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INTERIM REPORT

Auth. 112681 - Resource Investigations

Item 7. Heavy Metals Investigations

THAWING PLACER GRAVELS ON THE NOME COASTAL PLAIN

by

John J. Mulligan

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Area VIII Mineral Resource Office

INTRODUCTION

The Bureau of Mines, as a part of the heavy metals program, started research on the thawing of permanently frozen placer deposits during the summer and fall of 1966 in cooperation with the United States Smelting Refining and Mining Co. The cooperative program is based on research and development by this company and its predecessors on the Nome coastal plain. Between the end of World War I and the beginning of World War II, cold water thawing was developed from a theoretical possibility to a production technique that made possible the mining of many millions of cubic yards of frozen gravel annually. Development and improvement of thawing techniques was halted by the shut down of gold mines during World War II, and the decline of gold mining after World War II discouraged the resumption of research and experimentation. Cold water thawing practices remain virtually unchanged since the United States Smelting Refining and Mining Co. made large-scale field tests on the submarine beach in 1938 and 1939.

The objective of the Bureau of Mines investigation in cooperation with the United States Smelting Refining and Mining Co. is to lower the cost of thawing permanently frozen gravels to 10 cents per cubic yard or less. The first step is to determine the extent to which the time-proven cold water thawing process can be mechanized and to determine what effect this will have on costs. If mechanization does not lower costs to 10 cents per cubic yard, other thawing methods will be investigated.

This interim report includes some material from Heavy Metals Situation Report No. 13, "Gold Placers of the Nome Plain." Additional technical data and information are included; the results of the study to date (June 30, 1967) are discussed, and a tentative work plan is presented.

LOCATION AND ACCESS

Nome, Alaska (figs. 1-2) is centrally located on a crescent-shaped coastal plain that extends about 30 miles along the Bering Sea coast and about 4 miles inland. Gold can be panned on the present beach from one end of the crescent to the other, but most of the productive gold placer deposits of the coastal plain have been found within 5 miles of Nome.

Nome is the center of air traffic, the chief port-of-call for ships, and the distribution center of the Seward Peninsula. All passengers and mail and much of the freight are transported to the Seward Peninsula by air. Regularly scheduled airlines based in Fairbanks and Anchorage make daily flights into Nome. Planes ranging in size from large commercial to small bush types are available for charter. General cargo steamships from Seattle make three trips per year to Nome and the Bering Sea ports. Standard Oil Co. tankers also serve a bulk distribution plant for petroleum products of all types. The first ship leaves Seattle about May 20 and the last

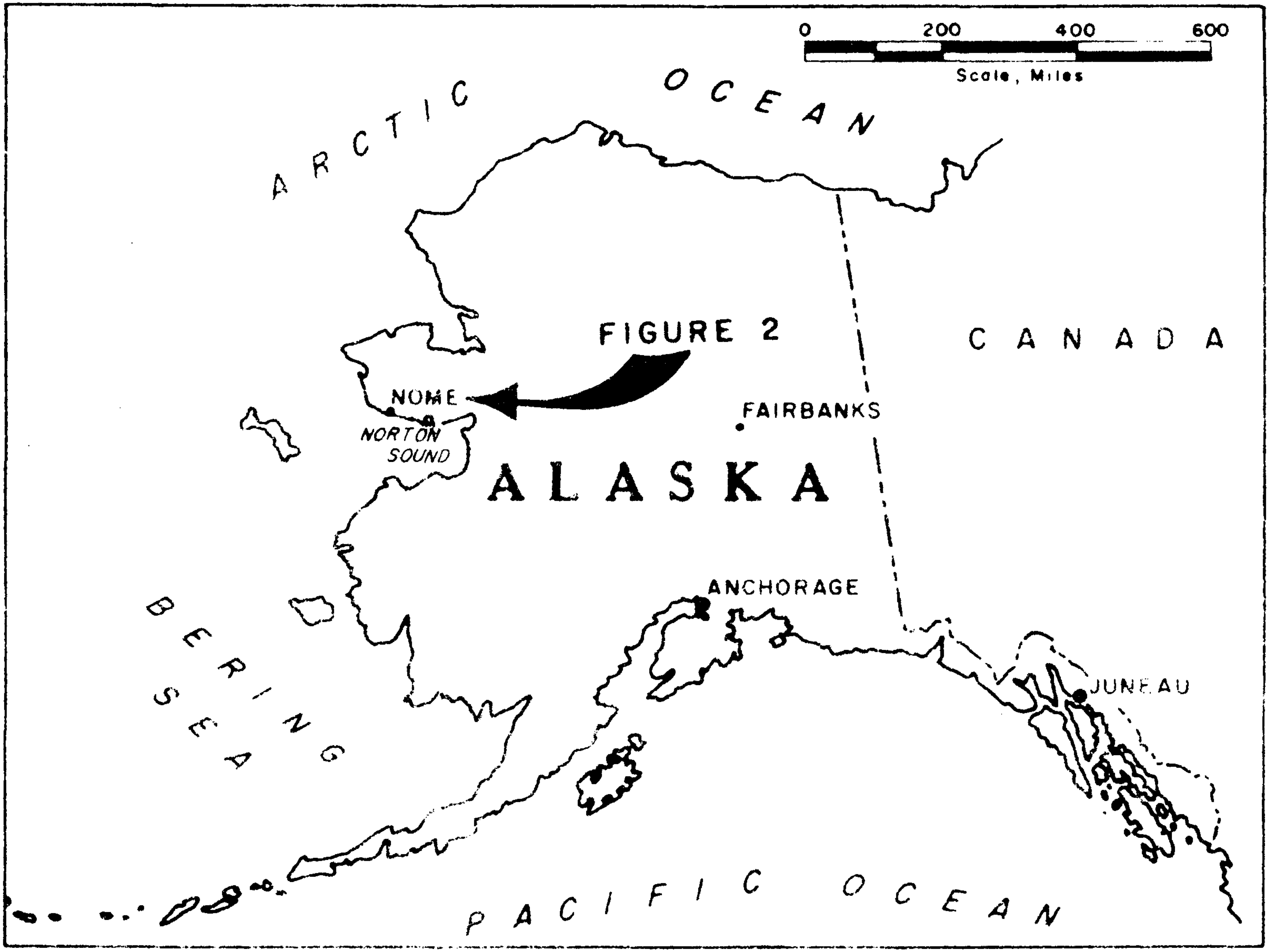

FIGURE 1 - Index Map of Alaska

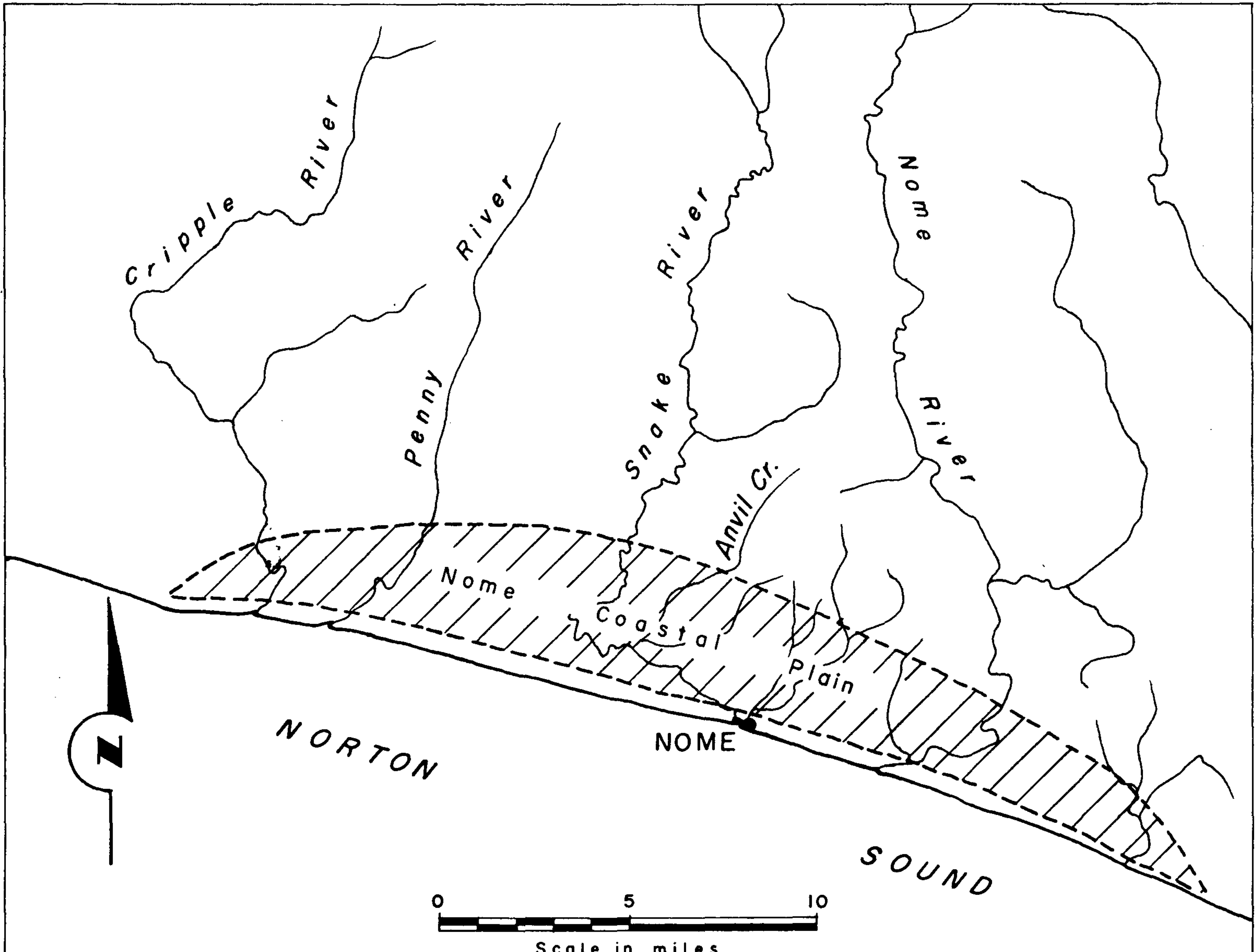

FIGURE 2.- Nome Coastal Plain.

about September 1. The ships are scheduled to leave the Bering Sea in early October. No ports have docks where ships can unload; all freight is lightered ashore by tugs which tow barges carrying 50 to 150 tons. Tugs, barges, and landing craft are used for local coastwise shipping. When the load size is large enough to justify it, shipments are brought in by tug and barge from the west coast of the United States or from other parts of Alaska.

Freight rates are too complex to cover in this report. However, the following are generally indicative of freight costs:

The C130 Hercules (L-382) aircraft can carry 25 tons, and the airline distance from Nome to Anchorage is 542 miles and from Nome to either Chicago or San Francisco is about 3,000 miles. The rate for a flight originating in the contiguous states is $3.25 per mile. The rate for flights originating in Anchorage is $3.50 per mile. The rate for flights originating in Nome is $3.75 per mile. The user must pay for the return empty unless a return cargo is available.

Air freight rate from Anchorage or Fairbanks to Nome is $0.09 per pound. The air freight rate from Seattle to Anchorage is $0.23 per pound or $17.00 per cwt.

The rate for drilling equipment shipped by Alaska Steamship Co. from Seattle to Nome:

	Dollars	
	per cwt	per cubic foot
Terminal charges, Seattle	0.07625	0.1125
Ocean freight	1.07500	2.1500
Lighterage and terminal charges, Nome	.28500	.5700
Total	1.43625	2.8325

For instance, a drill rig weighing 30,000 pounds and having a volume of 3,000 cubic feet:

	Cubic foot basis	Weight basis
Total freight	$4,308.75	$849.75

Freight is computed both by weight and volume, and the higher total is the charge; in this case, $4,308.75.

The following are typical passenger rates via commercial aircraft.

	Without tax	With tax
Seattle - Nome	$179.00	$187.95
Juneau - Nome	100.00	105.00
Anchorage - Nome	55.00	57.75
Fairbanks - Nome	50.00	52.50

The following are typical air freight rates:

Juneau - Nome (under 100 pounds)	$0.28 per pound
Juneau - Nome (over 100 pounds)	.19 per pound
Juneau - Nome (5,000 pounds and over)	.18 per pound
Seattle/Tacoma - Nome, via Fairbanks or Anchorage (under 100 pounds)	.32 per pound
Seattle/Tacoma - Nome, via Fairbanks or Anchorage (over 100 pounds)	.26 per pound
Anchorage - Nome (under 100 pounds)	.12 per pound
Anchorage - Nome (over 100 pounds)	9.10 per cwt
Fairbanks - Nome	.09 per pound

CLIMATE

The following is quoted from a Weather Bureau summary of local climatological conditions:

> The climate of Nome, Alaska is moderated by the open water of Norton Sound from early June to about the middle of November. Storms moving through this area during these months are accompanied by extended periods of rain and cloud. The daily temperature range is very slight during the summer months and the nearly continuous cloud cover during July and August gives an average of 32 cloudy, 13 partly cloudy, and only 7 clear days for the 2-month period. The freezing of Norton Sound in November causes a rather abrupt change from a maritime to a continental climate. The majority of low pressure areas during this period take a path south of Nome, drawing cold air down from the north and giving strong easterly winds accompanied by frequent blizzards.
>
> Temperatures generally remain well below freezing from the middle of November to the latter part of April, and January is the coldest month of the year. The lowest temperature on record occurred on January 25, 1919, when the temperature fell to 47° below zero. Temperatures begin to rise near the end of February and reach a maximum in July. The highest temperature on record, 84°, occurred on July 3, 1936. An unusual aspect of the yearly

temperature trend is the short period of thawing weather in January. In spite of the generally low temperatures, the maximum during the month is often above freezing and the 'January thaw' expected by old time residents usually occurs in fact.

Precipitation is at a maximum during the late summer months and at a minimum in April and May. Snow begins to fall in October but does not usually start to accumulate on the ground until the first part of November. Then the depth increases during November, December, and January, reaching a maximum depth late in February or early March. The snow cover decreases rapidly in April and May and normally disappears by the middle of June. The greatest snow depth ever recorded at Nome was 74 inches in March 1949.

Average wind speeds for each month are not excessive (they range from 8.8 to 11.0 miles per hour); but severe storms are not uncommon and winds of over 70 miles an hour have been recorded several times. Strong winds occurring when snow cover is present produce blowing snow conditions and severely hinder transportation.

Some pertinent climatological data are summarized in table 1. Table 2 shows the number of days per year that the dredges worked from 1936 to 1940, a period of high and profitable productivity. The dredging season is determined by the availability of water and by the buildup of ice in the dredge ponds. Only the top few feet of thawed ground freezes. The digging and recovery plant on a dredge can be protected from cold, but the dredge hull swinging back and forth breaks the ice on the pond and pushes it into piles that refreeze on the side of the dredge pond until the dredge no longer has room to swing. Dredges can work about 170 days per year, but the period when the cold water thawing is effective varies from 90 to 120 days. Therefore, the amount of ground thawed per day must be nearly double the dredging rate per day. The cold water thawing season is limited by both air and water temperatures. The water temperature should not go much below 40° F and the air temperature should not be cold enough to freeze water in the feeder pipes.

TABLE 1. - Weather summary, Nome

Month	Percent of possible sunshine	Mean number of days									
		Sunrise to sunset			Precipitation, 0.01 inch or more	Snow, sleet, hail, 0.01 inch	Heavy fog	Temperatures			
								Maximum		Minimum	
		Clear	Partly cloudy	Cloudy				70° and over	32° and below	32° and below	0° and below
January.....	44	11	6	14	9	3	2	0	29	31	18
February....	46	11	5	12	9	3	1	0	25	28	15
March.......	57	11	6	14	10	4	1	0	28	31	16
April.......	53	9	7	14	9	2	1	0	18	29	6
May.........	51	7	9	15	8	-	3	0	5	22	-
June........	48	7	9	14	9	0	5	1	0	4	0
July........	32	4	6	21	13	0	3	1	0	-	0
August......	26	3	7	21	18	0	1	-	0	2	0
September...	34	5	7	18	15	-	-	0	-	10	0
October.....	35	7	7	17	11	2	-	0	10	25	-
November....	36	10	5	15	10	3	1	0	23	28	7
December....	30	10	5	16	10	4	2	0	29	31	16
Year........	41	95	79	191	131	21	20	3	167	241	78

TABLE 2. - Dredging season, Nome district, Seward Peninsula, Alaska, 1936-40

Year	Starting dates	Number of dredges	Total dredge days	Average days per dredge
1936	May 17.................	3	515	172
1937	May 28.................	3	510	170
1938	May 23.................	3	468	156
1939	Missing................	3	483	161
1940	May 12.................	3	567	189
Average length of dredging season:				5/848
				170

PROPERTY AND OWNERSHIP

The ownership of the large number of claims covering placer deposits on the Nome plain was not investigated because the United States Smelting Refining and Mining Co. and predecessor companies have been operating in practically undisturbed possession for over 40 years. It is the company's policy not to divulge data on reserves or grade, but the company officials do indicate that they control reserves ample for them to continue mining operations on the same general scale for 20 to 40 years. This inference seems to be reasonable and generally in agreement with descriptions of the deposits in publications of the U.S. Geological Survey. Apparently the reserves are large enough to justify research and there is no danger of unintentional trespass; therefore, it is considered unnecessary to spend time and money to verify title.

HISTORY AND PRODUCTION

Gold was discovered in Anvil Creek and adjacent streams (fig. 2) in 1898. Prior to World War I these streams were the principal producers in the region. Mining of the coastal plain deposits started when gold was discovered on the present Nome beach in 1899; a great crowd of hand miners practically exhausted the richer concentrations in less than two years. The second beach was discovered at about this time; the third beach was discovered in 1904, and all of the presently known buried beaches were discovered and roughly outlined within the next few years.

The first dredge was built in 1905 and by 1911 nine dredges were operating in the Nome area. At first, the dredges were limited to thawed ground along stream channels. A series of experiments culminated in the patenting of a cold water thawing technique by J. H. Miles in 1920. This development made large-scale dredging feasible on the Nome gravel plain. Thawing equipment and methods developed at this time continued in use until the close of operations in 1962. Meanwhile, a steady refinement in the construction of dredges and recovery plants culminated in the building of a jig-type bucketline dredge on the submarine beach in 1957. Unexpectedly high thawing and digging costs made the operation of this dredge unprofitable despite a highly efficient recovery plant. The dredge on the submarine beach was shut down in 1959 and all dredging on the Nome plain ceased in 1962.

The gold production of the Nome district from the beginning of mining until the present is listed in table 3. Production of both the adjacent creek placers and the gravel plain placers is included. Since the 1930's, most of the gold has been produced by dredges on the gravel plain.

TABLE 3. - Total gold production, Nome district, Seward Peninsula, Alaska

	Gold	
	Ounces	Value
1898-1930	3,275,626	$ 67,707,200
1931-32, at $20.67	99,826	2,063,403
1933, at $25.56	41,670	1,065,085
1934, at $34.95	63,031	2,202,933
1935-65, at $35.00	1,000,574	35,020,090
Total, 1898-1964, inclusive (68 years)	4,480,727	108,058,711

Average production rate, 1898-1965: 65,893 ounces per year.

Average production rate, 1898-1930: 99,261 ounces per year.

Average production rate, 1931-60: 27,118 ounces per year.

The four years, 1939-42, inclusive, were a period of high productivity of the placers on the Nome gravel plain; 17 million cubic yards of gravels were thawed for less than 8 cents per cubic yard. During the 5-year period, 1954-58, inclusive, 8 million cubic yards of gravel were thawed; the average cost had risen to 26 cents per cubic yard and in some sections exceeded 40 cents. Thawing methods and equipment remained essentially the same; the increased cost apparently resulted principally from the increase in labor costs. Thawing costs had more than tripled, and in some cases, exceeded the value of the recovered gold. Mining became unprofitable; the dredges were shut down as the thawed ground was worked out; the last dredge shut down in 1962.

THE NOME GRAVEL PLAIN

Geology

The following is quoted from a report by Geological Survey geologist D. M. Hopkins, and others (2):1/

> The coastal plain at Nome, Alaska, is underlain by the most complete sequence of Pleistocene marine and glacial sediments known in the American Arctic. Three marine stratigraphic units (Submarine Beach, Third Beach-Intermediate Beach, and Second Beach) record at least three distinct intervals during which sea level stood as high or higher than at present and during which sea temperatures were warmer than at present. A fourth interval of high sea level may be presented by 'Fourth Beach" at the inner edge of the coastal plain. Glacial drift of the Iron Creek (Nebraskan or Kansan) glaciation and of the Nome River (Illinoian) glaciation separates the three marine units, and outwash, alluvium, colluvium, wind-blown silt, and peat that accumulated during Wisconsin and Recent time cover the glacial drift and the youngest of the marine sediments.
>
> The shallow continental shelf beneath the Bering Sea probably was a land area until crustal warping created the present marine basin in Late Tertiary time. The earliest late Cenozoic marine encroachment in the Nome area is recorded by the sediments of Submarine Beach, probably of late Pliocene age; sea level then lay at an altitude that exceeded -20 feet by an unknown amount.
>
> Later, sea level rose to form Fourth Beach, possibly during the Aftonian (First) Interglacial; Fourth Beach now lies at an altitude of 120 feet. Sea level fell, and the coastal plain was invaded by ice during the Iron Creek glaciation which may be of either Nebraskan (First) or Kansan (Second) glacial age. After the ice withdrew, sea level rose again during the Yarmouth (Second) Interglacial to form Third Beach and the associated offshore deposits known locally as Monroeville and Intermediate Beach; sea level probably lay somewhat higher than 75 feet during Third Beach time. During the Illinoian (Third) glacial, the coastal plain was again invaded by ice of the Nome River glaciation. The ice once more withdrew, and sea level rose 35-40 feet above its present position to form Second Beach of Sangamon (Third) Interglacial age.

1/ Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

Sea level fell well below its present position during the Wisconsin (Fourth) glacial age. Ice did not reach the coastal plain at Nome, but a thin mantle of loess was deposited everywhere, and intense frost action resulted in the movement of colluvium that now masks the original glacial microrelief on the drift of the Nome River glaciation (Illinoian).

At the end of the Wisconsin glaciation, 9,000 to 10,000 years ago, the summer climate warmed greatly at Nome, and ice wedges that had formed during the preceding glacial interval were removed by thawing. The climate grew cooler again as rising sea level approached its present position and no subsequent large climatic changes can be recognized in the pollen and stratigraphic record at Nome.

Gold Placers

The gravels that underlie the coastal plain at Nome (figs. 1-2) probably constitute the largest gold placer deposit in Alaska. Gold is unevenly distributed more or less throughout the coastal plain gravels. Average grade apparently is greatest in the Nome River-Snake River area. Reworking of the disseminated deposits during periods when the sea level was both higher and lower than at present formed placer concentrations in stream channels at stream mouths, on beaches, and on offshore bars. Only such concentrations have been considered minable, but in some areas, gold from the overlying gravels added appreciably to the recovery. The principal beaches that have been mined and their usual names are shown on figure 3. Note that the submarine beach includes two beaches usually known as the outer and inner submarine beach. Only the principal beaches delineated by mining operations are included on this map. Both extension of these beaches and other beaches are known or conjectured, but have not been well delineated; presumably because they were less attractive to early day miners.

Submarine Beach

The submarine beach deposit (fig. 4) includes 50 to 70 feet of frozen gravel overlain by 6 to 13 feet of muck and ice. In a section explored by shafts and drillholes, the gravel included two layers of boulders; one layer on or near bedrock and the other 10 to 25 feet above. Boulders also occur elsewhere in the section. The boulders range up to about 1 cubic yard in size, and they are impacted in a fine sand or silt-like sediment that is not clay. The submarine beach deposits are believed to be ideal for testing permafrost thawing techniques for four reasons. The first reason is that the grade of these deposits is thought to be ample for mining at a

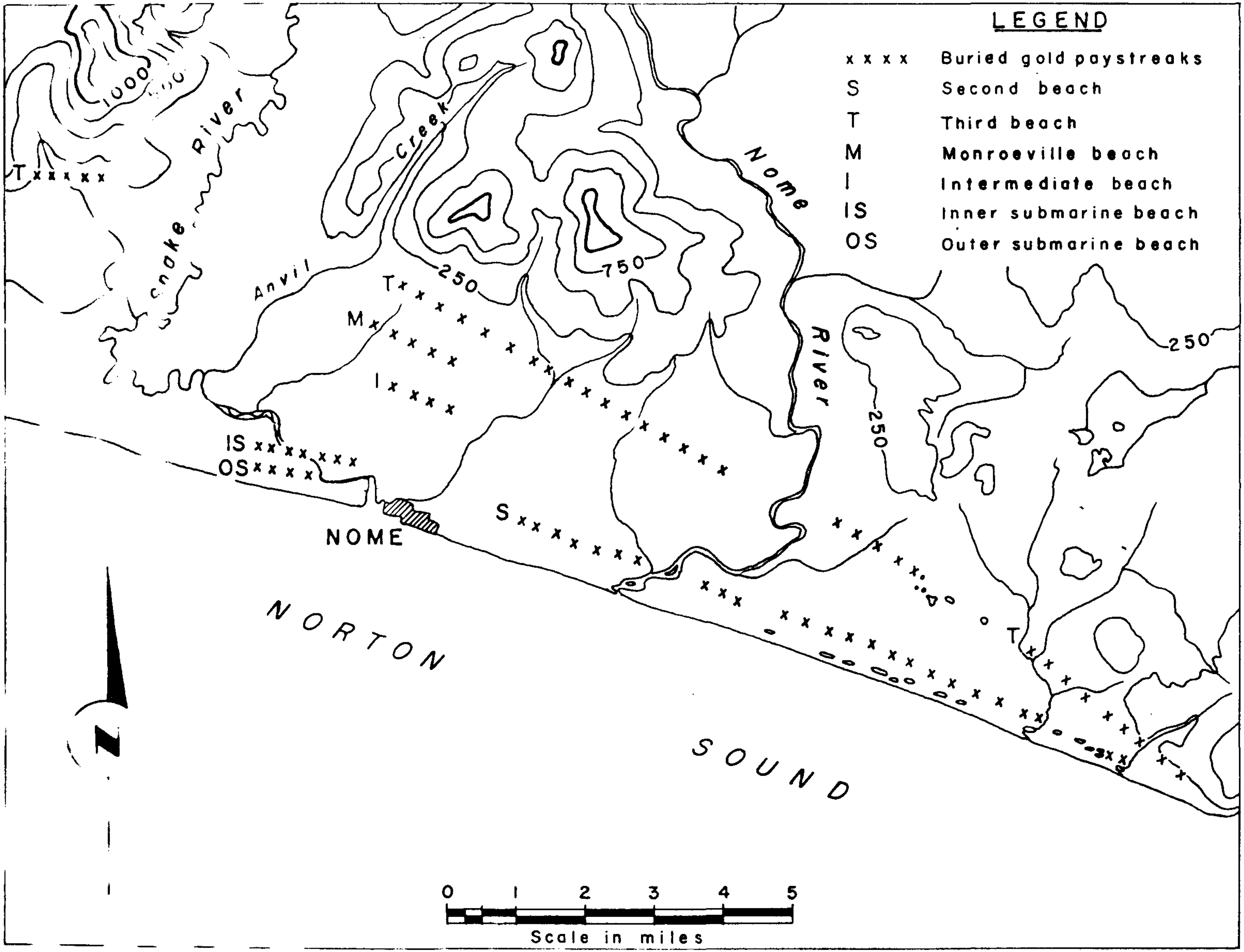

FIGURE 3.-Ancient Beach Lines, Nome Coastal Plain.

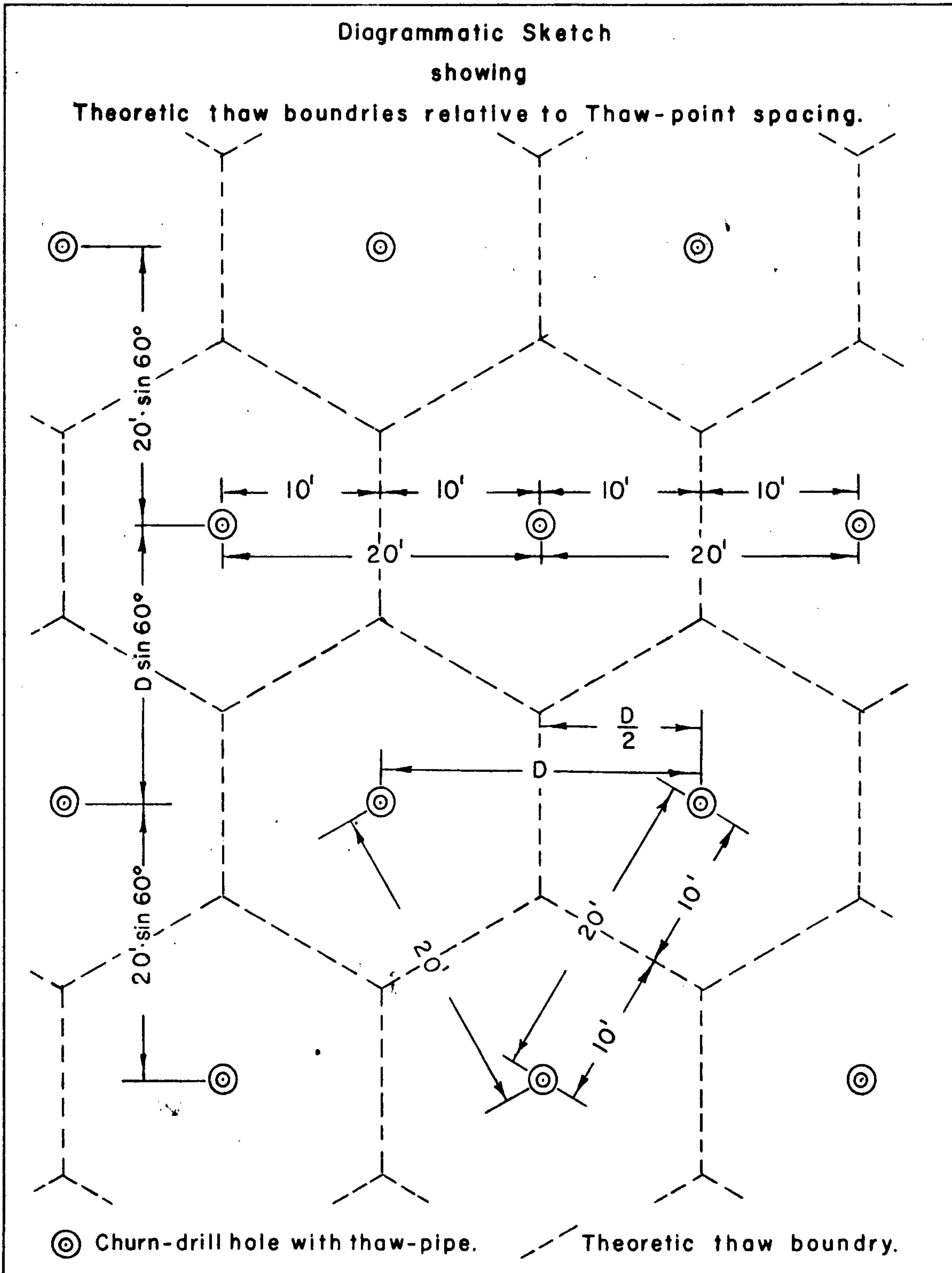

FIGURE 4.- Diagrmmatic Sketch, Thawfield, 20- feet spacing.

profit under present conditions if the engineering problems can be solved. The second reason is that the mixture of muck, clay, gravel, cobbles, boulders, and beach sands in this area presents problems so difficult that any technique that works here probably will work in any permafrost area. The third reason is that the submarine beach area is adjacent to the city of Nome, the Nome airfield, and the Alaska Steamship Co. docks. Probably, it is more conveniently located with respect to transportation and communication than any other valuable permanently frozen placer gold deposit. The fourth reason is that abundant water is available for thawing. A pump station near the mouth of Snake River was used for many years; a station could be re-established in this area that would furnish an ample supply of water. The sea also is close, if it is desired to experiment with the use of salt water. The high-level ditches that supplied water for mining the third and fourth beach line also are available since no mining is being done at present.

COLD WATER THAWING

A thaw field pattern is diagrammed in figure 5. In the submarine beach test area, the depth to bedrock averages about 70 feet. Depth obviously influences the rate of thaw about a thaw point, but in this area it can be disregarded when comparing thaw rates because the depth is relatively uniform throughout the test area. Each thaw point will thaw a roughly cylindrical zone that progresses outward. The volume thawed by each point can be considered as a cylindrical solid that increases in radius until it impinges on adjacent thawed cylinders. In order that the sum of the volumes of the thawed zones will equal the total volume of the block it is convenient to consider the thawed zone as a hexagonal solid centered about the thaw point. Assuming that the distance between points is "D" the volume of the solid, either hexagonal or cylindrical, is proportional to $\left(\frac{D}{2}\right)^2$. Table 4 shows the volume to be thawed per foot of drillhole for center to center spacings from 1 to 36 feet.

TABLE 4. - Volume (V) of influence of thaw points

Distance[1/] (D)	$\left(\frac{D}{2}\right)$	$\left(\frac{D}{2}\right)^2$	Volume influenced[2/] V (cubic feet per foot)	V (cubic yards per foot)
1	0.5	0.25	0.87	0.009
2	1.0	1.00	3.46	.128
3	1.5	2.25	7.79	.288
4	2.0	4.00	13.86	.513
5	2.5	6.25	21.65	.802
6	3.0	9.00	31.18	1.155
7	3.5	12.25	42.43	1.571
8	4.0	16.00	55.42	2.053
9	4.5	20.25	70.15	2.598

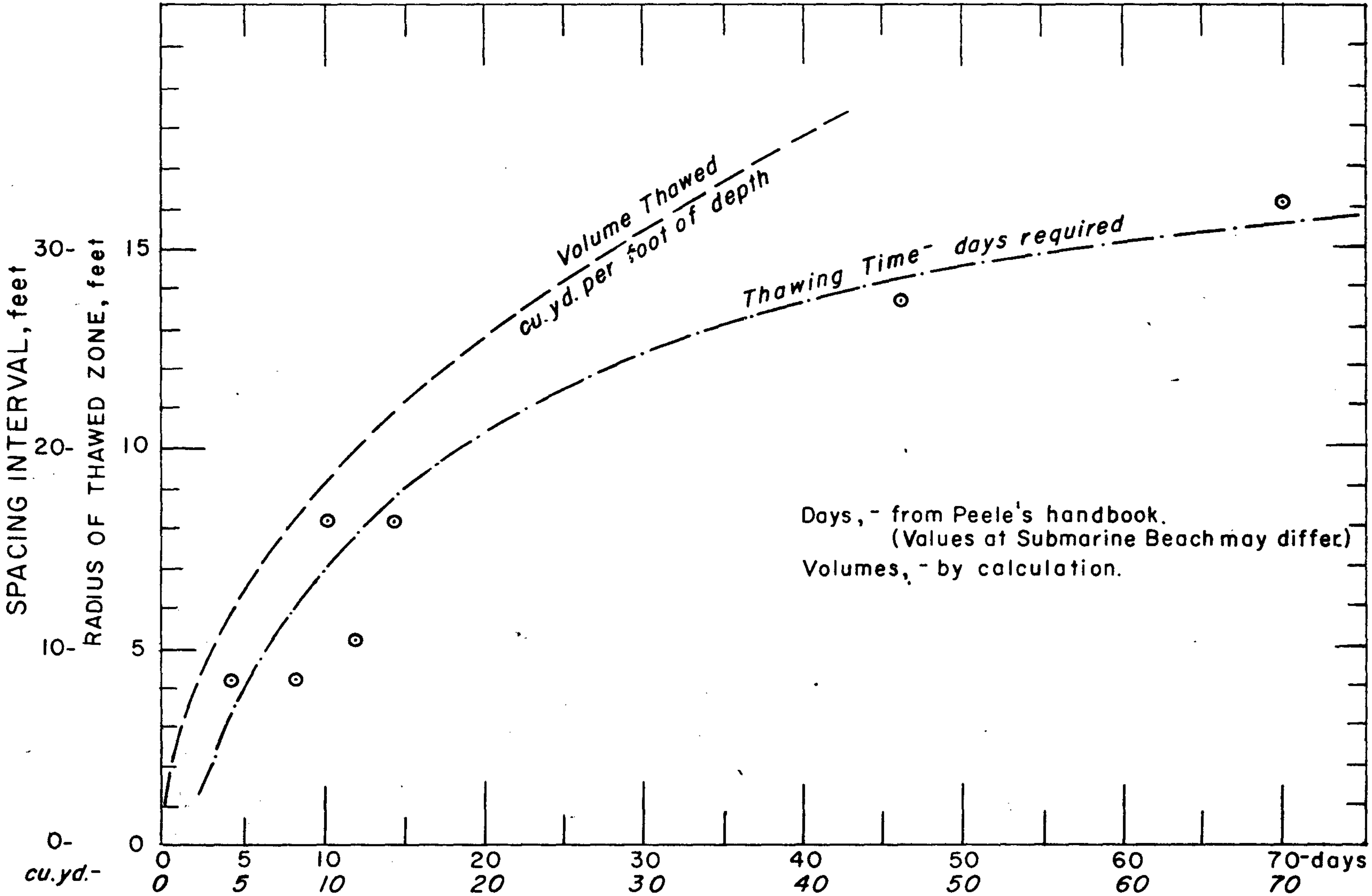

FIGURE 5.- Thawing Time and Point Spacing.

TABLE 4. - Volume (V) of influence of thaw points -- continued

Distance[1/] (D)	(D/2)	(D/2)^2	Volume influenced[2/] V (cubic feet per foot)	V (cubic yards per foot)
10	5.0	25.00	86.60	3.207
11	5.5	30.25	104.79	3.881
12	6.0	36.00	124.70	4.618
13	6.5	42.25	146.35	5.420
14	7.0	49.00	169.74	6.287
15	7.5	56.25	194.85	7.217
16	8.0	64.00	221.70	8.211
17	8.5	72.25	250.27	9.269
18	9.0	81.00	280.58	10.292
19	9.5	90.25	312.63	11.579
20	10.0	100.00	346.40	12.830
21	10.5	110.25	381.91	14.145
22	11.0	121.00	419.14	15.524
23	11.5	132.25	458.11	16.967
24	12.0	144.00	498.82	18.475
25	12.5	156.25	541.25	20.066
26	13.0	169.00	585.42	21.682
27	13.5	182.25	631.31	23.382
28	14.0	196.00	678.94	25.146
29	14.5	210.25	728.31	26.974
30	15.0	225.00	779.40	28.867
31	15.5	240.25	832.21	30.823
32	16.0	256.00	886.78	32.844
33	16.5	272.25	943.07	34.928
34	17.0	289.00	1001.10	37.078
35	17.5	306.25	1060.85	39.291
36	18.0	324.00	1122.34	41.568

1/ D = Thaw point spacing center to center.

2/ In order that the sum of the volumes thawed about a point will equal the volume of the block of ground thawed the thawed zone about a point is assumed to be a hexagonal solid. Area of a hexagon = 6 $\left(\frac{D}{2}\right)^2$ Tan A = 3.464 $\left(\frac{D}{2}\right)^2$.

Thawing rates can be expressed in many ways. Most commonly thawing rate is expressed in terms of cubic yards per day or per season. A more meaningful method is to express the thawing rate in terms of the radius of the zone thawed per degree day (DD). Degree days (DD) are the daily average temperatures of the water pumped to the points in degrees Fahrenheit minus 32° F multiplied by the number of days of reasonably constant water application. Table 5 summarizes the incoming water temperatures and degree days during the 1938 and 1939 test periods. Note that in 1939 the water was significantly warmer than in 1938. In the absence of additional data, it seems best to assume that 1938 was more nearly typical than 1939.

TABLE 5. - Incoming water temperatures, ° F, 1938 and 1939

Month	Day	1938 Average water temperature	Temperature, -32° F	1939 Average water temperature	Temperature, -32° F	1938 1939 Average water temperature	1938 1939 Average temperature, -32° F
June.........	1	-	-	-	-	-	-
June.........	2	-	-	-	-	-	-
June.........	3	-	-	-	-	-	-
June.........	4	-	-	-	-	-	-
June.........	5	-	-	-	-	-	-
June.........	6	-	-	-	-	-	-
June.........	7	-	-	-	-	-	-
June.........	8	-	-	-	-	-	-
June.........	9	-	-	-	-	-	-
June.........	10	-	-	-	-	-	-
June.........	11	-	-	-	-	-	-
June.........	12	-	-	-	-	-	-
June.........	13	-	-	-	-	-	-
June.........	14	-	-	-	-	-	-
June.........	15	-	-	-	-	-	-
June.........	16	-	-	-	-	-	-
June.........	17	-	-	-	-	-	-
June.........	18	-	-	53	21	-	-
June.........	19	-	-	55	23	-	-
June.........	20	-	-	58	26	-	-
June.........	21	-	-	58	26	-	-
June.........	22	-	-	59	27	-	-
June.........	23	-	-	60	28	-	-
June.........	24	53	21	57	25	55	23
June.........	25	58	26	53	21	56	24
June.........	26	52	20	55	23	54	22
June.........	27	55	23	51	19	53	21
June.........	28	49	17	57	25	53	21
June.........	29	48	16	63	31	56	23
June.........	30	49	17	64	32	52	20
Total........	7 1/	364	140	743 1/	327 1/	379	154
Average......		52	20	57	25	54	22

June 18-23, Average water temperature, 57° F, Degree Days, 151.
June 24-30, Average water temperature, 54° F, Degree Days, 154.
June 20-30, 1939, Total Degree Days, 283.
1/ 1939 total, 13 days.

TABLE 5. - Incoming water temperatures, ° F, 1938 and 1939--continued

Month	Day	1938 Average water temperature	Temperature, -32° F	1939 Average water temperature	Temperature, -32° F	1938 1939 Average water temperature	1938 1939 Average temperature, -32° F
July.........	1	46	14	63	31	54	22
July.........	2	48	16	60	28	54	22
July.........	3	49	17	61	29	55	23
July.........	4	46	16	60	28	54	22
July.........	5	45	13	60	28	52	20
July.........	6	45	13	55	23	50	18
July.........	7	45	13	50	18	48	16
July.........	8	52	20	50	18	51	19
July.........	9	2/	2/	52	20	52	20
July.........	10	2/	2/	51	19	51	19
July.........	11	53	21	51	19	52	20
July.........	12	51	19	49	17	50	18
July.........	13	55	23	49	17	52	20
July.........	14	2/	2/	49	17	49	17
July.........	15	49	17	55	23	52	20
July.........	16	48	16	52	20	50	18
July.........	17	46	14	56	24	51	19
July.........	18	47	15	56	24	52	20
July.........	19	51	19	60	28	56	24
July.........	20	52	20	60	28	56	24
July.........	21	53	21	60	28	56	24
July.........	22	54	22	55	23	54	22
July.........	23	52	20	56	24	54	22
July.........	24	53	21	60	28	56	24
July.........	25	50	18	60	28	55	23
July.........	26	56	24	60	28	58	26
July.........	27	54	22	59	27	56	24
July.........	28	56	24	57	25	56	24
July.........	29	54	22	55	23	54	22
July.........	30	53	21	55	23	54	22
July.........	31	49	17	55	23	52	20
Total.......	31	1,412 3/	518 3/	1,731	739	1,646	654
Average.....		50	18	56	24	53	21

2/ Data missing--no water pumped.
3/ 1938 total, 28 days.

TABLE 5. - Incoming water temperatures, ° F, 1938 and 1939--continued

Month	Day	1938 Average water temperature	Temperature, -32° F	1939 Average water temperature	Temperature, -32° F	1938 1939 Average water temperature	1938 1939 Average temperature, -32° F
August.......	1	49	17	56	24	52	20
August.......	2	47	15	56	24	52	20
August.......	3	46	14	60	28	54	22
August.......	4	47	15	61	29	54	22
August.......	5	49	17	60	28	54	22
August.......	6	51	19	57	25	54	22
August.......	7	53	21	56	24	54	22
August.......	8	51	19	55	23	53	21
August.......	9	51	19	55	23	53	21
August.......	10	50	18	50	18	50	18
August.......	11	50	18	50	18	50	18
August.......	12	50	18	52	20	51	19
August.......	13	51	19	53	21	52	20
August.......	14	49	17	52	20	50	18
August.......	15	51	19	54	22	52	20
August.......	16	50	18	54	22	52	20
August.......	17	49	17	55	23	52	20
August.......	18	50	18	50	18	50	18
August.......	19	49	17	50	18	50	18
August.......	20	49	17	49	17	49	17
August.......	21	48	16	50	18	49	17
August.......	22	47	15	49	17	48	16
August.......	23	46	14	51	19	48	16
August.......	24	47	15	49	17	48	16
August.......	25	47	15	50	18	48	16
August.......	26	49	17	50	18	50	18
August.......	27	49	17	53	21	51	19
August.......	28	49	17	52	20	50	18
August.......	29	49	17	50	18	50	18
August.......	30	49	17	50	18	50	18
August.......	31	49	17	48	16	48	16
Total........	31	1,521	529	1,637	645	1,578	586
Average......		49	17	53	21	51	19

TABLE 5. - Incoming water temperatures, ° F, 1938 and 1939--continued

Month	Day	1938 Average water temperature	Temperature, -32° F	1939 Average water temperature	Temperature, -32° F	1938 1939 Average water temperature	1938 1939 Average temperature, -32° F
September....	1	44	12	48	16	46	14
September....	2	45	13	48	16	46	14
September....	3	45	13	46	14	46	14
September....	4	42	10	47	15	44	12
September....	5	42	10	46	14	44	12
September....	6	42	10	46	14	44	12
September....	7	45	13	46	14	46	14
September....	8	43	11	45	13	44	12
September....	9	42	10	46	14	44	12
September....	10	43	11	48	16	46	14
September....	11	44	12	46	14	45	13
September....	12	46	14	46	14	46	14
September....	13	48	16	45	13	46	14
September....	14	48	16	43	11	46	14
September....	15	45	13	40	8	42	10
September....	16	42	10	42	10	42	10
September....	17	40	8	40	8	40	8
September....	18	41	9	39	7	40	8
September....	19	38	6	42	10	40	8
September....	20	40	8	42	10	41	9
September....	21	-	-	42	10	-	-
September....	22	-	-	43	11	-	-
September....	23	-	-	44	12	-	-
September....	24	-	-	43	13	-	-
September....	25	-	-	46	14	-	-
September....	26	-	-	45	13	-	-
September....	27	-	-	45	13	-	-
September....	28	-	-	46	14	-	-
September....	29	-	-	45	13	-	-
September....	30	-	-	43	11	-	-
Total, 1-20..		864	225	891	251	878	238
Average, 1-20		43	11	45	13	44	12
Total, 21-30.				444	124		
Average, 21-30				44	12		
October......	1	-	-	42	10	-	-
October......	2	-	-	41	9	-	-

TABLE 6. - Degree days,[1] June 20 to September 20

Month	Days	DD 1938	DD 1939	DD Average, 1938, 1939	Daily Average DD
June 20-30.......	11	220[2]	283	242[2]	22
July 1-31........	31	574[3]	739	654	21
August 1-31......	31	529	645	586	19
September 1-20...	20	225	251	238	12
Totals...........	93	1,548	1,918	1,720	74
Averages[4].......		17	21	18	18

1/ Degree days (DD) equals average incoming water temperature in degrees Fahrenheit -32.

2/ Extrapolated from June 24-30 only; June 20-23 missing.

3/ Three days missing--interpolated to include these.

4/ 93 x 18 = 1,674 degree days. Assume various mechanical troubles interrupt water flow to points for 2 percent of season; 1,674 x 0.02 = 33 DD. Therefore, a thaw season is 1,640 degree days; or for convenience and to be conservative, assume 1,600 degree days.

The cold water thawing process is well described in Peele's Mining Engineers Handbook. The data on thawing rates is too scanty to be conclusive, and is not directly applicable to the conditions on the submarine beach. However, the data indicates that the efficiency of cold water thaw points drops as the radius of the thawed zone increases. As graphically shown on figure 5, the volume thawed and the thawing times cited in Peele's handbook increase at generally the same rate as the volume of the thawed zone from a radius of 1 foot to about 8 feet; then the thawing time curve diverges with increasing rapidity from the curve of increasing volume. The extreme rate of divergence as the radius of the thawed zone increases above 14 to 16 feet suggests that thawing efficiency is impractically low--probably because most of the water escapes to the surface without coming in contact with frozen ground.

COMPANY TESTS AND RESULTS

Nature and Extent

The United States Smelting Refining and Mining Co. at the submarine beach, Nome, Alaska, in 1938 and 1939, experimented with three thaw pipe arrangements:

1. 1-1/2-inch thaw pipes in churn drill holes 32 feet center to center,

2. 1-1/2-inch thaw pipes in churn drill holes 22 feet center to center,

3. 3/4-inch thaw points driven in the centers of the triangles formed by the 32-foot center to center spacing. This in effect produced a pattern of thaw pipes about 18.4 feet center to center.

The 32- and 22-foot spacings were part of the original plan. The driving of intermediate points in part of the 32-foot pattern to produce in effect 18.4-foot spacings was an afterthought. Consequently, temperature points were not effectively placed to measure the rate of thaw about the intermediates.

Thaw Point Spacing

In conclusions, page 15, 1939 report, Walter Glavinovich, the engineer in charge of testing, states that with the 18.4-foot spacing it may be possible to thaw the gravels in one season. Other evidence throughout the report tends to verify this statement and also tends to indicate that with spacings greater than 18 feet center to center (9-foot radius of thawed zone) the ground cannot be thawed in one season. This apparently results not only because volume increases as the square of the radius but also because thaw point efficiency decreases rapidly as the radius of the thawed zone exceeds 8 to 10 feet.

The strongest evidence that 18 feet may be optimum spacing for thaw points on the submarine beach is contained in the conclusions on page 29 of the 1938 report. Block 1, drilled on 22-foot centers was reported to be 60 percent thawed. If this block, with 22-foot spacing was 100 percent thawed, the thawed zone at each thaw pipe would be a roughly cylindrical body having a radius of 11 feet about the thaw pipe and containing a volume of 15.524 cubic yards per foot of depth (table 4). Sixty percent of 15.524 cubic yards is 9.314 cubic yards which is equivalent to a radius of thaw of 8.6 feet. Block 2, with thaw points on 32-foot centers, was 37 percent thawed. If block 2 was 100 percent thawed, the radius thawed about each drillhole would be 16 feet and the volume thawed would be 32.844 cubic yards per foot of depth. Actual thaw was 37 percent, or 12.152 cubic yards per foot of depth; which indicates a thawed zone about each thaw pipe having a radius of about 9.8 feet. The average of 8.6 feet radius of thawed zone in block 1 and 9.6 feet in block 2 is about 9 feet. It seems evident that if blocks 1 and 2 had been drilled on 18-foot centers they would have been almost 100 percent thawed.

Page 32 of the 1938 report shows that temperature point 3-8A, 6.25 feet from a thaw point, completely thawed August 14 after 42 days of water application. The 42 days when water was pumped include a total of 764 degree days (DD) (table 5). The 1938 thawing season included 1,548 degree days (table 5). A thawed zone 6.25 feet in radius has a volume of about 5.0 cubic yards per foot of depth (table 4).

$$5.0 \text{ cubic yards} \times \frac{1,548}{764} = 10.1 \text{ cubic yards thawed if the point thawed at the same rate all season (1938).}$$

A thawed zone containing 10.1 cubic yards has a radius of slightly under 9 feet; that is, if thaw points had been spaced on 18-foot centers, thaw would have been almost 100 percent completed at the end of the 1938 season.

Page 23 of the 1938 report shows that 8 OX temperature points 4.5 feet from a thaw point were completed in 16 days prior to July 26. This included 299 degree days (table 5) out of a total of 1,548 degree days in the 1938 thawing season. A thawed zone with a radius of 4.5 feet has a volume of 2.598 cubic yards per foot of depth.

$$2.598 \text{ cubic yards} \times \frac{1,548 \text{ DD}}{299 \text{ DD}} = 13.450 \text{ cubic yards per season.}$$

A seasonal thaw of 13.450 cubic yards would be contained in a thawed zone having a radius of about 10 feet (table 1). However, the calculation does not allow for the lowering of thawing efficiency as the radius of the thawed zone approaches 10 feet. It seems probable that the zone actually thawed about this thaw pipe in 1938 had a radius slightly over 9 feet.

Water Requirements

Water requirements for thawing are summarized on page 29 of the 1938 report. Apparently the 22-foot spacing made more efficient use of water than the 32-foot spacing; 4.7 cubic yards per miners inch day (MID) were thawed with holes on 22-foot centers while 4.1 cubic yards were thawed per MID with holes on 32-foot centers. However, this difference may not be real as it is within the possible margins of error in this necessarily rough field test. It seems more realistic to assume that the average value, 4.4 cubic yards per MID, is characteristic of the submarine beach. This contrasts with 5.5 cubic yards per MID reported from the Little Creek area on the inland side of the Nome plain and suggests that the submarine beach is about 20 percent more difficult to thaw.

Churn Drilling and Point Driving Rates

The data in table 7, abstracted from the introduction to the United States Smelting Refining and Mining Co. 1947 report on thaw point driving, is indicative of both the scale of operations on the Nome plain and the average labor requirements for putting in thaw fields. Thaw point holes were drilled in winter with churn drills. Thaw points can be driven only during the summer when water is available to thaw ahead of the pipe. In general, thaw points cannot be driven efficiently to depths greater than 40 feet or in areas where large boulders are abundant. Note that the cost to put down the thaw points does not include the cost to open the points drilled during the winter and start the water flowing. Thaw pipes 1-1/2-inches in diameter normally are placed in churn-drill holes; with steam thawing equipment a skilled man can open eight per day. Thaw pipes for driving usually are 3/4-inch heavy duty iron pipe; these are much more tedious to open when they are left in the ground over the winter, but data on the average rate is not available.

TABLE 7. - Thaw point driving and drilling rates

Churn Drilling:	
Start	November 25.
End	April 1.
Working days, total	104 days.
Men employed	28 men.
Man days, total	2,912 man-days.
Hole drilled, total	175,000 feet.
Feet per man-day	60 feet per man-day.
Feet per man-hour (10-hour shift)	6 feet per man-hour.
Thaw Point Driving:	
Man-days, total	5,550 man-days.
Points driven, total feet	350,000 feet.
Feet per man-day	63 feet.
Feet per man-hour (10-hour shift)	6 feet per man-hour.

BUREAU OF MINES RESEARCH

Nature and Extent

The Bureau of Mines has started a research program designed to lower the costs of mining the permanently frozen placer deposits of the Nome coastal plain. The large, modern bucketline dredges are such efficient mechanisms that there seems to be little chance of significantly lowering digging and recovery costs. The only other item of expense large enough to be significant is ground preparation. The use of giant rippers, huge mechanical breakers, or modern explosives may have promise, but seem inherently too costly for use on deeply buried low-grade gold deposits. In any case, the best chance to make an immediate gain in minable reserves is to lower the costs of proven ground preparation methods.

The greatest single cost item in ground preparation is thawing. The cost of thawing deep ground is directly related to the difficulty of placing thaw pipes vertically downward to bedrock. Water at about 45° to 55° F is pumped to bedrock. As it makes its way upward, it warms and thaws the ground. The submarine beach deposit on the Nome plain averages about 70 feet deep; this is about 30 feet too deep for efficiently driving thaw points. The thaw points must be set in holes drilled to bedrock. The high cost of drilling makes it necessary to use maximum spacings. Current practice is to space holes 32 feet apart in all directions and to drill the holes with churn drills during the winter. With 32-foot spacing, thawing the ground requires two to three thawing seasons. Re-establishing circulation each spring adds greatly to the cost. The plumbing equipment necessary to thaw gravel for a dredge digging 5,000 to 10,000 cubic yards per day for 150 to 170 days per year represents a very considerable investment. Laying water supply lines, opening and reopening the thaw pipes, and keeping circulation going require a large crew of laborers throughout the thawing season. Ordinarily the summer season is well advanced before the thaw fields are working efficiently.

Thawing costs could be lowered if a drill or other mechanical device could be developed that would efficiently and cheaply place thaw pipes in the gravels. Thaw pipe spacing of 16 to 20 feet from center to center instead of the 32-foot spacing now used would require two to three times as many holes as are used in current practice, but with this spacing the ground could be thawed in one season with consequent savings in labor, thawing equipment, and interest on money invested. The churn drill currently used in thaw field drilling is operated by a driller and a helper; the average advance ranges from 10 to 14 feet per hour on from 5 to 7 feet per man hour. It seems probable that a better drill can be developed for use when it is necessary only to make a hole 2 or 3 inches in diameter and insert a 1-inch or 1-1/2-inch thaw pipe.

It is planned to test modern drills and drilling equipment on the submarine beach deposits at Nome, Alaska. The immediate objective is to develop equipment and thawing procedures that will make it possible to drill the ground, place the thaw pipes, thaw the ground, and remove the thaw pipes in one season. If deep dredging ground can be thawed without either the necessity of winter drilling or of opening frozen points in the spring, this will reduce costs considerably. The ultimate objective is to thaw the ground for 10 cents per cubic yard or less. Other phases of the work besides drilling the holes may have to be speeded up, but a cheap, high-speed method of drilling or otherwise placing thaw points is the first step and the essential key to all other improvements.

Tentative Drilling Costs

Assume that the thaw pipe holes are drilled on 18-foot centers and that the thaw pipe is emplaced while the machine is on the hole. Cost of emplacing the point should not exceed one-quarter of the total thawing costs, which in turn should not exceed 10 cents per cubic yard. On 18-foot centers each hole thaws 10.39 cubic yards per foot of depth. The average depth of holes in the submarine beach deposit will be about 70 feet.

$0.10 x 1/4 = $0.025 per cubic yard for placing thaw pipe.

10.39 x $0.025 = $0.26 per foot to drill the hole, place thaw pipe.

70 feet x $0.26 per foot = $18.20 per point.

The drilling should start about June 1 and end about September 10, a period of 100 days. Assume that a dredge can dig about 1,000,000 cubic yards per season on the submarine beach and that each hole on 18-foot centers thaws 10.392 cubic yards per foot of hole.

$$\frac{1{,}000{,}000 \text{ cubic yards}}{10.392 \text{ cubic yards per foot}} = 96{,}246 \text{ feet of thaw pipe.}$$

Assume one temperature check pipe for each 20 holes.

$$96{,}246 \text{ feet} \times \frac{1}{20} = 4{,}812 \text{ feet of temperature check pipe.}$$

Total = 101,058 feet of hole.

$$\frac{101{,}058 \text{ feet}}{100 \text{ days}} = 1{,}010 \text{ feet per day.}$$

Assume 24-hour-per-day operation.

$$\frac{1{,}010}{24} = 42 \text{ feet per hour.}$$

Assume two 10-hour shifts.

$$\frac{1{,}010}{20} = 50 \text{ feet per hour.}$$

Assume one 10-hour shift per day.

$$\frac{1{,}010}{10} = 101 \text{ feet per hour.}$$

To maintain an average of 100 feet per hour, including moving time, in ground averaging 70 feet deep, a thaw pipe must be emplaced every 43 minutes. The actual drilling speed must average about 2.5 feet per minute to allow time for coupling drill rods and pipes, moving, etc. Rod and pipe coupling must be automated and moving time must be cut to a few minutes per hole. A rate of 100 feet per hour may not be attainable, but a rate of 50 feet per hour should be attainable.

The drill rig will cost about $50,000. Assume amortization at $10,000 per year or about 10 cents per foot of drillhole. Assume bits, fuel, etc., at 10 cents per foot. To keep the total cost to 26 cents per foot this leaves only 6 cents per foot for wages and employee costs. At 100 feet per hour, this is $6.00 per hour which should make it possible to hire a good driller. However, if 50 feet of thaw pipe can be emplaced per hour and wages are $5.00 per hour including benefits, etc., or 10 cents per foot, the total cost of thaw pipe would rise to 30 cents per foot, or about 3 cents per cubic yard. This last figure seems reasonably attainable.

Tentative Work Plan

A three-year program is contemplated. The program can be accelerated if results are favorable. However, it must be realized that if solutions for the problem of thawing permafrost at low cost were obvious, the dredges would not have been shut down.

January through April 1967:	Research literature and study comparable operations.
May through September 1967:	Field test various methods of placing thaw pipes to bedrock. Emphasis will be on obtaining design data at minimum cost. Select thaw field sites, pumping stations, etc.
October 1967 through April 1968:	Additional literature search. Based on literature search and results of field tests, make equipment designs and tentative cost estimates.
May through October 1968:	If cost estimates are reasonably favorable, machines will be built, purchased, or rented and an experimental thaw field will be put in operation. If

	cost estimates remain too high to be practical, the thaw field will not be put in, but additional procedures or methods of lowering the costs will be field tested.
November 1968 through April 1969:	Refine equipment designs and operating procedures utilizing field experience, study of comparable operations, and literature research. If cost estimates remain too high to be practical, alternative methods will be studied.
May through October 1969:	Field tests as indicated by previous work.
November 1969 through April 1970:	Compile data and publish final report.

Progress to Date

Background Research

The principal drill manufacturers were contacted, the drilling problems involved were outlined, and suggestions were requested. The diversity of equipment recommended and the obvious impracticality of many recommendations indicate that commercially available drilling equipment developed principally for blast hole drilling may be too specialized for thaw pipe drilling. It may be necessary to modify or improve existing equipment or perhaps to develop entirely new equipment for that purpose.

Four types of drilling equipment should be tested during the summer of 1967 if the equipment can be obtained and transported to Nome or to a generally similar permafrost area.

Sonic drill,

Surface percussion drill,

Rotary drill,

Down-the-hole percussion.

Tests will be designed to determine cost factors including penetration rate, bit wear, rod wear, and fuel consumption. Subsequent tests will be designed to develop operating techniques for the type or types of drill that prove to be most successful.

A sonic drill was delivered to the Bureau of Mines Denver Mining Research Center in mid-May. If preliminary trials are encouraging, the drill will be sent to Nome for on-site tests. The other types will be obtained from contractors or dealers in Fairbanks, Anchorage, or Seattle on a rental basis as mutually satisfactory arrangements can be made. Negotiations now are underway.

Jet piercing is being considered in addition to the above drills. The manufacturer claims that the cost of jet piercing gravel is well within the desired price range per foot. It is planned to check these claims. If they appear justified, some arrangement will be made to test jet piercing in an area comparable to the Nome plain. Jet piercing presents special problems because the equipment is not available in or near Alaska and the currently available models are large and costly rigs designed for chambering blast holes in taconite.

Other types of drills to be considered include the Becker and similar rigs developed from diesel pile drivers. These have been used with good results in unfrozen glacial gravels and similar deposits. The usual method is to put a homemade shoe on 3-inch oilfield drill pipe and pound it to bedrock. The Becker utilizes a double wall casing; air and water are pumped down between the inner and outer wall; the sample is blown up the center of the casing. This is an efficient sampling device in some types of deposits, but casing wear may be too costly for effective use in frozen compacted sediments that include boulders.

Field Tests

A preliminary test of a rotary drill also equipped for down-the-hole percussion drilling was made in May at Chatanika, Alaska. Testing at Chatanika was a necessary expedient because the only immediately available drill rig was too large to transport to Nome via the available commercial carriers. Four holes, each 100 feet deep, were drilled in gold-bearing placer gravels chosen as similar to the gravels of the Nome plain. For comparison, a fifth hole drilled 90 feet for a water well in Birch Creek schists, was logged and timed.

Because various types of rigs will have to be used in initial tests, only the actual drilling speed and the bit wear are considered pertinent data. The problem at this stage is to determine the most effective drilling methods. Rod handling efficiency, setup time, etc., are tabulated for later reference when designing or ordering a thaw field drill.

The drill rig used was a truck-mounted T-650 Reichdrill (Chicago-Pneumatic) equipped to drill 6-inch holes. The rig required one operator who was not assisted in any way. The grindings from each hole were recovered on a plastic tarp to test the adaptability of the drill for sampling, but sample collecting was not allowed to interfere with the test of drilling speed.

Table 8 lists typical cobbles and boulders noted on nearby dredge tailings. The smaller material in the gravels appears to be generally similar but was not sampled and measured. Tables 9 through 13 summarize drilling results.

TABLE 8. - Typical boulders and cobbles found with gravels on dredge tailings near holes Nos. 1 through 4 1/

Longest dimension, inches	Material
14	Schist and quartz.
10	Quartzite.
14	Vein quartz.
15	Vein quartz and schist.
16	Quartzite.
11	Vein quartz.
6	Phyllite.
6	Quartz diorite.
6	Hornblende granite.
6	Quartzite.
6	Vein quartz.
6	Vein quartz.
8	Basalt.
8	Gneiss.
13	Gneiss.
14	Vein quartz.
14	Vein quartz.
16	Vein quartz.
14	Vein quartz.
17	Vein quartz.
16	Vein quartz.
15	Vein quartz.
15	Vein quartz.
17	Quartzite.
18	Vein quartz.
22	Vein quartz.
23	Vein quartz.
30	Vein quartz.

1/ Data obtained by walking across the tailing piles, stopping every fourth step to measure and sample the largest nearby cobble or boulder.

TABLE 9. - Field log, hole 1, Chatanika

Date: May 17, 1967.
Location: In trail near substation.
Drill: T-650 Reichdrill (Chicago-Pneumatic).
Compressor: 450 cfm, 250 psi.
Bits: Williams Tricone rock bit W4W, 8-inch, 0 to 6 feet; Williams Tricone rock bit W4W, 6-inch, 6 to 100 feet.
Casing: Heavy duty 6.25-inch inside diameter, 6 feet long.
Water mixed with air to remove cuttings: 0 to 100 feet, 75 gallons.

Time	Depth	Stop watch	Remarks
9:20	0.0	-	Start setup; lift with jacks 15 seconds; raise tower, 30 seconds; make up tool string, 3 minutes 15 seconds. Tool string: rod, 20 feet; sub and bit, 2 feet.
9:34	0.0		
9:39	6.0		Drill with 8-inch Tricone and set top casing.
9:39	6.0		Delay; prepare for logging hole, saving sample, etc.
10:24	6.0	+ 0:00	Top of muck.
	10.0	+ 4:30	
	20.0	+ 6:25	
			Change rod, 45 seconds.
10:31	20.0	+ 0:00	Start drill.
10:43	40.0	+11:00	
10:45	40.0	+ 0:00	Change rod, 1 minute.
10:56	60.0	+10:56	
10:56	60.0		Flush hole, change rods, 1 minute.
10:57	60.0	+ 0:00	Start drilling.
11:08	80.0	+10:20	
11:09	80.0		Change rod, 1 minute.
11:09	80.0	+ 0:00	
	81.0		In cobbles intermittently.
	90.0		
	99.0		Color change to gray and smooth out--bedrock.
11:24	100.0	+14:50	
11:25	100.0	+ 0:00	Start to pull out.
11:35		+ 9:40	Rods out of hole.
11:37			Casing collar pulled.
11:39			Tower down.
11:40			Jacks up, ready to roll.

Formation log

Feet	Character of material
0 - 6	Tailings, thawed.
6 - 12	Muck, frozen.
12 - 35	Fine gravel and silty sand, frozen.
35 - 99	Fine to medium gravel with cobbles and boulders, black sludge 90 to 95 feet, frozen.
99 - 100	Schist bedrock, frozen.

TABLE 9. - Field log, hole 1, Chatanika--continued

Water measure

34.4 to 95.4 measured 13.0 cubic feet or 0.2131 cubic feet per foot.

Summary of drilling speed

Description	Time, minutes	Feet per minute
Set up	5:00	
Drill and case, 0 to 6 feet	5:00	1.20
Drill, 6 to 20 feet	6:25	2.18
Drill, 20 to 40 feet	11:00	1.82
Drill, 40 to 60 feet	10:56	1.83
Drill, 60 to 80 feet	10:20	1.94
Drill, 80 to 100 feet	14:50	1.35
Drill total time, 6 to 100 feet	53:31	
Drill average speed, 6 to 100 feet		1.76
Changing rods and blowing hole	6:00	
Pulling rods	9:40	
Tower down, jacks up	3:00	
Total time	82:11	
Average drilling rate including setup and tear down time, feet per minute		1.22
Average drilling rate including setup and tear down time, feet per hour		73

Remarks

Top rotation appears to be superior to kelly table rotation because bit remains at bottom of hole as rods are added. This not only cuts out a move but also tends to prevent caving or damage to walls of hole.

The hole drilled appears smooth to the eye and water measure tends to confirm this. The 6-inch rotary could be developed into a frozen placer sampling drill. Major problems are collecting sample and, possibly, cleaning bottom of hole.

TABLE 10. - Field log, hole 2, Chatanika

Date: May 17, 1967.
Location: In trail near substation.
Drill: T-650 Reichdrill (Chicago Pneumatic).
Compressor: 450 cfm, 250 psi.
Bits: Williams Tricone rock bit W4W, 8-inch, 0 to 5 feet; Williams Tricone rock bit W4W, 6-inch mounted on Mission series 200 Hammerdril A51-20, 5 to 70 feet; Williams Tricone rock bit W4W, 6-inch (same bit used in hole 1, 6 to 100 feet), 70 to 100 feet.
Casing: Heavy duty, 6.27-inch inside diameter, 6 feet long.
Water mixed with air to remove cuttings: 135 gallons, 0 to 62 feet with down-hole hammer. Water probably contributed to trouble with the hammer by washing lubricant from control rod. Approximately 25 gallons used while drilling rotary without down-hole hammer.

Time	Depth	Stop watch	Remarks
12:36			Move, hole 1 to hole 2.
12:42			Start set up.
12:46	0.0		Start drilling.
12:49	5.0		Bottom 5 feet for collar casing.
12:53	5.0		Collar casing set. Couple on Mission down-hole hammer and Williams Tricone W4W 6-inch bit; identical with bit used without down-hole hammer.
1:05	5.0	+ 0:00	Start drilling with Hammerdril. Hammer and rotate 16 to 18 rpms. Use 250 psi air pressure.
1:18	22.0	+13:70	
1:20	22.0	+ 0:00	Rod added.
1:23	25±	+ 3:00	Pull out of hole. Hammer binding. Insufficient lubrication?
2:38			Hammerdril reassembled, and oil coming.
2:42			Bit, hammer, and 20 feet of rod in hole.
2:44	25.0	+ 0:00	Start drilling.
2:45	25.0		Trouble restarting hammer.
3:01	42.0	+16:13	
3:02	42.0	+ 0:00	Rod added.
3:09	48±	+ 6:45	Hammer stopped--blow the hole, surge up and down.
3:20	48±	+ 0:00	Hammer started again.
3:21	48±	+ 1:00	Hammer quit again.
3:24	48±		Poured alcohol (Heet) down the drill pipe.
3:27	48±	+ 0:00	Hammer started. No Tanner gas setup on this rig. Quit using water. Air doesn't clean hole very well; have to surge up and down, add water, and blow to clean hole.
3:36	58±	+ 9:32	Disconnect and pour alcohol and oil down the line.
3:40	58±	+ 0:00	

TABLE 10. - Field log, hole 2, Chatanika--continued

Time	Depth	Stop watch	Remarks
3:44	62.0	+ 3:58	
3:46	62.0	+ 0:00	Use little to no water, then add water.
3:57	72.0	+11:00	Pull off; hammer freezing, pour alcohol and oil.
4:01	72.0	+ 0:00	
4:08	72.0	+ 7:08	Froze up--no more alcohol on hand; finish with rotary.
4:28	72.0	+ 0:00	Continue with Tricone bit.
4:32			Turning on boulder, no advance 1 minute.
4:34	80.0	+ 6:00	
4:36	80.0	+ 0:00	
4:46	100.0	+ 9:58	Surged and cleaned hole for a couple of minutes.
4:48	100.0		
4:49		+ 0:00	Start to pull out.
4:59		+ 9:35	Bit out of hole.
5:01			Casing out of hole.
5:02			Drop derrick.
5:03			Blow out compressor.
5:05			Jacks up, ready to roll.

Formation log

Feet	Character of material
0 - 5	Tailings, thawed.
5 - 19	Muck and silt, frozen.
19 - 20	Muck and silt with logs or timber, frozen.
20 - 70	Medium to fine gravel, frozen.
70 - 92	Boulders, cobbles, medium gravel; largest boulder required 1 minute to drill through.
92 - 96	Black sludge.
96 - 100	Bedrock.

Water measure

No water measure on this hole.

Summary of drilling speed

Description	Time, Minutes	Feet per minute
Move..	6:00	
Set up..	4:00	
Drill, 0 to 5 feet............................	3:00	
Casing, 0 to 5 feet...........................	4:00	
Total move and set up.........................	17:00	

TABLE 10. - Field log, hole 2, Chatanika--continued

Summary of drilling speed--continued

Description	Time, minutes	Feet per minute
Hammerdril - Tricone bit:		
Drill, 5 to 22 feet	13:07	1.30
Drill, 22 to 25 feet	3:00	1.00
Drill, 25 to 42 feet	16:13	1.05
Drill, 42 to 48 feet	6:45	.89
Drill, 48 to 58 feet	9:32	1.05
Drill, 58 to 62 feet	3:58	1.01
Drill, 62 to 72 feet	11:00	.91
Drilling, total time	63:35	
Drilling, 5 to 72 feet, average		1.05
Rotary - Tricone bit:		
Drill, 72 to 80 feet	6:00	1.33
Drill, 80 to 100 feet	9:58	2.01
Clean hole	2:00	
Pulling rods	9:35	
Pulling casing	2:00	
Drop derrick	1:00	
Blow out compressor	1:00	
Jacks up and ready to roll	2:00	

Remarks

Use of the down-hole hammer with the Tricone bit apparently offers no practical advantage in drilling frozen gravel. During brief periods while the hammer worked well the penetration rate may have slightly exceeded the rate of advance with rotation alone, but cuttings did not appear to clear the hole as efficiently as with rotary alone. Constant trouble with the hammer may be due to freezing, but more likely is due to lubricant being washed from control rod by water required to thaw and flush cuttings. Use of foaming agents, detergents, or Tanner gas alone or in combination or with the water might help.

TABLE 11. - Field log, hole 3, Chatanika

Date: May 18, 1967.
Location: In trail near substation.
Drill: T-650 Reichdrill (Chicago-Pneumatic).
Compressor: 450 cfm, 250 psi.
Bits: Williams Tricone rock bit W4W, 8-inch, 0 to 5 feet; Mission 200 Hammerdril, model A51-20 with 6-inch button bit, 5 to 20 feet; Williams Tricone rock bit W4W, 6-inch (same bit used in holes 1 and 2), 82 to 100 feet.
Casing: Heavy duty 6.25-inch inside diameter, 6 feet long.
Water mixed with air to remove cuttings: 65 gallons.

Time	Depth	Stop watch	Remarks
8:18			Start to jack.
8:20			Jacked up, mast raised, changing from 6- to 8-1/2-inch bit to collar hole.
8:27	0.0		Hole for collar casing completed.
8:30	5.0		Rig special collar casing to collect sample. Rig for down-hole hammer and button bit.
9:09	5.0		Start drilling with 6-inch button bit turning 12 to 14 rpm.
9:11-:18	5.0		Stop, put on usual collar casing; 6 feet long, 6.25 inches in diameter.
9:19-:31	5.0		Adjust line oiler.
9:32	5.0	+ 0:00	Start drilling, 12 to 14 rpm.
9:37	8.0	+ 4:50	Hammer freezing(?), pull up. Put alcohol in air line.
9:43	8.0	+ 0:00	Start again.
9:46	17.0		Gravel. Hammerdril estimated 4 feet per minute with plenty of water, then either binds or freezes. Less trouble with freezing or binding when drilling dry or with little water, but also slower drilling rate. Unable to get hammer efficiently working; if enough water added to clean hole the hammer freezes or binds.
9:53	22.0	+10:00	Flushing hole.
9:57	22.0	+ 0:00	
10:05	30±	+ 8:00	Stop to place tarp to collect sample.
10:10	30±	+ 0:00	Drilling dry, 30 to 42 feet.
10:14	42.0	+ 4:28	
10:17	42.0	+ 0:00	Drilling dry, 42 to 62 feet.
10:29	62.0	+11:22	
10:31	62.0	+ 0:00	Drill with water. With water machine drills faster, estimated 4 feet per minute.
10:37	70±		Hammer frozen or bound, no progress.
10:42	70±		Resume drilling with water.
10:49	82.0	+18:00	Continued freezing or binding of hammer.

TABLE 11. - Field log, hole 3, Chatanika--continued

Time	Depth	Stop watch	Remarks
10:51	82.0		Flush hole. Hammer frozen or bound. Pull tools out of hole, thaw, and blow out the hammer. Try again.
11:15	82.0	+ 0:00	Hammer hanging up again. Pull tools out of hole. Dismantle hammer. Found control rod and inner side of hammer scarred. No evidence of dirt. Plenty of oil on outside of piston. Suspect that hammer will not tolerate the amount of water necessary to remove the grindings. Button bit shows no wear.
12:46	82.0	+ 0:00	Drilled with Tricone (same bit used in No. 1 hole and No. 2 hole).
12:57	100.0	+10:40	Bedrock at 98.0
1:11			Tools out of hole.
1:12			Casing pulled. Put in old 6-inch tube in place of top casing. Put on 8.5-inch rotary bit.
1:18			Tower down.
1:19			Jacks up, ready to roll.

Formation log

Feet	Character of material
0.0 - 3.5	Tailings, thawed.
3.5 - 6.0	Tailings, frozen.
6.0 - 17.0	Muck and silt, frozen.
17.0 - 22.0	Fine to medium gravel, frozen.
22.0 - 92.0	Medium gravel, frozen.
92.0 - 98.0	Medium gravel with cobbles or boulders, frozen.
98.0 - 100.0	Bedrock, mica schist, frozen.

Water measure

25.85 to 95.1 measured 15.00 cubic feet or 0.2166 cubic feet per foot.

Summary of drilling speed

Description	Time, minute	Feet per minute
Set up	9:00	
Drill, 0 to 5 feet	3:00	1.67
Drill, 5 to 8 feet	4:57	.60
Drill, 8 to 22 feet	10:00	1.40
Drill, 22 to 30 feet	8:00	1.00
Drill, 30 to 42 feet	4:28	2.68
Drill, 42 to 62 feet	11:22	1.76
Drill, 62 to 82 feet	13:00	1.54

TABLE 11. - Field log, hole 3, Chatanika--continued

Summary of drilling speed--continued

Description	Time, minute	Feet per minute
Total, 8 to 82 feet..............................	46:50	
Average, 8 to 82 feet............................		1.58
Total, 82 to 100 feet............................	10:40	
Average, 82 to 100 feet..........................		1.69

Remarks

The button bit used with the Mission Hammerdril showed no measurable evidence of wear after drilling 77 feet.

The button bit performed better than the summary of drilling speed indicates. During most of the period while drilling, the hammer was binding, frozen, or otherwise working at low efficiency. During brief and unexpected intervals the hammer would loosen up and hammer freely. Because these intervals were unpredictable, the exact rate of progress could not be measured; however, both the driller and the engineers estimated the progress at about 4 feet per minute, or about double the best rate achieved while drilling by any other means.

TABLE 12. - Field log, hole 4, Chatanika

Date: May 18, 1967.
Location: In trail near substation.
Drill: T-650 Reichdrill (Chicago Pneumatic).
Compressor: 450 cfm, 250 psi.
Bits: Williams Tricone rock bit W4W, 8-inch, 0 to 5 feet; Williams Tricone rock bit, W4W, 6-inch, 5 to 100 feet (same bit used in holes 1, 2, and 3).
Casing: Heavy duty 6.25-inch inside diameter, 6 feet long.
Water mixed with air to remove cuttings: 0 to 20 feet, 25 gallons; 20 to 40 feet, 30 gallons; 40 to 60 feet, 37 gallons; 60 to 80 feet, 34 gallons; 80 to 100 feet, 55 gallons; total, 181 gallons.

Time	Depth	Stop watch	Remarks
1:22			Move completed.
1:24			Jacked up and level.
1:25			Derrick up.
1:26	0.0		Start hole.
1:29	5.0		

TABLE 12. - Field log, hole 4, Chatanika--continued

Time	Depth	Stop watch	Remarks
1:29-:39	5.0		Set tarps, etc., to catch sample.
1:42	5.0	+.0:00	Start drilling with 6-inch Tricone, rotate 60 rpm. Drilling with plenty of water mixed with air.
1:52	20.0	+ 9:18	
1:53	20.0	+ 0:00	
2:03	40.0	+ 9:44	
2:04	40.0	+ 0:00	
2:14	60.0	+ 9:50	
2:15	60.0	+ 0:00	
2:26	80.0	+11:00	
2:28	80.0	+ 0:00	
2:38	100.0	+10:25	
2:49			Rods out of hole. Bit appears to be good for at least two more holes.
2:54-:56			Top casing pulled and 6-inch protective casing placed.
2:58			Derrick down and jacks up.
2:59			Drive away.

Formation log

Feet	Character of material
0 - 3	Tailings, thawed.
3 - 4	Muck, thawed.
4 - 5	Muck and timber, frozen.
5 - 15	Muck and silt, frozen.
15 - 20	Fine to medium gravel, frozen.
20 - 25	Medium to coarse gravel, frozen.
25 - 27	Medium gravel, frozen.
27 - 28	Cobbles and coarse gravel, frozen.
28 - 34	Medium gravel, frozen.
34 - 35	Coarse gravel, frozen.
35 - 46	Medium gravel, frozen.
46 - 47	Coarse gravel, frozen.
47 - 52	Medium gravel, frozen.
52 - 53	Coarse gravel, frozen.
53 - 61	Medium gravel, frozen.
61 - 63	Coarse gravel, frozen.
63 - 70	Medium gravel, frozen.
70 - 73	Coarse gravel, frozen.
73 - 79	Boulders, cobbles, coarse gravels, frozen.
79 - 84	Medium to fine gravel, frozen.
84 - 86	Coarse gravel, frozen.
86 - 90	Medium to coarse gravel, frozen.
90 - 91	Black muck and twigs, frozen.
91 - 97	Fine gravel and sand, frozen.
97 - 100	Bedrock, mica schist.

TABLE 12. - Field log, hole 4, Chatanika--continued

Water measure

29.5 to 92.7 measured 13 cubic feet or 0.2057 cubic feet per foot.

Summary of drilling speed

Description	Time, minutes	Feet per minute
Set up	4:30	
Drill, 0 to 5 feet	3:00	1.67
Drill, 5 to 20 feet	9:18	1.61
Drill, 20 to 40 feet	9:44	2.06
Drill, 40 to 60 feet	9:50	2.03
Drill, 60 to 80 feet	11:00	1.82
Drill, 80 to 100 feet	10:25	1.92
Total, 5 to 100 feet	50:17	
Average, 5 to 100 feet, drilling only		1.89
Change rods	5:00	
Pull rods	11:00	
Tear down and ready to roll	3:00	
Total time	77:17	
Average time, including set up, drill, change rods, tear down		1.29
Drilling rate 77 feet per hour.		

TABLE 13. - Field log, hole 5, Chatanika

Date: May 19, 1967.
Location: Water well in old section of Chatanika.
Drill: T-650 Reichdrill (Chicago-Pneumatic).
Compressor: 450 cfm, 250 psi.
Bits: Williams Tricone rock bit W4W, 6-inch (same bit used in holes 1 through 4), 0 to 90 feet.
Casing: None.
Water mixed with air to remove cuttings: 30 gallons (estimated).

Time	Depth	Stop watch	Remarks
10:00	0.0	+ 0:00	Arrive at drill site and backed into position.
10:10	0.0		Leveled, mast erected, ready to drill.

TABLE 13. - Field log, hole 5, Chatanika--continued

Time	Depth	Stop watch	Remarks
10:11	0.0	+10:45	Ready to drill with 6-inch Tricone, 60 rpm.
10:18	0.0	+ 0:00	Delay, not part of drilling.
10:28	20.0	+ 9:20	
10:29	20.0	+ 0:00	Change rods.
10:37	40.0	+ 7:48	
10:40	40.0		Delay to allow for possible inflow of water.
10:42	40.0	+ 0:00	
10:51	60.0	+ 9:12	
10:54	60.0		Delay--check for water.
10:55	60.0	+ 0:00	
11:04	80.0	+ 8:40	Delay to check for water--small inflow.
11:10	80.0		Checked water inflow.
11:10		+ 9:00	
11:15	90.0	+ 0:00	
11:20	90.0	+ 5:00	Bottom of hole, 10+ gpm water inflow.
11:32			All tools out of hole. Drill left at well site to install well casing.

Formation log

Feet	Character of material
0 - 16	Iron-stained schist.
16 - 22	Hard muscovite schist.
22 - 34	Brown, sandy schist with strong moisture.
34 - 36	Hard muscovite schist.
36 - 37	Quartz vein in schist.
37 - 42	Brown, sandy schist.
42 - 50	Muscovite schist.
50 - 58	Brown, sandy schist.
58 - 61	Muscovite schist.
61 - 62	Dark gray schist.
62 - 66	Muscovite schist with quartz.
66 - 68	Muscovite schist.
68 - 70	Brown, gray schist.
70 - 76	Soft brown schist.
76 - 80	Quartz veins, some water.
80 - 90	Schist with quartz veins, 10+ gpm water. Bottom hole 90 feet with 10+ gpm estimated inflow.

TABLE 13. - Field log, hole 5, Chatanika--continued

Summary of drilling speed

Description	Time, minutes	Feet per minute
Set up	10:00	
Drill, 0 to 20 feet	9:20	2:14
Drill, 20 to 40 feet	7:48	2.56
Drill, 40 to 60 feet	9:12	2.17
Drill, 60 to 80 feet	8:40	2.31
Drill, 80 to 90 feet	5:00	2.00
Average, 0 to 90 feet		2.24
Change rods	4:00	
Pull out tools	12:00	

Remarks

The average speed of 2.24 feet per minutes indicates that the Birch Creek schist is somewhat easier to drill than the frozen gravels at Chatanika.

Bit Cost Estimate

Williams Tricone rock bit W4W, 6-inch:

Hole 1	94
Hole 2	30
Hole 3	18
Hole 4	95
Total	237 feet.

The total footage that this bit could drill, based on degree of damage evident on bit at the completion of hole 5 was 500 to 600 feet. The bit cost $88.00 at the factory; assume $10.00 freight, or $98.00 total.

$$\frac{\$98}{500 \text{ feet}} = \$0.20 \text{ per foot bit cost.}$$

The same bit in 4-3/4-inch size reportedly has equally good wearing characteristics. This bit costs $43.00 at the factory; assume a freight charge of $7.00 or a total of $50.00.

$$\frac{\$50}{500 \text{ feet}} = \$0.10 \text{ per foot bit cost.}$$

Tentative Conclusions

The limited testing at Chatanika suggests the following:

1. The down-the-hole percussion hammer is not well adapted to drilling frozen gravels. If enough water was added to the air stream to cause the cuttings to clear the drill without refreezing the lubricating oil was washed from the control rod of the drill causing the piston to bind and seize.

2. Rotary drilling is an improvement over churn drilling for placing thaw pipes. Additional drilling with smaller size bits will be needed to estimate costs. However, tentative estimates suggest that costs may be low enough to be practical. The top drive type machines appear to be better adapted for the work than the kelly-table type.

3. The percussion drill with button bits may be superior to the rotary drill for thaw field drilling. Troubles with the down-hole hammer made the trials at Chatanika inconclusive. However, during brief intervals when the hammer was running at optimum speed and hitting freely the rate of progress was about double the rate of progress with rotary alone. Bit wear for the 70 feet drilled was not detectable. Trial of a surface percussion drill with independent rotation and button bits is the next step indicated.

Modern 6-inch rotary drills have been used to sample thawed gold placers in South America and at Goodnews Bay in Alaska, but were unsatisfactory because the volume of sample could not be controlled by careful casing driving as it can be with a churn drill. However, water measurements of holes drilled with a 6-inch rotary drill in frozen placer gravels at Chatanika indicate that reasonably smooth hole was drilled. Recovering the sample from the hole appeared to present no serious problem. However, a churn drill will average 25 to 50 feet per day and a self-propelled rotary may drill 500 to 600 feet or more per day. The volume of sample to be handled may be 10 to 20 times greater than in common churn drilling practice. The traditional sampler equipped with a rocker and gold pan just cannot keep up.

The capabilities of the high-speed rotary drill cannot be fully utilized for placer sampling until a mechanical rougher is devised that can clean up the samples without delaying the drilling. The drilling rate, including everything except moving time, for hole 4 was 77 feet per hour and for hole 1 was 73 feet per hour which suggests that a T-650 Reichdrill with 6-inch Tricone bit should average about 75 feet per hour in the gravels of interior Alaska. The volume of hole 4 was 0.2057 cubic feet per foot and of hole 1 was 0.2131 cubic feet per foot; the average of both is about 0.2 cubic feet per foot. A 6-inch rotary drill, therefore, would produce 15 cubic feet of sample per hour. Gravels and sand may vary from 90 to 120 pounds per cubic foot. The sample treatment plant should be able to handle 15 x 120 or 1,800 pounds per hour.

Sampling is beyond the scope of this project. Development of sampling and sampling handling techniques for use with a rotary drill will be the subject of a separate project proposal.

OTHER PROBLEMS

The following are additional problems that will require research:

1. The basic principles of heat transfer and thawing as applied to permafrost. The first stage of this study would involve a literature search, perhaps supplemented by laboratory experiments. Particular attention should be given to Russian, Canadian, and Scandanavian literature on this subject. This would be followed by controlled experiments both in the laboratory and the field to develop mathematical concepts of heat transfer as applied to thawing permanently frozen gravels.

2. The relationship between the amount and temperature of water supplied to a thaw point and the rate of thaw about this point. This is the practical application of the theoretical principles of heat transfer. Experience data from the literature and from mining company records would have to be supplemented by controlled field experiments. Placer miners express the amount of heat supplied in Miner Inch Degree Days (MIDD), but the concept was developed from observation and experience and may not be a valid approach.

3. As thawing of gravel proceeds, a critical point is reached when enough heat has been stored in the ground so that it will not freeze again; a "sweating" process then begins that tends to eliminate "frost horses." Recognition of this critical point may be of considerable economic significance.

4. Relative efficiency of vertical thaw pipe holes versus angle holes. Vertical holes have always been used because churn drills can only drill vertical holes and point driving equipment is most efficient if the pipe is vertical. Some placer men believe that because of the slumping of ground as it thaws angle holes would bring the water into more effective contact with the frozen ground.

5. The possibility of using reverse circulation. Instead of pumping water down the point, use the point to withdraw cold water from the ground and allow warm surface waters to percolate downward through the gravels. This system was used in the early days; water was introduced into the ground at the edge of a block and pumped from shafts in the center. Reverse circulation might be combined with the present practices. Possibly the ground should be thawed with points in the conventional manner until it becomes somewhat permeable. Then most of the points could be removed and reverse circulation used to complete the thaw.

6. Methods of increasing permeability so that the water can come in more direct contact with the frozen gravels should be studied. If any method seems to be economically practical, it should be investigated.

7. Methods of thawing deep ground that do not require placing thaw points. Solar thawing and other methods now used only to thaw shallow placers may be adaptable for use in deeper ground.

8. The areas covered by thawed dredge tailings are the best building sites in both the Nome and Fairbanks areas and also are valuable sources of gravel. If a dredging operation could in some manner recover payment in a reasonable time for benefiting the community, it would help to make the operation economically feasible. This aspect of dredging economics should be given careful study.

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