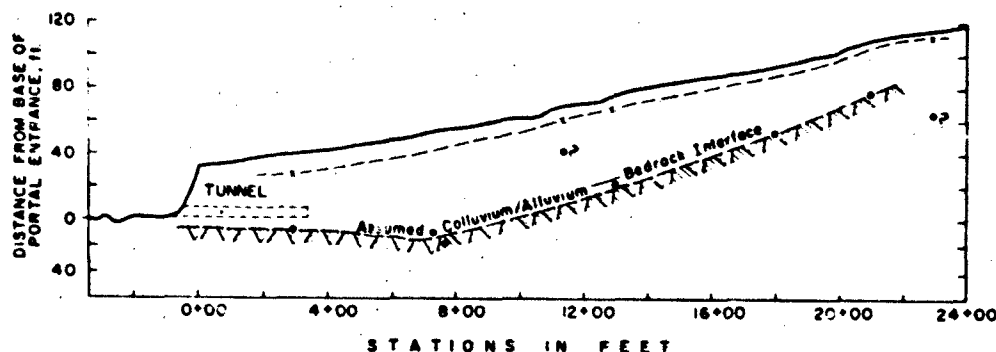


Figure 4. Depth to bedrock along entire seismic line. Dots indicate projected depth to bedrock from seismic information. x indicates a break in the upper part of the silt section in some of the profiles.

Gravels

The average thickness of the gold bearing gravel overlying the bedrock in the vicinity of the tunnel is around 13 ft (J. D. Crawford, USSMR Co., 1965). These relatively old gravels are not exposed in the tunnel, except possibly in a reworked form near the portal. The several gravel-rich zones along the tunnel section appear to be of two general types, based on particle size and age of the material. The first, near the portal between sta. 0+00 and 1+00, contains fresh angular rock fragments several inches in size, possibly deposited by streams and modified by solifluction processes. In the upper part of this gravel section the material commonly occurs in bands, lenses and pods (Fig. 5). These may have been mantled with Illinoian silts, as observed in several other Pleistocene sections in the Fairbanks area. The silts, if present, were later removed, by erosion, down to the gravel during Sangamon (interglacial) time, for the gravel is now overlain by silt of Wisconsin age, with a gradational contact from which organic material was dated at around 14,000 years. The second general type occurs between sta. 2+50 and 3+60. In the upper part of the tunnel exposures this zone contains small angular rock fragments, and is largely made up of material in the coarse sand to small gravel range with little material exceeding 2 in. in size. Small sedimentary structures retained in these gravels, such as orientation of the long axes of the particles and thin interbedded bands of silt, suggest stream deposition of the material. Areas rich in fibrous organic material are commonly found adjacent to these zones (Fig. 6). This section was incorporated in sediments that dated around 30,000 years, suggesting a mid- to late-Wisconsin age.

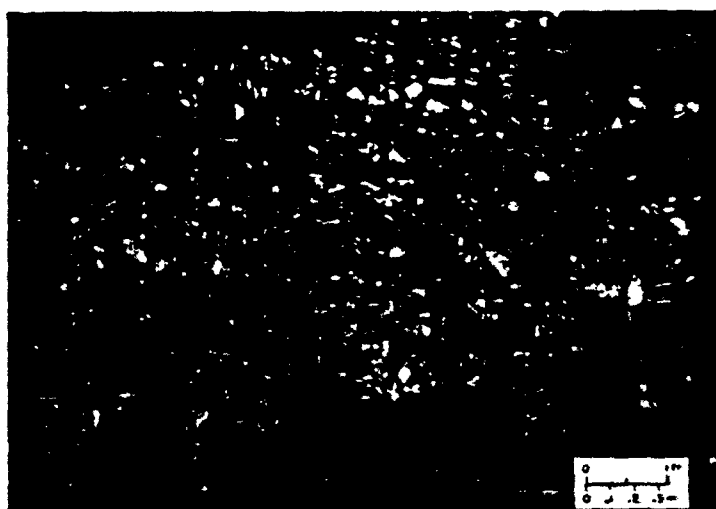
Silts

Of the material that constitutes the late Pleistocene sediments in the area, silt is by far the dominant type. The silt sections are as much as 55 ft thick. Even though the silt of the Fairbanks area has been reported as being Illinoian to Recent in age, no evidence of the Illinoian section is found along the 35-ft escarpment at the tunnel site, or in the available tunnel exposures.

Several mechanical analyses were run on the tunnel and hilltop silts for a comparison of the hilltop parent material and the retransported end-product (Fig. 7). The similarity between the valley silts and the hilltop materials is



a. Sta. 1+04.



b. Sta. 0+32. Here some of the axes of the rock fragments have a preferred orientation (imbrication) which suggests stream deposition.

Figure 5. Bands and lenses of rock fragments incorporated in the silts of the tunnel section. The abundance of the rock material in these sections is far greater than in the normally well-sorted sections.

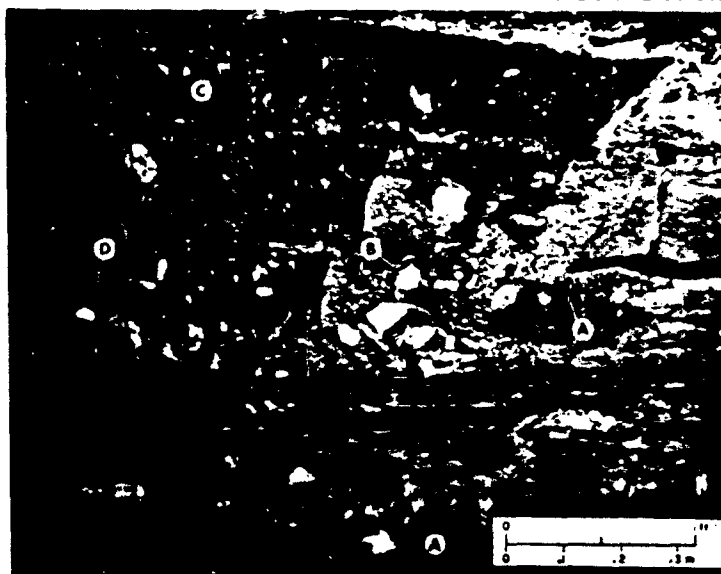


Figure 6. The section at sta. 00+96 illustrates the extreme variability of the material: (A) organic material, (B) rock fragments, (C) massive ice, and (D) silt.

apparent. The analysis of composite silt samples from the tunnel section indicated that 68% of the material falls within the silt range. This compares with 72% for the eolian sections on the surrounding hilltops.

The sediments were described and sampled along the 360-ft tunnel (Fig. 8) as well as in the vertical shaft (Fig. 9). The frozen silt samples were cored from the exposures with a slightly modified USA CRREL ice auger. Tungsten carbide cutters were substituted for the conventional steel cutters and the core barrel was adapted to a hand-held, rotary percussion electric drill. This combination proved to be very successful, permitting thirty 1-ft long samples to be taken in a 4-hr period. Forty-six samples were collected along the horizontal tunnel section and 20 additional samples were collected at 2-ft intervals in the vertical ventilation shaft that intersects the tunnel at sta. 3+55.

These samples were processed in the laboratory to determine: (1) bulk density, (2) dry density, (3) moisture content (105C), (4) organic content, and (5) some of the grain specific gravities. The void ratios and ice volumes were calculated, and some of the specific gravities were interpolated from an organic content-specific gravity curve based on laboratory tests. All the above values are given in Table I.

The bulk densities and dry densities of the samples from the vertical shaft were not determined directly in the laboratory but were calculated from grain specific gravities determined by the air pycnometer, and the weights of the constituents. It was assumed that the samples were saturated, and this was substantiated by work done on the tunnel section materials. Additional properties of the sediments were delineated from the shaft section: (1) specific conductance of the soil water extract, and (2) the carbon-nitrogen ratios of some of the samples.

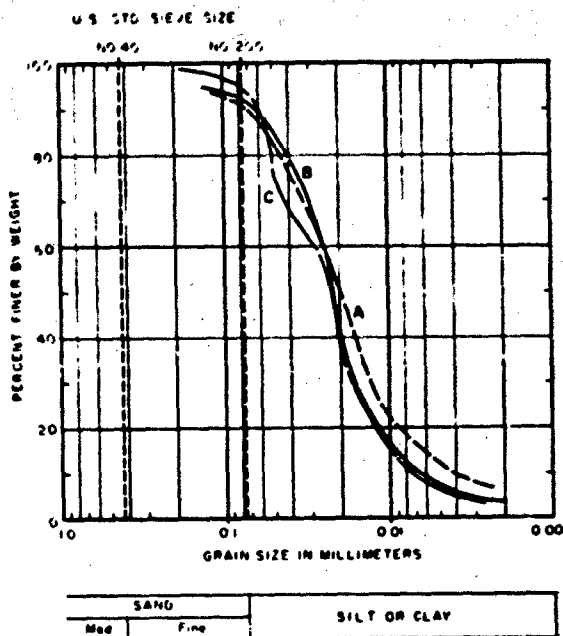


Figure 7. Mechanical analysis of tunnel material and hilltop silt sections. A - Hill-top silt (loess) collected from 10-ft section on Birch Hill (Fort Wainwright). B - Hill-top silt (loess) collected from 15-ft exposure near University of Alaska experimental station. C - Composite sample from entire tunnel section.

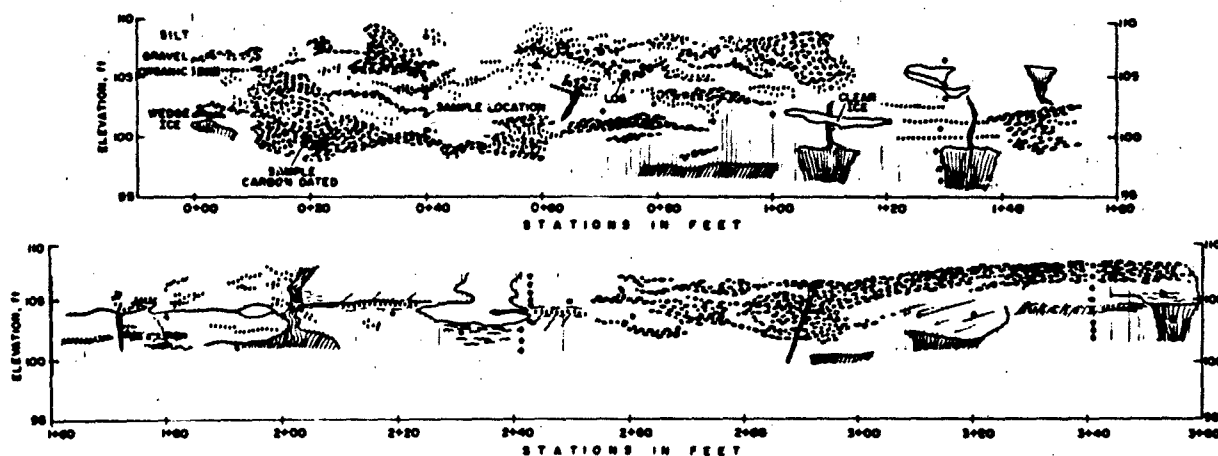


Figure 8. Idealized sketch of tunnel section showing distribution of major tunnel constituents; silts, gravel, organic material and ice. Dots indicate sample locations.

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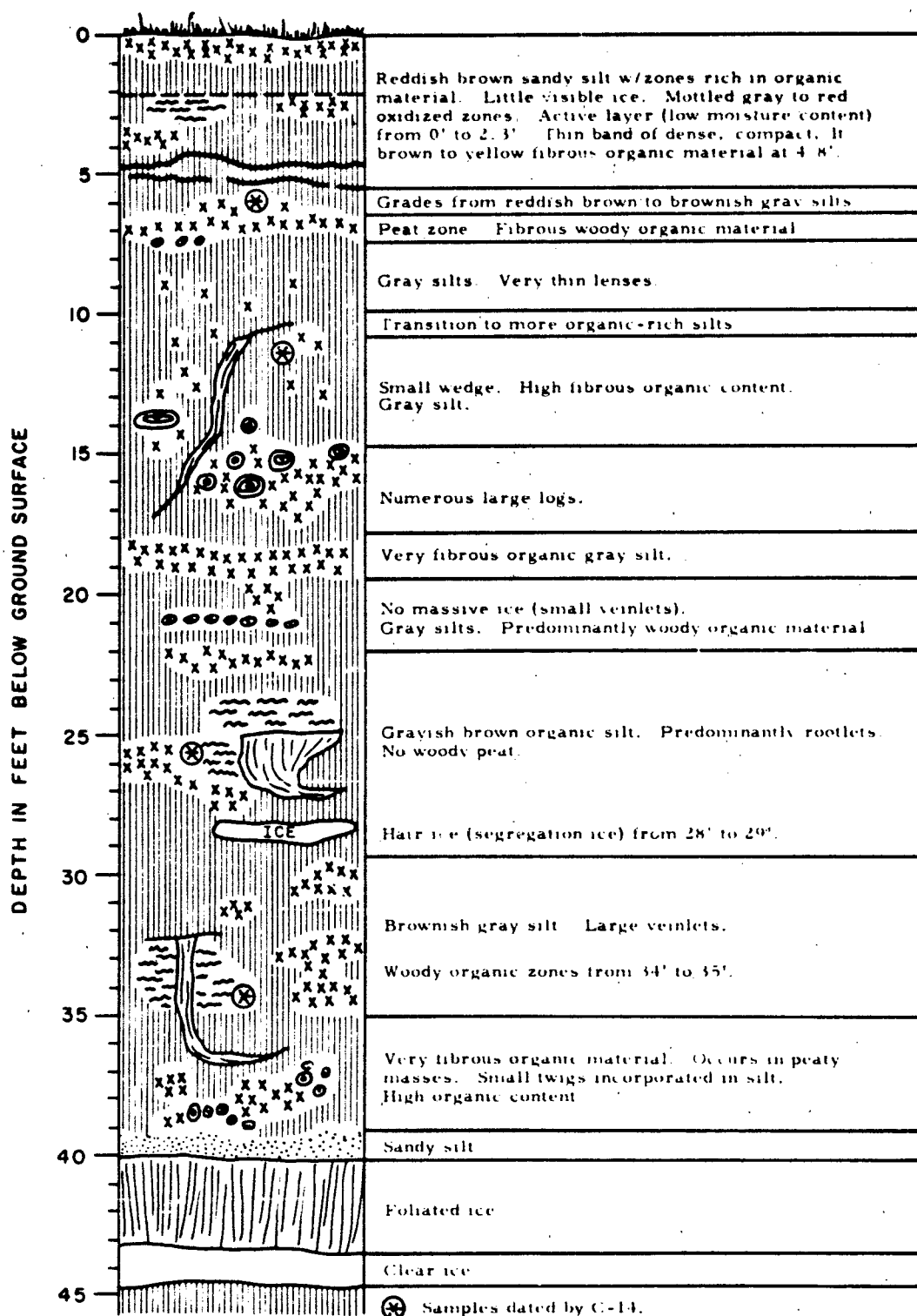


Figure 9. Diagrammatic section of vertical ventilation shaft at sta. 3+55. Samples taken at 2-ft intervals. All silts are amorphous.

GEOLOGY OF THE USA CRREL PERMAFROST TUNNEL

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TABLE I. PHYSICAL PROPERTIES OF MATERIAL.

Sample no.	Bulk density, γ		Dry density, γ_D		Moisture content w (%)	Void ratio e	Grain spec. gr.	Vol. org. (%)	Vol. ice (%)
	(lb/ft ³)	(g/cm ³)	(lb/ft ³)	(g/cm ³)					
TUNNEL									
0-40(1)	96.8	1.55	60.0	0.96	60.9	1.78	2.68	2.7	64.1
0-40(2)	90.5	1.45	49.9	0.80	79.7	2.33	2.68	2.7	69.9
0-40(3)	98.0	1.57	61.8	0.99	57.8	1.67	2.66	3.9	62.7
0-40(4)	95.5	1.53	58.7	0.94	62.4	1.80	2.65	4.3	64.3
0-40(5)	99.3	1.59	63.7	1.02	54.7	1.58	2.65	4.6	61.3
0-73(1)	91.2	1.46	51.8	0.83	75.7	2.18	2.64	4.1	68.6
3-80(1)	94.3	1.51	56.8	0.91	66.3	1.92	2.66	4.1	65.8
3-90(1)	88.0	1.41	46.8	0.75	87.9	2.55	2.66	3.1	71.1
1-10(1)	100.5	1.61	66.8	1.07	50.7	1.47	2.65	4.7	59.4
1-10(1)	80.5	1.29	35.9	0.57	126.8	3.66	2.65	2.5	78.6
1-23(1)	103.6	1.66	71.8	1.15	44.7	1.29	2.64	5.6	56.3
1-30(1)	83.7	1.34	40.0	0.64	107.8	3.09	2.63	3.3	75.6
1-30(2)	93.6	1.50	58.8	0.91	65.6	1.88	2.62	5.0	65.2
1-30(3)	104.3	1.67	72.4	1.16	44.5	1.27	2.63	5.9	56.1
1-30(4)	91.8	1.47	53.1	0.85	72.9	2.07	2.61	5.1	67.5
1-30(5)	86.8	1.39	45.0	0.72	91.3	2.60	2.61	4.3	72.2
1-30(6)	91.8	1.47	53.7	0.86	72.0	2.07	2.63	4.6	67.4
1-30(7)	95.5	1.53	59.3	0.95	61.2	1.73	2.59	6.6	63.4
1-80(1)	80.5	1.29	36.2	0.58	122.8	3.52	2.63	3.3	77.9
2-20(1)	-	-	-	-	109.7	-	-	-	-
2-30(1)	32.4	1.32	39.3	0.63	111.4	3.19	2.63	5.7	76.2
2-40(1)	96.1	1.54	60.0	0.96	63.3	1.72	2.63	5.2	58.1
2-40(2)	93.6	1.50	56.8	0.91	66.1	1.88	2.61	5.7	60.4
2-40(3)	91.8	1.47	54.3	0.86	70.1	1.97	2.57	6.8	66.3
2-40(4)	87.4	1.40	46.8	0.75	86.5	2.44	2.59	5.1	65.0
2-40(5)	93.6	1.50	56.2	0.90	67.2	1.91	2.61	5.8	60.2
2-40(6)	94.9	1.52	60.6	0.97	57.1	1.52	2.45	7.4	55.4
2-40(7)	100.5	1.61	66.8	1.07	50.5	1.42	2.59	7.3	53.8
2-40(8)	102.3	1.64	63.7	1.10	47.9	1.38	2.63	5.8	47.9
2-40(9)	91.3	1.49	55.6	0.89	67.8	1.92	2.60	5.9	60.3
2-50(1)	99.9	1.60	65.6	1.05	52.3	1.50	2.64	5.1	55.1
2-60(1)	103.6	1.66	71.2	1.14	45.2	1.29	2.62	6.5	56.4
2-70(1)	100.0	1.59	64.3	1.03	54.3	1.56	2.63	5.6	60.9
2-80(1)	82.4	1.32	38.1	0.61	114.7	3.43	2.73	1.8	77.4
2-90(1)	88.7	1.42	48.1	0.77	84.0	2.41	2.63	4.1	70.7
3-10(1)	92.4	1.48	54.3	0.87	70.8	2.02	2.61	5.1	66.8
3-10(1)	89.9	1.44	50.6	0.81	77.0	2.16	2.58	6.1	62.7
3-20(1)	85.5	1.37	43.7	0.70	96.8	2.77	2.62	4.1	73.5
3-40(1)	81.2	1.30	36.8	0.59	120.7	3.50	2.66	2.2	71.3
3-40(2)	90.5	1.45	50.6	0.81	78.8	2.28	2.65	3.6	69.5
3-40(3)	88.7	1.42	48.1	0.77	84.4	2.43	2.64	3.7	64.9
3-40(4)	89.3	1.43	48.7	0.78	83.1	2.38	2.64	4.2	64.5
3-40(5)	89.3	1.43	49.3	0.79	81.6	2.33	2.62	4.5	64.1
3-40(6)	88.7	1.42	48.7	0.78	81.4	2.30	2.59	5.6	69.7
3-40(7)	83.7	1.34	40.6	0.65	104.6	2.95	2.59	4.4	68.5
3-40(8)	79.3	1.27	35.0	0.56	128.2	3.53	2.53	5.2	71.4
VERTICAL SHAFT									
# 2	114.9	1.84	86.8	1.39	31.8	0.94	2.73	3.4	48.4
# 4	87.3	1.43	50.9	0.84	74.7	2.00	2.45	7.4	66.7
# 6	100.5	1.61	66.6	1.07	50.5	1.44	2.60	5.5	58.9
# 8	108.0	1.73	77.8	1.25	39.0	1.13	2.66	2.6	53.2
#10	97.4	1.56	62.5	0.99	57.1	1.63	2.61	4.3	62.0
#12	104.3	1.67	72.5	1.16	44.0	1.27	2.63	4.2	55.9
#14	84.3	1.35	41.5	0.66	102.1	2.88	2.57	3.2	74.2
#16	90.5	1.45	51.1	0.82	76.8	2.19	2.61	3.2	68.7
#18	91.6	1.50	55.9	0.89	67.6	1.95	2.64	6.0	66.0
#20	90.5	1.45	50.9	0.81	77.8	2.25	2.65	2.9	69.2
#22	90.5	1.45	50.9	0.81	77.8	2.25	2.65	2.9	69.2
#24	80.5	1.29	35.6	0.57	126.3	3.71	2.69	1.4	78.8
#26	78.0	1.25	32.8	0.52	138.8	3.91	2.58	2.9	79.6
#28	86.8	1.39	46.0	0.74	84.6	2.48	2.57	4.5	71.3
#30	88.0	1.41	47.7	0.76	84.3	2.38	2.58	-	70.4
#32	93.0	1.49	56.2	0.90	66.0	1.85	2.56	4.9	64.9
#34	78.0	1.25	33.9	0.54	130.1	3.39	2.39	4.5	77.2
#36	77.4	1.24	33.7	0.54	130.1	3.30	2.32	4.5	76.7
#38	95.5	1.53	58.7	0.94	62.4	1.73	2.62	3.6	64.1
#40	86.1	1.38	45.4	0.72	89.6	2.46	2.52	4.7	71.1
#40	99.9	1.60	65.7	1.05	51.8	1.47	2.60	4.0	59.5

Sample No. = Position along tunnel section.

Bulk density: $\gamma = \frac{\text{Total wt.}}{\text{Total vol.}}$ Dry density: $\gamma_D = \frac{\text{Wt. solids}}{\text{Total vol.}}$ Moisture content: $w = \frac{\text{Wt. H}_2\text{O}}{\text{Wt. solids}} \times 100$ Void ratio: $e = \frac{\text{Vol. voids}}{\text{Vol. solids}}$ Vol. % ice: $\% V_i = \frac{V_i}{V_{\text{Total}}} \times 100$ Vol. % org.: $\% V_{\text{org}} = \frac{V_{\text{org}}}{V_{\text{Total}}} \times 100$

The material that makes up the tunnel section has unusual properties, which are determined largely by its high ice volume.

The bulk density values of the material range between 78 and 115 lb/ft³ and average 92 lb/ft³, with moisture contents between 32 and 13% by dry weight. The dry densities ranged from 33 - 87 lb/ft³ with an average of 54 lb/ft³. Tests performed on silts from the Fairbanks area by the Corps of Engineers indicate that the maximum dry density as determined by the modified AASHTO method is 107.4 lb/ft³ with an optimum water content of 17.1%. The dry density for undisturbed unfrozen samples varied from 97.1 - 101.5 lb/ft³ with natural moisture contents of 22.9 - 26.9%.

The fine grained gray to gray-brown mineral material in the sections is largely silt sized, with sand to sandy silt constituting the coarsest material in the fine grained fraction. In both the tunnel and the vertical shaft distinctive differences in the physical appearance of the sediment can be attributed to the varying amounts of organic material and ground ice in the sediment. Figure 8 shows the distribution and variability of some types of material that made up the tunnel section.

The silts generally lack recognizable sedimentary structures, although upon close inspection some of the amorphous zones reveal very thin laminations. The convoluted, distorted nature of the sediments is commonly clearly marked by the contrast between zones rich in organic material and zones containing mineral material of varying grain size.

In several cases, horizontally oriented organic zones appear to be displaced by normal faults. These faulted sediments are found in zones adjacent to the larger ice wedge complexes, where sufficient forces may be developed during wedge formation to cause minor displacements. The distribution of the silt in the section is indicated in the idealized tunnel sections (Fig. 8, 9).

The most striking gradation in the color of the sediments was found in the upper portion of the tunnel shaft in and just below the active layer. The upper silts were mottled, had a red-brown to brown coloration, and graded to the more typical brown-gray silts at a depth of 5 ft.

Ground ice

One of the more obvious physical differences in the appearance of the fine-grained sediments in the tunnel section is caused by the varying amounts of ice in the silt. The ice types can be divided into two general groups: (1) the small lenses and masses formed by ice segregation, referred to as Taber ice (Péwé, 1966), segregation ice or hair ice (Fig. 10), and (2) the more massive structures, the large foliated ice wedges and the large clear masses (buried Aufeis) (Fig. 8, 11).

The large volume of ground ice incorporated in the sediment is unique for both geological and engineering reasons. The large truncated ice wedges found in the section provide an excellent geological tool for determining the past depositional and climatic conditions. Large volumes (as great as 80%) of interstitial ice would tend to impart strength properties to the material similar to ice itself.

All the data on sediment physical properties were gathered from the more silty members containing the first type of ice. The lenses varied in size from small veinlets with hairline dimensions to large lenses and bands of ice often

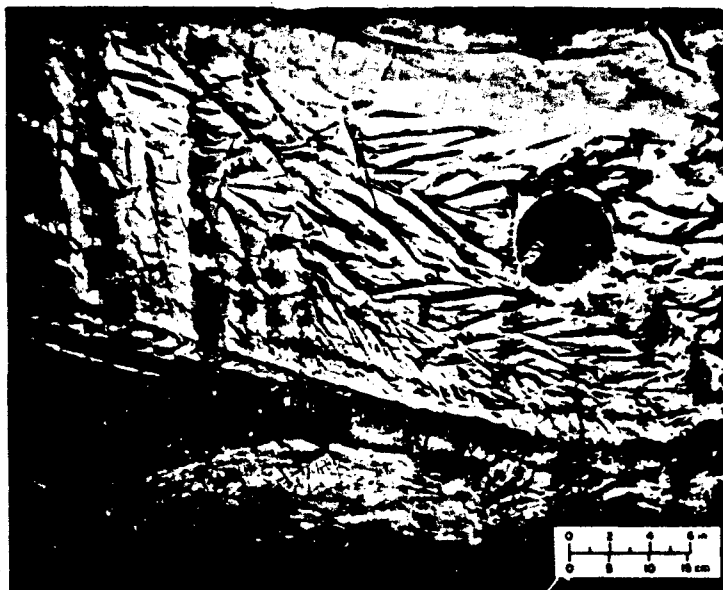


Figure 10. Lenses of segregation ice typical of the large types, in the exposure of sta. 2+05.

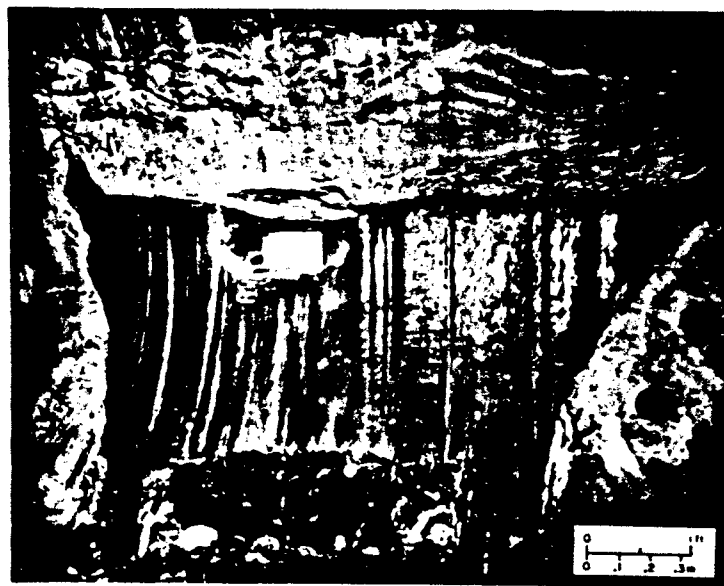


Figure 11. Flat-topped ice wedge at sta. 3+55 overlain by sands that contain fluvial structures. Sampled zone at the base of the wedge provided material for determination of an average age of the wedge development.

several tenths of an inch in thickness and several inches in length. In most cases the ice volume is great enough so that individual blocks or peds of mineral material are completely surrounded by a matrix of ice. Ice volumes of this material ranged from 54 to 79%.

There are several areas along the tunnel exposure in which an abundance of both types of massive ice is present (sta. 0+90, 1+10, 1+35, 1+42, 2+05, 2+30, 2+95, 3+15, 3+50). Even though these structures are quite large they make up a small part of the total ground ice volume of the tunnel. Most of the wedge configurations are very complex with trends that are difficult to determine without a study of the wedge foliation patterns.

The clear structureless ice, referred to as Aufeis, as found at sta. 2+30, is thought to originate as pond ice, or a spring or stream icing at a paleosurface, the ice becoming incorporated in the frozen section by rapid burial as a result of slumping or the flow of thawed mineral material.

The massive ice in the shaft is restricted to three zones that contain small wedges less than 9 in. in width, except for the large wedge at the base of the shaft (Fig. 9). This large foliated ice body overlies clear ice that is not typical of that usually associated with ice wedges. Almost all of the wedges in the exposures have flat tops that may reflect some interruption in their formation. This aspect of the wedges is discussed in the following section. Relative distribution of the large ice features is shown in Figure 8. The mechanics of formation of these wedge structures has been described by Taber (1943), Black (1951, 1952), Lachenbruch (1960, 1963) and Péwé *et al.* (1965b).

Chemical gradient

Ten samples from the vertical shaft and five from the tunnel were processed to determine both the total cation content of the extracted soil water, and the organic carbon to nitrogen ratio. It was hoped that these parameters could be used in conjunction with the standard geological methods to establish more positively the geological and environmental history of the area.

Specific conductance was determined on the soil water extracted from the thawed samples by the vacuum filter technique. The total concentration of Ca, Mg, K, and Na was determined. The methods used are reported by Brown (1966) and O'Sullivan (1966). Total cation concentration versus conductance provided a correlation coefficient of 0.98, suggesting that additional data on the Fairbanks silts could be easily obtained without detailed chemical analysis by use of this relation. With the milliequivalent/liter values available the relative chemical concentration can be expressed as meq/100 g of oven-dried soil. This expression combines the meq/l values determined by specific conductance with the moisture content of the sample in the equation:

$$\text{meq/100 g} = \frac{\text{meq/l} \times \text{moisture content}}{1000}$$

The values for total cation concentration in the vertical section show a marked break in the chemical profile with depth (Fig. 12, 13). The values for total cation concentration expressed in meq/100 g of oven-dried soil averaged 0.31 above the break (27 ft) and 2.79 below it. This increase in total cation concentration below the break can be used as a possible indicator of varying conditions in the depositional environment, during and after deposition. A reasonable assumption is that the longer the material is subjected to thaw the longer the time available for freshening of the sediment by removal of the soluble salts by the ground water.

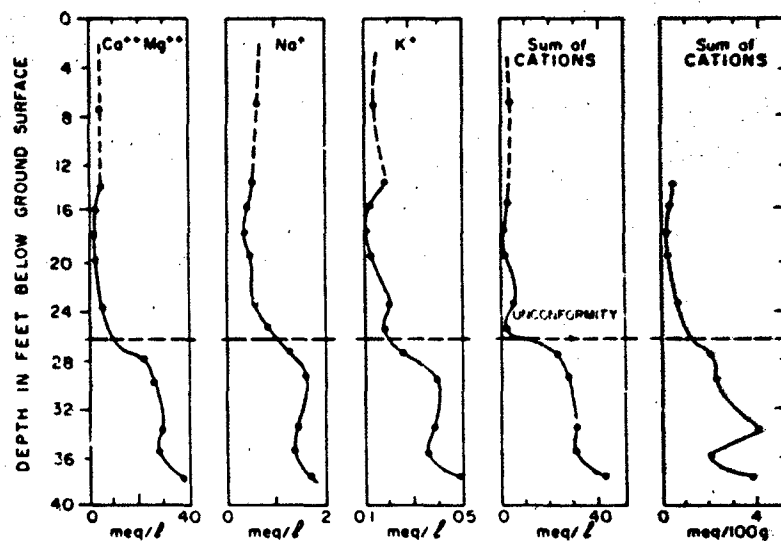


Figure 12. Chemical concentration with depth in meq/l.

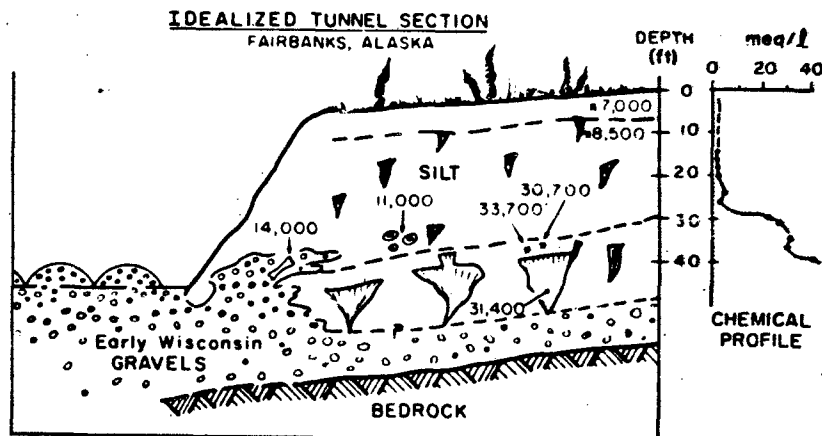


Figure 13. Ice wedge distribution and relative position of radiocarbon dates from the tunnel section.

It was anticipated that significant differences between organic carbon and nitrogen ratios in the section might reflect major changes in the post-depositional environments. Only minor variations in the values exist, with ratios ranging from 9.2 to 13.6, and averaging 10.6. Since the ratios represent such a small range it is difficult to establish if the variations are meaningful and what the concise reason for the variations might be. Although the values do seem to reflect the observed chemical break in the section, the average of the

two samples above the break is 9.4 in contrast to 10.6 for the three samples below the break; again this is only a minor difference to which little significance can be attached. These ratios are somewhat lower than those found in the present day Fairbanks surface soils (Rieger *et al.*, 1963).

STRATIGRAPHY

A study of the stratigraphy of the section reveals a record of the past climatic history of the area, based upon the structure and distribution of the ice wedges, chemical gradients, sedimentary structures, radiocarbon dates, and the lithology of the material exposed along the tunnel section and vertical ventilation shaft.

Four samples were selected for radiocarbon dating from the vertical shaft and seven from the tunnel. A variety of datable material was available from the massive silts which contain the large volume of organic material required for dating purposes. This material is made up of small organic fibers, plant fragments and rootlets, which constitute from 1.5 to 7.5% of the sediment volume. The material is incorporated in the silts as masses and blocks of peaty material and as individual rootlets and fibers with a spacing similar to that found in contemporary near-surface soil horizons. In both the tunnel section and in the vertical shaft woody material is also exposed, consisting of logs and twigs, and inarticulate segments of large woody bushes and trees. Bone fragments of large vertebrates were also found throughout the section and provided additional datable material. In contrast to the conventional datable material the relative age of several of the large wedge structures was determined from organic residue and amorphous plant material extracted from the melt of large volumes of ice from the wedges, similar to the technique first used by Brown (1966) at Barrow.

The samples processed from the shaft consisted of fine fibrous vegetal material such as rootlets, stems, and plant fragments dispersed in varying concentrations in the frozen silt. The samples submitted for dating were carefully sieved and sorted so that only similar types of material would be processed. Table II gives the location, material and age of each sample. Their relative stratigraphic positions in relation to the other samples dated are shown in Figure 9.

The sample locations in the vertical shaft were selected to allow estimates of rates of deposition to be made and to determine the relationship between the age of the sediments and the striking chemical gradients in the section. In addition, samples selected adjacent to and below the tops of buried ice wedges provided information on the chronology of events responsible for termination of wedge growth.

Rough approximations of the depositional rates can be made from the two samples highest in the section, although obviously these rates may have varied greatly throughout the 6-ft section. The dates for depths of 6 ft (I-2118) and 12 ft (I-2119) suggest that a minimum of 6 ft of sediment was deposited between the surface and the first sample in 7000 years and that the next 6 ft was deposited during the next 1500 years.

The second sample, I-2119, was adjacent to and just below the top of a small flat-topped ice wedge.

Table II. Samples dated.

TUNNEL

<u>Sample no.*</u>	<u>Location</u>	<u>Material</u>	<u>Age (years)</u>
I-1369†	0+59	Log	11,400±450 (9,450 BC)
I-1370†	1+00	Log	11,000±280 (9,050 BC)
I-1841	3+56	Twig	33,700±2500 -1900 (31,700 BC)
I-1842	3+55	Ice wedge residue	31,400±2900 -2100 (29,400 BC)
I-1843	2+05	Ice wedge residue	32,300±2000 -1600 (30,300 BC)
I-2196†	0+15	Bone	15,470±420 (11,520 BC)
I-2197†	0+15	Bone	14,280±230 (12,330 BC)

VERTICAL SHAFT

	<u>Depth from surface</u>		
I-2118	6 ft	Fine fibrous organic	6,970±135 (5,020 BC)
I-2119	12 ft	Fine fibrous organic	8,460±250 (6,510 BC)
I-2120	26 ft	Fine fibrous organic	2,510±570 560 BC)
I-2121	34 ft	Fine fibrous organic	30,700±2,100 -1,600 (28,700 BC)

* Dating was by Isotopes, Inc., Westwood, New Jersey.

† Samples acquired and submitted by Dr. G. Swinzow.

The third date in the series (I-2120) was discarded as the dating lab implied doubt about its validity because of the small sample size and low percent of carbon.

The oldest date from this section was 30,700 years (at 34 ft) which again compared favorably with depth-age relationships from the other dated sections in the Fairbanks area (Péwé, 1958), on Ready Bullion Creek (Péwé et al., 1965a) and with dated material almost immediately below the shaft in the tunnel section (I-1841, I-1842).

In the tunnel, dates of 9450 and 9050 years BC were obtained from logs collected near the portal at sta. 0+59 and 1+00, approximately 33 ft below the surface, in zones containing abundant woody material (Swinzow, 1965, personal communication). The sediments in these sections are convoluted and distorted.

Disarticulate bone material was collected at sta. 0+15 from the contorted gravel zone, approximately 5 ft stratigraphically lower in the section than the 9000 year BC dates. This material yielded ages of 11,520 and 12,330 years BC. The material was obviously retransported and possibly stream deposited. The large ice wedges at sta. 2+05 and 3+55, which are stratigraphically lower than the preceding samples, provided average ages of 30,000 and 29,400 years BC respectively. The dated residue was concentrated from the melt of approximately 3 ft³ of ice, 40 and 42 ft below the surface. The residue originated from surface water rich in organic and mineral material which percolated into and filled the repetitive contraction cracks from a paleosurface.

The oldest material dated was a small twig from the fluvial sands above the flat-topped wedge at sta. 3+55. The sandy material was probably deposited in drainage channels which formed after the truncation of the wedge. The 31,700 BC date for the twig suggests that the woody material was retransported and does not date the time of deposition of the sands.

Figure 13 presents an idealized summary section showing the distribution and relative size of the ice wedges in the section and associated radiocarbon dates and chemical profile.

The ice wedge structures, particularly the presence or absence and size of the buried ice wedges, and the relationship of the surrounding sediments to the wedge can be particularly useful in interpreting the geological and climatological history of an area (McCulloch et al., in press; Brown, 1965, 1966; Péwé et al., 1965a). Flat-topped buried wedges may indicate a degradation of the perennially frozen ground and an interruption in wedge development, a possible indication of (1) a regional warming, or (2) some erosional or depositional event. Such wedges may reflect a complex two-stage development where a wedge was truncated and conditions then became rigorous enough for the wedge to again become active. This renewed growth is often indicated by a small wedge that extends upward from the top of the large flat-topped mass, as shown in Figure 11.

The ice wedge structures can be broken into two groups based on their size. In the upper 30 ft of the section the wedges are very small and from the limited exposures none appear to exceed 1 ft in width, in contrast to the exceedingly large forms as much as 3-6 ft in width found below the 30-ft depth.

The possible truncation and burial of the small wedge highest in the section probably took place no more than 8500 years ago. The actual time required for the formation of a wedge this size is very short, several hundred years under optimum conditions.

The size and position of this small wedge corresponds with other buried flat-topped wedges found in other exposures in the Fairbanks area (Péwé, 1952). A section on Ready Bullion Creek also reveals several buried flat-topped wedges within 10 ft of the surface. Dating of these sections indicates that they may have been truncated at the end of Wisconsin time (Péwé *et al.*, 1965a).

The wedges are reported to be unconformably overlain by silts of recent age that retain evidence of sedimentary structures, in contrast to the massive Wisconsin silts. The similarities between the two locations based on the limited amount of exposure available in the tunnel shaft are the similar depths to the top of the first flat-topped ice wedge in the section and the age of the sediments in the upper 10-15 ft of section. The upper 6 ft of sediment in the tunnel section is not bedded as it is in the Ready Bullion section. Instead it has a massive marbled appearance with a reddish to gray coloration, an indication of oxidation and possible decomposition of the organic material incorporated in the upper section. The differences in the index properties between the young material in the upper part of the section and the Wisconsin age sediments can be seen in Table I.

The other small wedges found at irregular intervals above the 30-ft break can be interpreted as indicating fairly rapid deposition with few periods with a stable land surface, or thermal conditions conducive to wedge growth.

The break previously mentioned at the 30-ft depth as indicated by the radiocarbon dates and chemical gradients is also suggested by the striking difference in the size of the ice wedges. The large wedge forms are exposed below the break at sta. 0+90, 1+10, 1+30, 2+00, 2+95, 3+15 and 3+55. These large wedges suggest a period of stability of the land surface of sufficient duration for the wedges to attain their large size.

CONCLUDING STATEMENTS

Two recognizable unconformities appear in the section. The upper unconformity at a depth of 10 ft is marked by a small ice wedge and a change in the nature of the sediment from reddish gray mottled oxidized silts in contrast to the more organic-rich amorphous silt below the break. At a depth of approximately 30 ft the second unconformity seems to be apparent. It is marked by the change in size of the ice wedges, as well as the flat-topped forms all at the same stratigraphic position, the jump in the radiocarbon dates from 14,000 to 30,000 years and the 20-fold increase in chemical concentration with depth.

Based on the above factual stratigraphic information and a knowledge of events during the late Pleistocene time in other areas, past events in the tunnel section can be interpreted.

The upper unconformity can be found in other sections in the Fairbanks area and is interpreted as representing degradation of the frozen ground during a period of widespread regional warming (the hypsithermal) sometime between 4000 and 8500 years ago. This event appears to be recorded in the section by a small flat-topped wedge occurring in the upper portion of the vertical shaft, and by a change in lithology of the sediment. Dates from this horizon are between 5020 and 6510 years BC. The sediments above the break are thought to be retransported silts of recent age, overlying the late Wisconsin silts.

The most obvious "unconformity" at a depth of approximately 30 ft is well documented in the tunnel section. This unconformity was probably caused by some regional warming or local depositional or erosional event. Additional evidence for an unconformity at this depth in the Fairbanks area is suggested by the dates from the Ready Bullion section, where a thick layer of relatively young sediments similarly overlies sediments 30,000 years old. The unconformity is not marked by any apparent changes in the physical properties of the material that can be seen in the tunnel section above or below the break with the exception of the chemical profile and the size of the ice wedge structures. A warming event, if responsible for its formation, may correlate with an interstadial in mid-Wisconsin time. This warm interval is thought to be responsible for high stands of the sea between 27,000 and 35,000 years ago which is referred to as the Worenzofian transgression (Hopkins, 1966). Evidence for this transgression has been found in several coastal areas in Alaska (Sellmann *et al.*, 1965; Hopkins, 1966).

The large size of the wedges also suggests that depositional rates were fairly slow during the period of wedge development so that a stable land surface could develop from which the large wedges could form. Second cycle development in these large forms is suggested by small cracks and secondary wedges extending upward from the top of the large forms.

It can also be concluded that within the last 30,000 years a minimum of 30 ft of silt was deposited, under greatly varying depositional conditions and rates, and that all of the sediment examined in section with the exception of some of the gravels low in the section near the tunnel portal are of Wisconsin age. The sediments in the lower 15 ft represent events that took place prior to the last 30,000 years.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H.		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE GEOLOGY OF THE USA CRREL PERMAFROST TUNNEL, FAIRBANKS, ALASKA		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report		
5. AUTHOR(S) (Last name, first name, initial) Sellmann, Paul V.		
6. REPORT DATE July 1967	7a. TOTAL NO. OF PAGES 26	7b. NO. OF REFS 29
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. DA Task IVO25001A13001 d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 199 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY U. S. Army Cold Regions Research and Engineering Laboratory
13. ABSTRACT This study provides the pertinent regional and historical geology of the tunnel site and immediate surroundings as well as data on the index properties and seismic velocities of the material through which the tunnel passes. The tunnel, located in the discontinuous permafrost zone, is discussed with emphasis on bedrock, gravel, silt, ground ice, and chemical gradient. A study of the stratigraphy of the section reveals a record of the past climatic history of the area, based on the structure and distribution of the ice wedges, chemical gradients, sedimentary structures, radiocarbon dates, and the lithology of the material exposed along the tunnel section and vertical ventilation shaft. Two recognizable unconformities appear in the section. The large size of the wedges suggests that depositional rates were fairly slow during the period of wedge development. It can also be concluded that within the last 30,000 yr a minimum of 30 ft of silt was deposited, most of which is Wisconsin age.		

DD FORM 1473
1 JAN 64

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Permafrost tunnels--Alaska Glacial geology--Stratigraphy--Alaska Geology--Age determination Ground ice--Alaska						

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