SIGNIFICANT PARAMETERS OF MINING PROPERTIES IN ARCTIC AND SUBARCTIC AREAS OF NORTH AMERICA

Mineral Industry Research Laboratory
University of Alaska-Fairbanks
Fairbanks, Alaska 99701

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By

David A. Hackney

Chris Lambert

Bruce W. Campbell
and
John J. DiMarchi
Editors

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ABSTRACT

This paper is a review of those factors unique to mining in the Arctic and subarctic. The information was developed from an exhaustive literature search and personal visits to several northern mines in North America.

The intent is to present a broad overview of many of these factors, to identify and stimulate consideration of parameters that are likely to be overlooked by companies and persons without prior arctic experience. Topics of discussion include exploration, cold weather plant design, cold weather equipment operation, blasting in permafrost, living conditions and employee relations.

The appendices are a brief discussion of a number of the arctic and subarctic operations in North America.

In brief, mining in northern regions is practical provided the deposit has sufficient value to support the higher construction, transportation and operating costs associated with the remoteness and cold weather. Hiring and retaining good employees and integrating the native labor force into the operation have proven to be the most difficult problems. Equipment and plant operation are problems more easily solved.

PREFACE AND ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

Definition

As man strives to increase the standard of living for all people, the need for basic raw materials and energy becomes more intense. This need has forced resource suppliers to the remote and difficult areas of the world. The subject of this report, the Northland, is one such remote and difficult region to be explored and exploited for the betterment of mankind.

Purpose and Scope

The purpose of this report is to present a brief discussion of many of the significant aspects relating directly to mine development in the cold regions of North America. It is hoped that a developer, after reviewing this report, will be aware of the problems of the north.

Many mining companies and prospectors are actively engaged in exploration activity in the subarctic and arctic areas. Some of their discoveries have been turned into profitable mines and others will be in the future.

This report is a review of recent arctic and subarctic mining operations and other developments with respect to those parameters that are unique and significant to the Northland. The information presented in this report was gathered through an extensive literature search, classroom work, personal interviews, and field visits to mines in Alaska, Quebec, Labrador, Yukon Territory, and Scandinavia. The report is a broad overview of many topics, each of which require more space than is available here for complete analysis. The body of the report covers the main topics in general, and the appendices contain specific descriptions of many northern mines and development sites.

The amount of information presented in the appendices on each mine varies depending on the literature available and the cooperation of sources contacted. Also, the author was unable to visit all sites because of financial and time limitations.

Arctic and Subarctic Areas Defined

A definition of the arctic and subarctic areas depends upon the background and purpose of the author. A geographer may define the arctic as that area north of the Arctic Circle where, on the longest day of the year, the sun fails to set. The tree line and tundra boundaries may be used by a forester. An economist may consider the extent of economic development and agriculture. Meteorologists describe the arctic in terms of temperature and precipitation averages and extremes. A geotechnical engineer may define the arctic as that area with discontinuous permafrost. Johnson and Hartman (1971) in the Environmental Atlas of Alaska define the Arctic as those lands that

> "... have no months with mean monthly temperatures greater than 50°F and at least one month with a mean temperature of 32°F or colder."

They further define the subarctic as those lands that

> "... have from one to four months with monthly mean temperatures greater than 50°F and at least one month with a mean temperature of 32°F or colder."

Because of the importance of ground conditions in mine planning and building foundation design, the geotechnical definition will be used for setting the boundaries for this report.

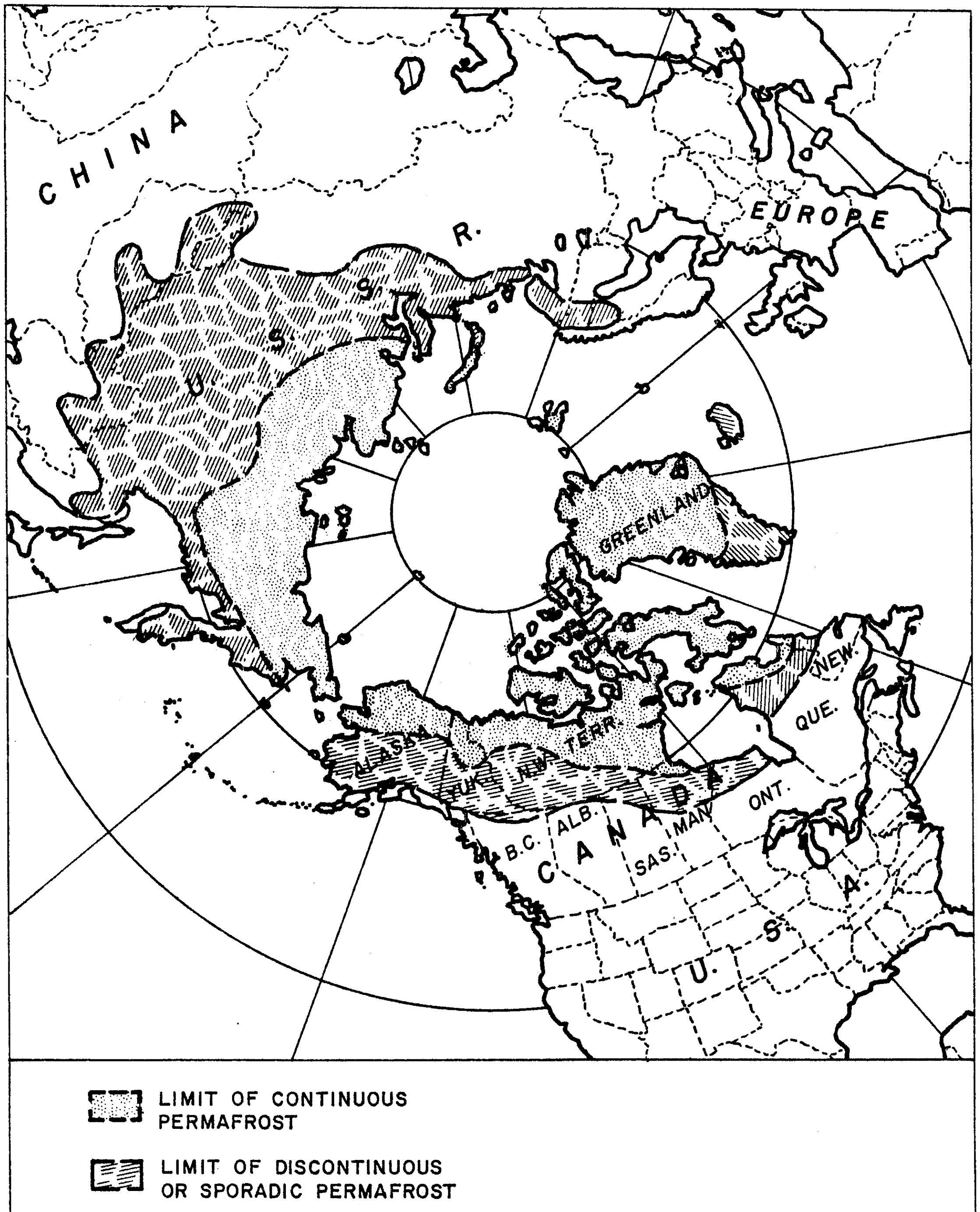


FIGURE I-1

NORTHERN HEMISPHERE PERMAFROST BOUNDARIES

Source-Phukan (1976)

Table 1-1

Watson's Climatic Breakdown of Alaska

	ARCTIC	CONTINENTAL	TRANSITIONAL	MARITIME
Mean Annual Temp	+10 to 20°F	+15 to 35°F	+25 to 35°F	+40°F
Temp Variation*	+28 to 32°F	+34 to 42°F	+20 to 35°F	+12 to 14°F
Mean Jan Min Temp	22 to 16°F	28 to 16°F	8 to 20°F	0 to +32°F
Mean Jan Max Temp	10 to +14°F	10 to +12°F	+8 to 28°F	+20 to 42°F
Mean July Min Temp	+34 to 50°F	+40 to 52°F	+42 to 50°F	+40 to 52°F
Mean July Max Temp	+48 to 68°F	+56 to 76°F	+52 to 70°F	+58 to 68°F
Total Precip	4 to 12"	8 to 20"	12 to 160"	40 to 220"
Total Snowfall	20 to 50"	50 to 70"	50 to 100"	50 to 200"
Humidity	Low	Low	Medium	High
Cloud Frequency	Medium	Low	Medium	High
Winds Expected	Strong	Light	Medium	Medium
Expected Jan Wind Chill**	1650	1110	1110 to 1390	970
Degree Days Heating +	16,000 to 20,000	14,000 to 18,000	10,000 to 14,000	8,000 to 10,000
Degree Days Freezing ++	5,000 to 8,500	5,000 to 7,500	2,000 to 6,500	0. to 500
Vegetation	tundra/ grass	stunted forest	farming/ forest	rain forest

* Temperature variation from the mean. (times 2 equals the range)

** Wind chill units: kilogram-calories per square meter per hour.

\+ Degree days heating: degrees variation below 65°F times the number of days below 65°F.

++ Degree days freezing: degrees variation below 32°F times the number of days below 32°F

Table 1-1 is based on interpretation of information presented in The Environmental Atlas of Alaska (Johnson and Hartman, 1971).

Figure 1-1 shows a polar view of the arctic (continuous permafrost) and subarctic (discontinuous permafrost) areas of the Northern Hemisphere.

Johnson and Hartman, in describing the climate of Alaska, rely on the work of C.E. Watson, U.S. Weather Bureau. Watson preferred to divide the subarctic into continental and transitional zones. Table 1-1 is a summary of Watson's climatic breakdown of Alaska with temperature, precipitation and wind factors compared. The Maritime Zone includes all of Southeastern Alaska, the Aleutian Islands, Kodiak Island and the coast along southern Alaska. The Transitional Zone includes all of western Alaska south of Nome and the Susitna River, Cook Inlet and Copper River areas south of the Alaska Range. The Continental Zone extends from the south slope of the Brooks Range to the south side of the Alaska Range and west to McGrath. Finally, the Arctic Zone includes all of the Brooks Range and areas north, and extends southwest nearly to Nome.

In Canada, the Arctic and subarctic areas extend far to the south in midcontinent and swing north near the Atlantic Ocean. Scandinavia, despite its northern location, has a temperate climate. Discontinuous permafrost is found in northern plateau areas. Northern European Russia has a subarctic climate. In Siberia, the cold pole of the Northern Hemisphere is found at Oymyakon (68°N) where the mean January temperature is -60°F with a record low of -95°F. Gold and diamonds are mined near Oymyakon (Hall, 1975).

The arctic and subarctic climate has been pushed far to the north in Scandinavia and western Russia by the warm ocean currents from the Gulf of Mexico. The warm Japanese current influences the climate in western Canada, Alaska and eastern Siberia.

Johnson and Hartman correctly point out that permafrost below the Arctic tundra prevents rainfall from soaking into the ground, resulting in many shallow lakes, wet muskeg and significant river run-off. This, when combined with the low evaporation rate and low winter transpiration rates, provides an adequate water supply despite a precipitation rate that would result in arid conditions elsewhere.

CHAPTER 2

EXPLORATION AND DEVELOPMENT

Introduction

In response to the need for oil, natural gas, coal and other minerals, exploration activity in arctic and subarctic areas has intensified. Much of the area has been investigated only superficially. The seasonal nature of arctic working conditions dictates meticulous planning, large inventories, back up systems, and emergency supply sources.

Mineral exploration is big business in Canadian North. Eighteen million dollars were spent in the Northwest Territories in 1974 on the search for base metals, uranium, gold and silver. In the Yukon Territory, 12 million dollars were spent. Exploration activity in 1975 increased 25 million dollars in the Northwest Territories and 16 million dollars in the Yukon Territories (North of 60^{0}, 1975).

Transportation and Supply

In many cases, fully one half of the total exploration budget is devoted to transportation (Gryback, 1976). Modes of transportation include barge, cat train, snow road, hovercraft and tracked vehicles. Due to a lack of road and rail facilities and the seasonal nature of water transportation, exploration crews rely heavily on air support.

Aircraft can provide year round service by utilizing ice runways on a lake or bay during the winter and gravel river bars in the summer. Light aircraft equipped with floats can use lakes and broad rivers. During development of the rich iron deposits at Mary River on Baffin Island, Baffinland Iron Mines Ltd. used the frozen Sheardown Lake as a landing strip for Nordair DC-4 Constellation freight service (Watts, and Megill, 1965). Nordair provides Boeing 737 service to the Nanisivik development on Baffin Island. The Boeing 737 was landed on an eight thousand foot ice runway on Strathcona Sound while the 3.5 million dollar Arctic Class "B" airport was under construction (Yates, 1975). Table 2-1 displays a cost comparison of available freight service from Edmonton, Alberta to Inuvik, Northwest Territories. The 1982 cost level is nearly twice that of 1975.

TABLE 2-1

Method	From	To	Cost ¢/lb (1975)
Truck & Barge	Edmonton	Inuvik	5.0
Truck	Edmonton	Hay River	16.5
Air	Hay River	Inuvik	
Truck	Edmonton	Whitehorse	16.0
Air	Whitehorse	Inuvik	
Air freight	Edmonton	Inuvik	29.0
Air container	Edmonton	Inuvik	22.0

source - Dayall (1975)

Exploration crews are often served by small planes like the Piper PA-18 "Super Cub" which can land on river bars and bare ridges which would be unsuitable for other aircraft (Gryback, 1976). Helicopters, however, are the main work horse of the exploration crew. Although the rental rate for a helicopter of similar pay load is approximately three times that of a fixed wing craft, their greater versatility and applicability to mineral exploration has resulted in wide acceptance.

Cat trains and snow roads are used in the arctic for moving heavy loads. Cat trains are used in the winter months when the ground is frozen and protected by a layer of snow. Crawler tractors smooth a pathway and other tractors pull large sleds which carry freight. Increased labor cost and competition from large freight aircraft have reduced the use of cat trains. Snow roads, build of compacted snow and ice with a surface capable of supporting a standard highway tractor trailer can be used as an alternative to cat trains. Snow roads are built from snow accumulated along snow fences, from reworked snow in place or from artifical ice and snow. Such a road was used for supplying construction camps during DEW Line construction and later during arctic oil development. Snow roads often take advantage of the flat surfaces of a frozen river or lake. Roads crossing river or lake ice are often reinforced by increasing the ice thickness or by providing structural reinforcement (Rhoads, 1973). Ice can be thickened by clearing the snow to increase heat transfer or by pumping water on the road surface to freeze. Brush, logs, and planks can also be frozen into the ice roadway to increase its load carrying capacity (Rhoads, 1973).

Shipments via water routes on the arctic are highly seasonal. Barge traffic on large rivers can be utilized from June into October. Barge shipment to the arctic coast from Seattle can be carried out only once each year. The water is ice-free only long enough to allow unloading and return. The navigation season in Hudson Strait is restricted to the three month period from the end of July to the end of October (Thurner, 1976). Shipments to Little Cornwallis Island for development work at the Polaris Project are limited to six weeks in midsummer. Ships with specially strengthened hulls to withstand ice pressure are required for shipments in the Canadian Arctic Islands (Redpath, 1974).

Hovercraft have been used in the arctic to a limited extent. During the oil pipeline construction, hovercraft were used for moving freight across the Yukon River prior to bridge completion. Hovercraft are used by the oil industry for exploration in the MacKenzie Delta region of Canada. Hovercraft have several important limitations. Some of these are: limited climbing and side-slope ability (5-10 percent), great width in proportion to pay load capacity, low obstacle clearance, and a wide turning radius needed because of aerodynamic steering.

About 49 percent of the Alaskan population live in urban areas (Haglund, 1973). The sparseness of the population is further illustrated by the fact that 4,498 people live in the 38,281 square mile North Slope Borough (Directory of Borough and City Officials, 1975). An operator cannot expect to find fuel, food and services in a small arctic village in quantity for a summer long field effort. The resulting long supply lines require a larger than normal inventory on site.

<u>Seasonal Work</u>

Exploration in the arctic is a seasonal effort. Field work is normally carried out in the summer months, May through September, taking advantage of the warm weather and extended daylight hours. Problems are more severe in the winter months. The expected working daylight hours for any given month and latitude can be found in Figure 2-1. The values found on this chart are the numbers of hours that outdoor activities can be performed without artifical lighting (Johnson and Hartman, 1971).

Another seasonal constraint imposed on arctic exploration is the condition of the tundra. Low ground pressure vehicles are required for summer traverse of trundra areas. Tests reported by Burt (1971) indicate that low ground pressure vehicles do not affect the depth of thaw of the active layer or the permafrost, and the tracks require reseeding only at pot holes. These tests were not performed on sloping terrain. The use of these vehicles for reconnaissance programs is limited by their slow speed, inability to traverse rough terrain, and high maintenance.

<u>Communications</u>

The great distances involved in arctic work require good communication support. Radio interference can come from magnetic storms and associated electrical disturbances. Long range and nonline-of-sight communications require single side band (SSB) radios. The Geological Survey of Canada uses a CH25-SSB receiver transmitter at base camps located in the arctic. Fly camps are equipped with small portable SBX-11-SSB radios which are powerful enough to communicate with the base camp (Kerr, 1974).

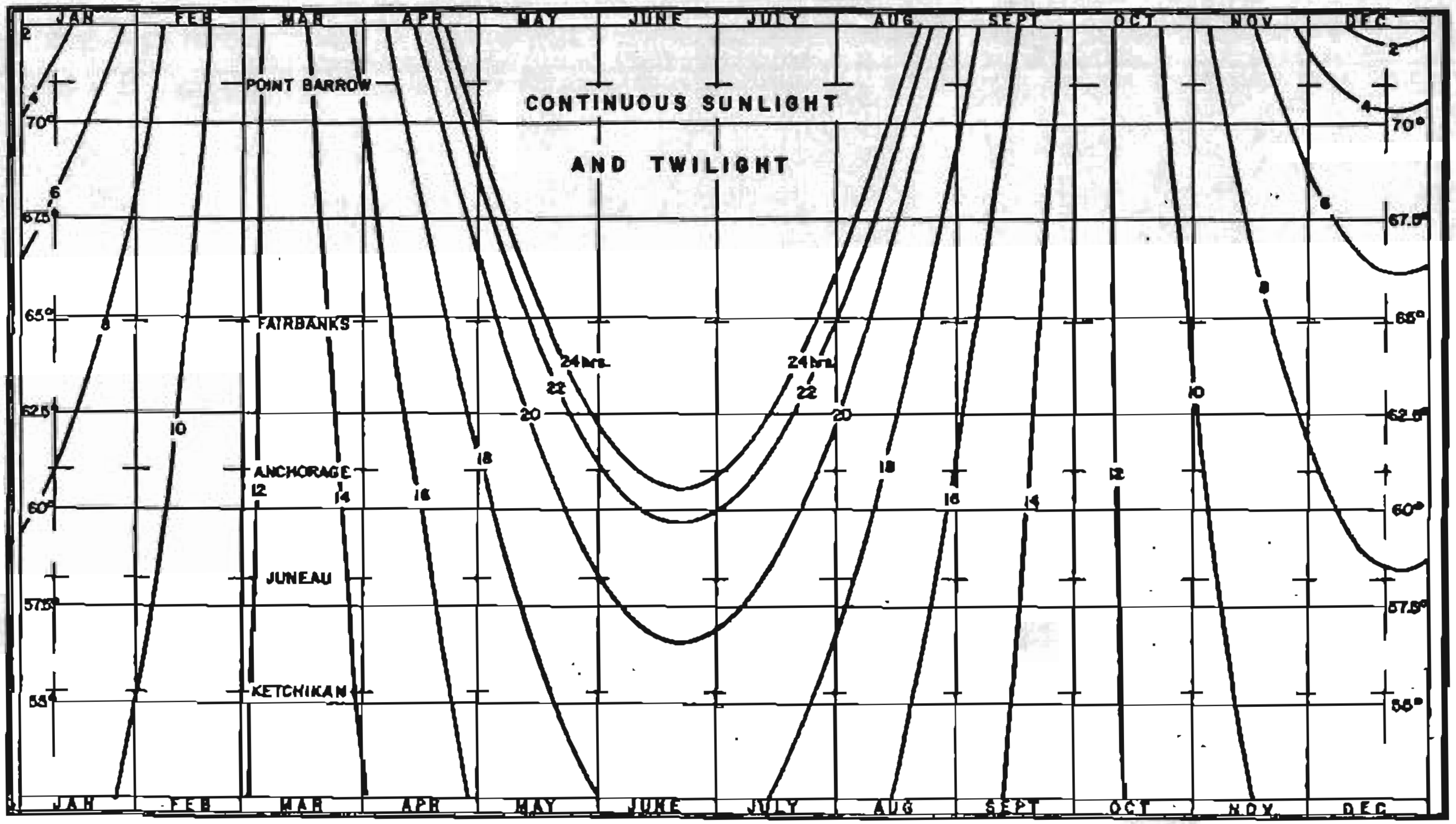


FIGURE 2-1
SUNLIGHT PLUS TWILIGHT IN NORTHERN LATITUDES

Source - Johnson (1971)

Very high frequency (VHF) radios are adequate for line-of-sight and short distance use. Light aircraft and helicopters are equipped with VHF radios which should be considered in the total communications system.

<u>Exploration in the North</u>

Permafrost will affect the results of seismic and self potential surveys (see Chapter 3). Permafrost restricts upward migration of ions, hindering geochemical prospecting (Wolff, 1973). Work by Allen and Hornbrook (1970) in the Coppermine River region of the Northwest Territories indicates that copper ions do migrate in permafrost regions and that meaningful anomalies can be found from large lake water, stream sediment, and surface soil samples. Geochemical prospecting may be aided by the rapid soil rising associated with solifluction and frost heaving (Wolff, 1973 and Allen, 1970). Natural frost boils, areas of broken vegetation exposing mud from the C-horizon, provide good geochemical soil samples (Wolff, 1973).

Because of low precipitation, some areas in the arctic and subarctic were never glaciated. These areas present different exploration problems than glaciated regions. The nonglaciated areas have had more time to weather, thus increasing the importance of weathered byproducts of minerals. It is, moreover, much easier to trace anomalies back to their source where the soil had not been transported by glacial action (Aho, 1966).

In unglaciated areas, soils are mature and soil samplings will be effective. On the other hand, the streams do not cut fresh rocks and the effectiveness of sediment sampling is reduced. It should be noted, however, that the cold climate inhibits weathering, and the depth of weathering may be less than in warmer regions. This makes geochemical and geophysical methods more effective (Aho, 1966).

CHAPTER 3

PERMAFROST AND FROZEN GROUND

Permafrost is any rock or soil material that has remained below 0°C (32°F) continuously for two or more years (Ferrians, Jr., 1969). This description is independent of moisture content, organic content or soil characteristics. Permafrost ground can be dry, contain ice crystals and lenses or be solid ice. Moisture content, soil gradation and soil temperature are important factors when considering the engineering properties of frozen ground.

Ice occurs in the frozen ground as coatings on soil grains, crystals, lenses, wedges or massive ice. Ice lenses and larger areas of massive ice are formed by moisture migration as described under the section on frost heaves. Ice wedges form when surface water enters a crack in the ground and freezes. Repeated freezing and filling forms ice wedges which are triangular in shape and point downward. The top of the ice wedge triangle is at the bottom of the active layer. Ice wedges may grow until they connect with adjacent wedges. Since the ground contracts in three dimensions, the cracks form polygonal shapes. These polygons vary in size according to the tensile strength of the ground. Rice and Alter (1975) in describing frozen ground phenomenon give an excellent account of ice wedge formation.

The depth of permafrost in an area can be estimated when the mean annual temperature and the geothermal gradient are known. The average geothermal gradient is 3°C per 100 meters (1.8°F per 100 feet) depth (Rice, 1975). The actual gradient can be measured by placing a thermo—couple string in a vertical hole. Figure 3-1 gives a graphical representation of the permafrost temperature system. Thus, the bottom of the permafrost is the point at which the gradient crosses the 0°C line. The cone shape at the top of the curve represents the limits of the seasonal variation. The bottom of the active layer is the point at which the warm side of the cone curve crosses the 0°C line. The actual ground temperature curve will depend on the season. See whiplash curve in Figures 3-1. The effect of the warm summer temperature can still be seen in the ground temperature curve during the winter.

Superimposed upon this curve are the effects of climatic history, vegetation, hydrology, snow cover, forest fire history and man's activity. Computer analysis of temperature curve data at Kapuskasing, Ontario revealed a warm climatic period from 900 to 1100 A.D., a cold period from 1600 to 1750 A.D. and a warm period from 1880 to 1940 A.D. (Jessop, 1972). Vegetation acts as an insulation. When this insulation is modified by fire, flood, or man's activity, the temperature balance of the permafrost changes and can result in a drastic degradation in the permafrost.

Lakes deep enough so that they do not freeze to the bottom have a thaw bulb beneath them that varies in size depending upon the age of the lake. This thaw bulb and the unfrozen water in the lake can be a source of water. Very old lakes have no permafrost beneath them. If a lake of this kind should fill or become drained, the permafrost advances into the thaw bulb, refreezing the ground. As the refreezing process advances from all directions, an area of unfrozen water may be trapped, and the freezing pressure forces this water to the surface eventually forming an ice mound known as a pingo.

Water trapped beneath a thin layer of permafrost may be under artesian pressure generated from a nearby slope. A source of warmth may melt the permafrost, releasing water under pressure from beneath the permafrost layer. A pingo may also form if this artesian water reaches the surface through a crack (Rice, 1971).

The relative impermeability of the permafrost often results in a super saturated condition in the active layer. This saturated soil may creep down the slope, causing many problems for developers. This down slope movement, solifluction, can occur on slopes as gentle as three percent (Ferrians, 1969).

Frost Heaves

Newcomers to the North are often puzzled to find that objects placed in the ground such as power poles, mail box posts, survey monuments or ridge piles rise out of the ground over a few winter seasons. These objects are jacked out of the ground by the action of seasonal frost.

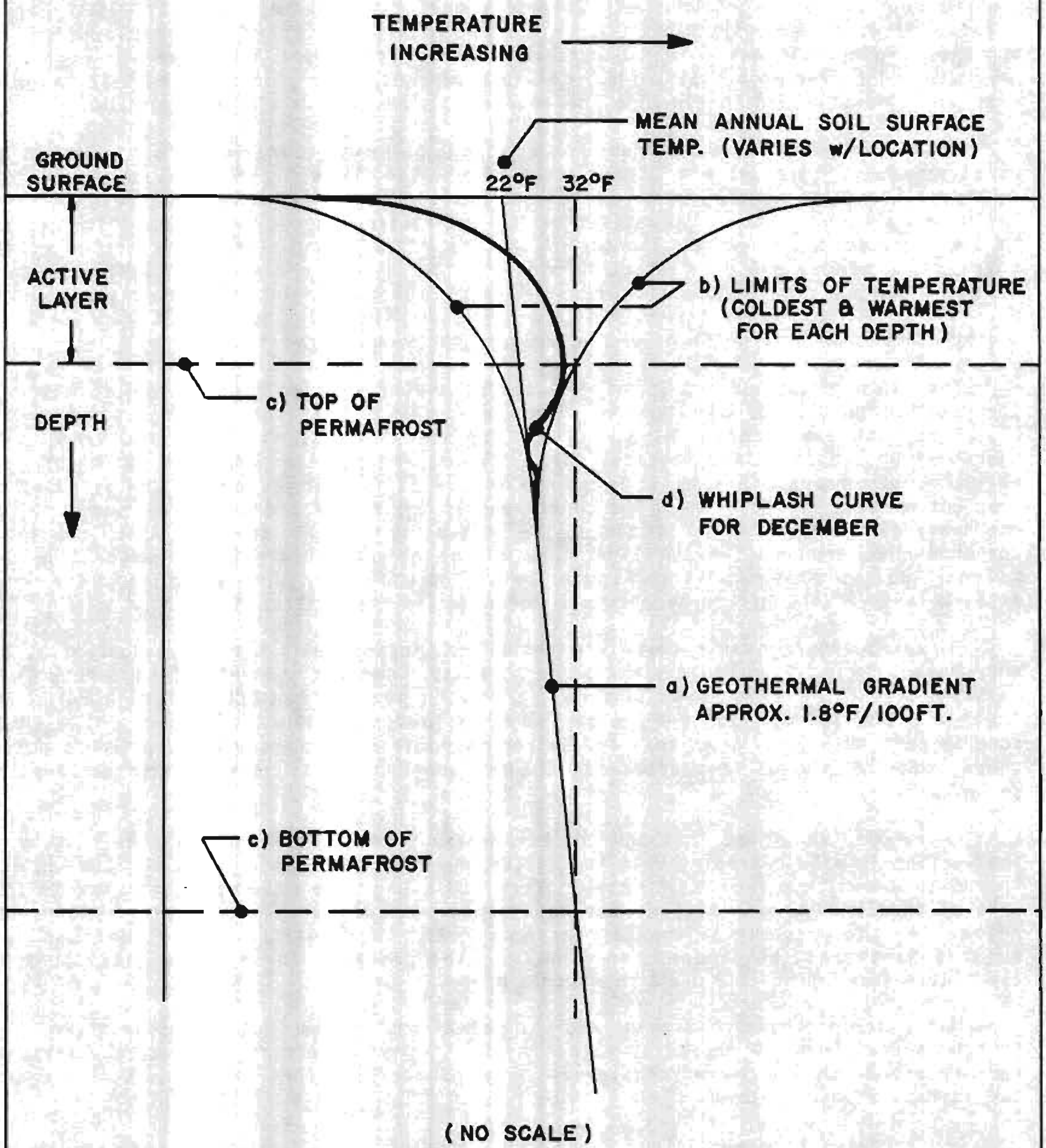


FIGURE 3-1

GEOTHERMAL GRADIENT IN PERMAFROST

Source-Rice (1971)

The frost jacking process requires fine-grained soil to promote water movement by capillary action. As the cold begins to penetrate the ground from the surface downward, soil freezes to the post. Water in the ground migrates by capillary action to the freezing front and forms ice lenses. These lenses usually (depending on permeability) continue to grow after the freezing isotherm has moved deeper because the high pressures in the pores allow the water to remain unfrozen at temperatures below $0^{o}C$. The water migrates to crystallization centers where it freezes in lenses. As these lenses form and grow, the surface of the ground is pushed upward. If the strength of the ice bond to the post (adfreeze strength) is greater than the resistance forces, the post moves upward with the heaving ground. When the ground begins to thaw (from the surface downward) it settles around the post, which is prevented from returning to its original position by the frozen soil beneath.

There are several solutions to this problem. The most effective being to sufficiently anchor the object to insure adequate resistive forces to the heaving action. Another common solution is to place a material around the post within the active layer which prevents bonding between the heaving ground and the post. Another solution is to prevent heave by removing the frost susceptible soil and replacing it with granular nonfrost susceptible soil. Another is to keep the ground frozen or to keep it thawed.

Frost heave action can also move soil down slope in a ratchet like action with the soil sliding down the slope during thawing (Brown and Pewe, 1973). Frost creep and solifluction are examples of mass wasting in permafrost areas that must be considered by developers.

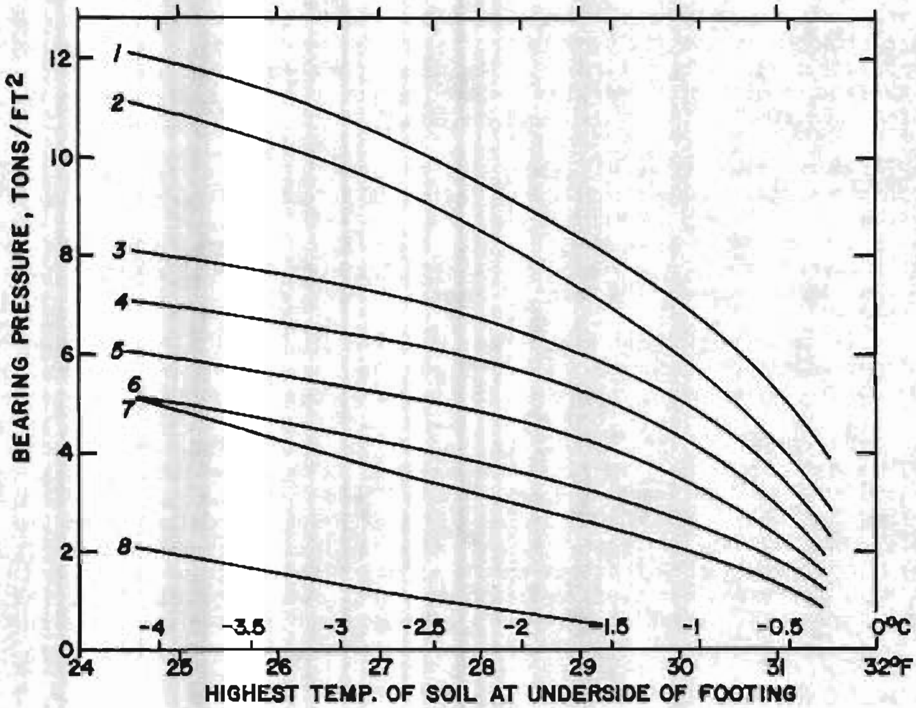
Roads, runways, railroads, etc., built in cold regions are subjected to this heaving action which can render the facility useless. Careful removal of the fine grained soil and replacement with free draining coarse-grained sand and gravel will prevent water migration to the freezing front and minimize heave. In the Spring, a road bed that had been heaved upward by ice accumulation in fine-grained soil often develops frost boils and pot holes. The thawed lenses (now water) are contained by the adjacent frozen ground and become spots of weakness that will collapse from traffic loads, forming soft muddy holes referred to as frost boils. Coarse grained fill material provides a pathway through which the water can drain.

<u>Engineering Properties of Frozen Ground</u>

Frozen ground behaves rheologically when subjected to a load (stress), that is, the reaction is strongly time and temperature dependent (Vita, 1976). Frozen ground can be divided into three types: friable frozen, plastic frozen and hard frozen (Phukan, 1976). Friable frozen ground is coarse grained with a low moisture content and behaves much like unfrozen ground. Plastic frozen ground has a significant unfrozen water content and behaves plastically. Hard frozen ground has low compressibility (10^{3} to 10^{4} cm2/kg) and is firmly cemented with ice. The transition temperature between hard and plastic frozen ground varies with the soil type. Silty sand is considered hard frozen if it is colder than minus $0.3^{o}C$, sandy loam is hard frozen below minus $0.6^{o}C$, clay loam is hard frozen below minus $1.0^{o}C$ and clay is hard frozen below minus $1.5^{o}C$ (Phukan, 1976).

Frozen ground is a four phase material: soil particles, ice, unfrozen water and gas. As a soil freezes, the water in the larger voids freezes first but remains unfrozen in the smaller voids and on the grain coatings. The first water to freeze is quite pure, increasing the impurities in the remaining water. The capillary tension in these smaller pores is higher and as long as they are connected, water will be drawn through them. The increase in impurities and the water pressure from the capillary tension will depress the freezing point of the unfrozen water to as low as $-5^{o}C$ ($23^{o}F$). Thus the mechanism for ice lense growth within the frozen layer is apparent. The water is unfrozen and mobile even when the soil appears frozen (Phukan, 1976).

The graph in Figure 3-2 shows the drop in soil strength with increase in temperature for various frozen soil types. The advantages of keeping the soil frozen hard can readily be seen. This graph should not be used for design purposes, as only a detailed site soils investigation can provide adequate information for a proper foundation design. Frozen ground is often at the warm (weak) end of the temperature range and may exhibit plastic properties when loaded.



LEGEND

1. BROKEN ROCK, COARSE GRAVELS.
2. COMPACT SANDS & GRAVELS FROM CRYSTALLINE ROCKS.
3. FAIRLY COMPACT SANDS & GRAVELLY SOILS FROM SEDIMENTARY ROCKS.
4. FINE SANDS, SILTY SANDS, & SANDY SILTS WITH CLAY.
5. CLAYEY SILTS WITH SAND, & CLAYS.
6. SILTY SOILS.
7. ALL KINDS OF SOILS, 1 TO 4, HAVING ICE LENSES. CLAYEY SOILS WITH ORGANIC MATERIAL FROM 3 TO 12% BY WEIGHT.
8. PURE ICE & ICE WITH PEAT.

NOTE: VALUES FOR PEATY SOILS TO BE FOUND BY SPECIAL TESTS.

FIGURE 3-2

VARIATION OF BEARING PRESSURE WITH TEMPERATURE FOR VARIOUS FROZEN SOILS

Source - Phukan (1976)

The plastic properties of frozen ground result in a creep phenomenon whereby the ground will subside slowly and continuously when loaded. Frozen ground deformation can be divided into four parts: instantaneous deformation, primary, secondary, and tertiary creep (Phukan, 1976). Primary creep is characterized by decreasing creep rate with time, secondary creep by constant creep rate with time and tertiary creep by an increasing creep rate until failure (See Figure 3-3). This figure is presented without a scale due to wide variations in soil type, moisture content, temperature, load and soil density. The time to onset of tertiary creep (failure) could be many years if the stress is low. Vyalov and Sanger have developed methods to estimate the onset of tertiary creep (Phukan, 1978).

Determination of Permafrost Extent

An estimate of the three dimensional extent of permafrost is desirable in discontinuous regions because of the many undesirable mechanical properties of frozen ground. Iron Ore Company of Canada has done extensive research on this problem because of the added cost of mining frozen ore at Knob Lake, Quebec. There is a marked increase in the sonic velocities and electrical resistivity of frozen ground as compared with thawed ground (Garg, 1973). Table 3-1 compares the compressional-wave velocities for frozen and unfrozen iron ore formations at Knob-Lake. Table 3-2 compares the average resistivity for frozen and unfrozen iron ore at Knob Lake.

TABLE 3-1

Velocity-Meters per Second

Ore	Unfrozen	Frozen
leached	1,372	5,486
unaltered	3,048	6,096

(source: Garg, 1973)

Table 3-2

Resistivity-Kohms per Meter

Ore Moisture	Unfrozen	Frozen
5 - 8%	1.53	23.6
10 - 15%	0.55	26.4

(source: Garg, 1973)

Terrain can also indicate the presence of permafrost. North facing slopes have a higher probability of permafrost than south facing slopes or areas of snow accumulation. Vegetation is an insulator which, if removed or disturbed, may result in permafrost degradation. Trees provide a shade from the sun, slow the cooling effect of winds and reduce snow cover. Water also has an effect on permafrost. Lakes that do not freeze to the bottom do not have permafrost beneath them unless they are very new lakes. Warm spring water in contact with frozen ground quickly brings the temperature near 0°C, and frost is weak at this temperature even though the latent heat in the ice prevents it from thawing quickly. Snow cover also has an effect on permafrost. Snow is a good insulator and, depending on snow pack density, can retard frost advance in the fall and retard thaw in the spring (Brown, 1969).

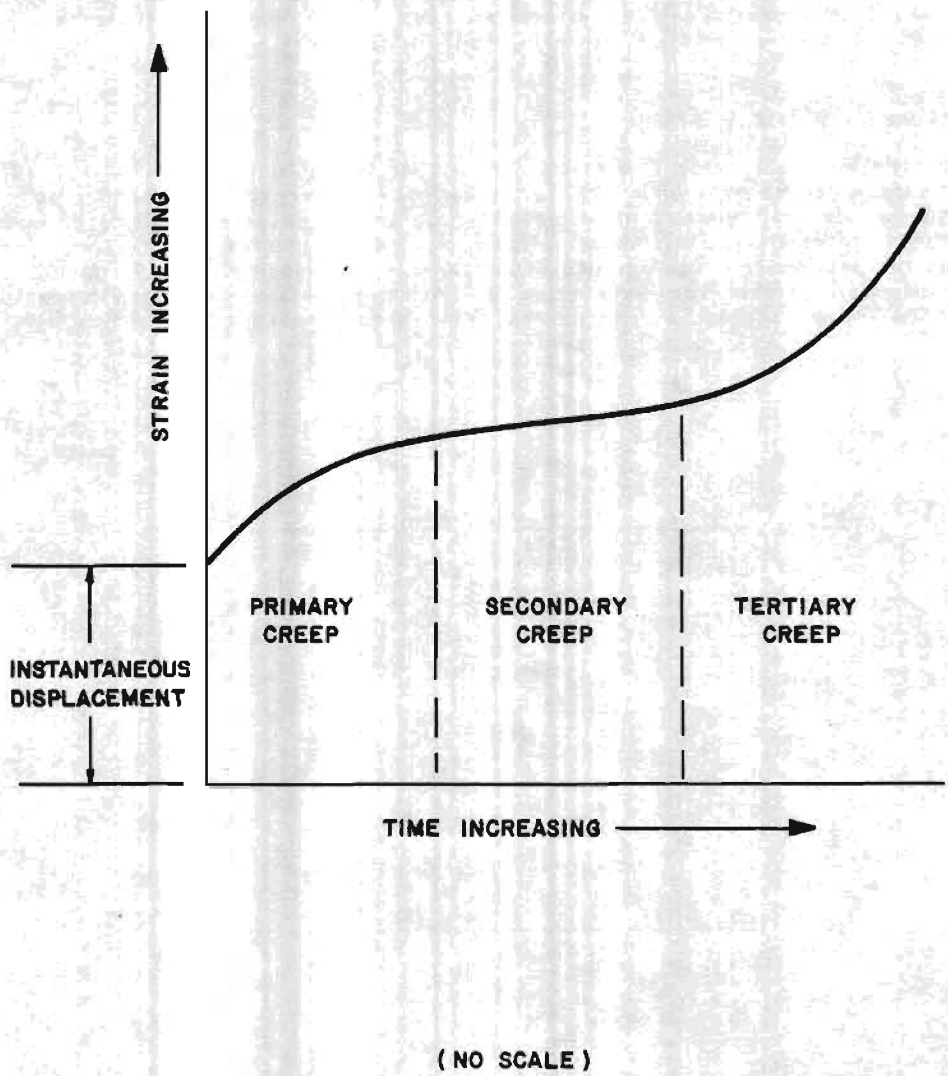


FIGURE 3-3

STAGES OF CREEP AT CONSTANT STRESS

Source-Phukan (1976)

Permafrost Effect on Underground Mining

Permafrost can actually be an advantage in some mines by reducing ground water flow and increasing wall strength. Underground drilling requires the use of dust supression, bit lubrication and cuttings removal. Drilling frozen ground presents problems. The addition of calcium chloride or sodium chloride depresses the freezing point of water (see Figure 3-4), but is highly corrosive and necessitates frequent drill overhaul. Salt water also causes skin irritation to workers. At the Black Angus Mine (Greenland) where the rock temperature is minus 5°C, enough CaCl or NaCl is added to the drill water to depress the freezing point to minus 5.5°C (Willson, 1973). Drill water and supply lines may be heated to keep the water flowing, which is the practice at United Keno Hill Mines. The drill steel must be kept moving and the water flowing or the steel will freeze in the hole, resulting in the loss of hole and steel. The drill steel must be immediately withdrawn from the hole when drilling is stopped.

It is possible to insulate problem areas with polyurethane foam which protects the frozen walls. Work by Dorman and Gooch (1970) at the Fox permafrost tunnel (Alaska) indicated success by using two to three inches of foam insulation. Such insulation is successful if provision is made for a supercooling period in the winter. The Russians have also found the use of polyurethane foam useful in controlling wall thaw (Baba, 1974).

Permafrost Effect on Surface Mining

Surface mines face slope stability, blasting, and dewatering problems when working in frozen ground. A slope that is competent when frozen may become incompetent and fail when thawed. Often water from the active layer, from within the permafrost or from below the permafrost, is encountered. Unfrozen ground within and below the permafrost layer is called talik. This water may freeze in the drainage ditch, sump or pump lines. To keep the ditch open, warm water can be piped above the ditch and dripped into the ditch or salt may be added. Pump lines must be drained when not flowing.

Openings in frozen ground tend to fill with ice in a few years if not kept active. When first opened, frost crystals will cover the walls, timbers and equipment, and ground water moving through the mine will freeze, eventually filling the mine. This can be used to an advantage in abandoned workings which if flooded will freeze and prevent ground subsidence. Also, frozen mine backfill may be strong enough to allow complete mining of pillars.

Underground Mine Ventilation

Ventilation air in underground mines in permafrost regions in winter and warm air in summer creates problems. Warm air circulated through a frozen mine thaws the walls and roof, often requiring increased support measures. Also, large volumes of air required by the use of Diesel equipment releases large quantities of heat and aggrevates the problem. Over all, it is probably better to maintain a minimum air temperature of less than 0°C in frozen ground. Heating air is also expensive. The ventilation system at Whitehorse Copper is designed for 123,000 cubic feet of air per minute heated by propane heaters capable of producing 12 million B.T.U. per hour. The problems of blasting frozen ground are briefly covered under the appropriate section of Chapter 6. Pit dewatering is a serious problem at Pine Point and Schefferville (see respective appendices). The presence of permafrost restricts water flow to the dewatering wells, and the water in the ore creates problems for drilling, blasting, loading and shipping.

Road Construction on Permafrost

During the route selection phase of road planning, extensive exploratory drilling will identify areas of high ice content. Routes should be planned with the objective of locating in nonfrozen areas with free drainage material. In many areas of the arctic, frozen ice rich soil can not be avoided. Excellent results have been obtained by overlaying five feet of gravel on the natural ground, but caution is advised. If permafrost is near 0°C, a layer of gravel may absorb sufficient heat in summer to thicken the active layer. To avoid this situation, or if gravel is scarce, styrofoam insulation can be laid beneath the gravel pad to insure that

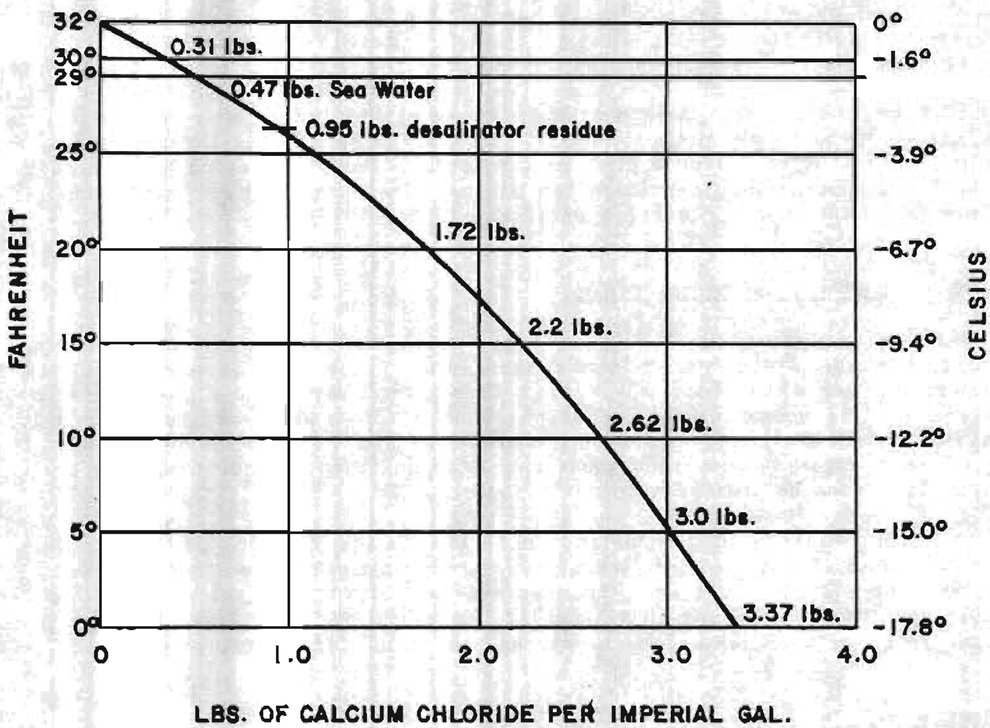


FIGURE 3-4

FREEZING POINTS OF VARIOUS CALCIUM CHLORIDE SOLUTIONS

Source-Walsh (1975)

thermal balance is maintained. Cross drainage culverts must be placed above the permafrost level in the road embankment, or they will freeze and remain frozen year-round.

Lateral drainage at the toe of the roadway embankment should be avoided (Aiken, 1972). The ground at this point is not protected by the gravel pad and will be subject to erosion. Moving water in a drainage ditch will accelerate thawing of permafrost. Ditches may be constructed with sufficient coarse material to prevent erosion.

Roadways in subarctic areas actually present a greater challenge than those in the arctic due to the increased depth of the active layer. Near Fairbanks, the active layer in gravel can be eleven feet deep (Keyes, 1971). The solution is to build with nonfrost susceptable material containing less than 5 percent minus 200 mesh size (Phukan, 1976), provide adequate drainage, and select routes with care.

CHAPTER 4

POWER

Most practical solutions to cold weather operation of equipment involve either the direct application of heat by electric heaters or storage in heated areas and buildings. The choice of sources for electrical and thermal energy are of critical concern. The cold regions have a wide variety of potential power sources, each with their advantages and disadvantages occasioned by construction costs, transportation costs, labor costs or environmental limitations.

Potential Power Sources

Potential sources in Alaska include oil, natural gas, coal, hydroelectric power, tidal power, geothermal power and wind power. Oil from Alaska's north slope and from fields in Cook Inlet is refined at North Pole near Fairbanks and Nikishka near Anchorage. Natural gas is produced on the Kenai Peninsula and may be available from Prudhoe Bay in the near future. Alaska also contains 170 million acres which are potential oil and gas basins where little exploration has taken place. Coal is presently mined only in the Healy area, and provides most of the electrical energy for central Alaska. There are vast areas of potentially economic coal in central and northern Alaska plus scattered small deposits. There are also 76 possible hydroelectric sites located around the state which could produce 172 million megawatts, (1974 Alaska Power Survey). The Cook Inlet tides have potential to generate one millon kw on a continuous basis (Shinohara, 1975). Geothermal sources may be tapped in many areas, but the technology is lacking to make them competitive with other sources. Likewise, wind power may benefit from a technological breakthrough to make economic production possible from Alaska's more remote wind sites.

The Canadians have made a concentrated effort to develop their hydroelectric sites to supply power for communities and industrial development. Hydropower supplies large portions of the energy needs of United Keno Hill Mines, Cyprus Anvil, Whitehorse Copper, Pine Point, giant Yellowknife and the Quebec-Labrador mines. This emphasis on hydropower continues with several large projects in the James Bay area. Although Canada does not, as yet, have a Prudhoe bay, oil and gas in commercial quantities have been found in the MacKenzie River Delta. Several coal deposits are known, but the small Tantalus Butte coal Mine, north to Whitehorse, was the only commercial operation in northern Canada. This coal was used to dry concentrate at the Cyprus Anvil lead zinc mine.

Scandinavian countries also have abundant hydroelectric power sources. By exporting large amounts of aluminum, magnesium and ferroalloys, Norway is essentially exporting power. Norway imports metallurgical grade coal from the nearby Arctic Svalbard Islands for use in the ferrosilicon industry. Oil and natural gas in the North Sea insure a wider choice of power sources in Northern Europe.

The choice of a power source for a new mine in a remote area is a Diesel generator set. The reason for this choice is the reality of the high capital cost and long lead time for hydroelectric and steam boiler generator installations. Diesel sets are inexpensive, quick and easy to set up, easy to operate, easy to expand by adding sets, and reliable. These advantages offset the high cost of obtaining, transporting, and storing Diesel fuel. Diesel motors can be maintained by the same employees who maintain mobile equipment. Diesel generators make excellent standby units. The use of water jacket heaters, glow plugs and automatic starting is assurance that a reserve unit can assume its full load within 10 seconds after a power failure. Standby power is vital in the Arctic. A power loss means that water freezes and heaters cease to function which can result in a complete evacuation of the site following a failure in winter. Diesel powered stations are practical for loads up to the 20 m.w. range for short periods of time (less than 20 years). Other power sources should be investigated for larger loads or longer periods of time.

To provide large quantities of power quickly to remote regions, the Soviets have developed floating power stations (Floating Power, 1976). These stations are ships fitted with 20 m.w. gas turbine-powered generators built for arctic weather conditions. The ships have a five foot draft, and can navigate very shallow waters with the aid of pontoons. The ship is protected from ice pressure damage by a heated hull. The waste heat from each unit is sufficient to heat an arctic community of twenty thousand. With the many miles of coast line and navigable rivers in Alaska and Northern Canada, floating power ships like these may find a use at small, short life mines.

Utility Company Power

If a mine were close to an existing power grid, it may be economical to run a transmission line and purchase power from a utility company. More than likely, some sort of subsidy would be required by the utility, but such an agreement may yield the cheapest power. A sixty-nine kilovolt transmission line can be constructed in Alaska for about $62,000 per mile, and substations built for about $10,000 per m.v.a. For longer distances, 138 k.v. lines can be run for $77,000 per mile. Table 4-1 shows the line loss as a function of load, distance and line size (1974 Alaska Power Survey).

Hydroelectric Power

For hydropower to be economical on a large scale its cost must be amortized over a long period of time (+50 years). Large stations cost about $500 per installed killowatt (1974 Alaska Power Survey).

The Canadian government has found it beneficial to build hydroelectric stations to supply power to remote mine and town sites (Power for the North, 1974). The Northern Canada Power Commission Act requires that the projects be self-sustaining. Thus all capital, interest and operating costs are paid by the users during the life of the power station. The Commission has a policy of working with the companies during the development of mining properties.

Hydroelectric projects have the advantages of being exempt from future fuel price escalations, being a clean power source, and providing flood control and recreation facilities. Design of dam sites, however, must consider fish and wildlife migration patterns, changes in water quality, and the wildlife feeding areas inundated. In some locations, hydroelectric power is the cheapest source of process heat, as is the case at the United Keno Hill Mines in the Yukon. Although oil is burned to supplement the 5 m.w. dam at Mayo, electricity, when it is available, is used to produce steam because of its low cost.

Table 4-1 Relationship of Capability, Losses and Transmission Distance for Assumed Loading (Mw) and losses (%).

Line	Load	Transmission Distance (miles)			
33-Kv Line	3 Mw	12	18	30	61
3/0 Conductor	6 Mw	6	9	15	30
	9 Mw	4	6	10	20
69-Kv Line	12 Mw	16	24	40	79
4/0 Conductor	18 Mw	11	16	26	53
	24 Mw	8	12	20	40
	36 Mw	5	8	13	26
138-Kv Line	24 Mw	84	125	209	—
477 MCM Conductor	48 Mw	42	63	104	209
	72 Mw	28	42	70	139
	96 Mw	21	31	52	104
	144 Mw	14	21	35	70
	Line Loss	2%	3%	5%	10%

Source - Alaska Power Survey (1974)

CHAPTER 5

COLD WEATHER PLANT DESIGN

Many operating problems in the north can be avoided by proper design of facilities. Design is always an important aspect of development, but it is most important in cold regions because of the seasonal nature of shipping for building materials and the necessity of completing exterior construction during the summer months. Thus a minor design mistake could cost a whole year in delayed completion time.

Operations in the north require heated buildings, and given the high cost of fuel, transportation, and storage, buildings are designed with minimum exterior surface area (MacLellan, 1972). This can be accomplished by sharing walls for mill maintenance shops, warehouses, power stations and offices. A designer in Scandinavia carried this idea to the extreme, however, and designed and built a plant so compactly that there was no room for maintenance, clean up of belt spills, or monitoring equipment. Living quarters should always be separate from plant buildings. Also, buildings must be designed to accomodate the large inventories and repair shops necessary in remote locations.

Buildings that are carefully designed and well maintained can be heated economically. As an example, heat can be recovered from ventilation air with heat exchangers.

Due to the highly transient nature of northern workers, high absentee rates and the low industrial skill levels of native (Eskimo and Indian) workers, designers should strive to keep operation as simple as possible. Likewise, ease of maintenance is an important consideration. The lower walls of buildings should be of heavy construction for protection from snow removal equipment (Bowling, 1972). This is especially important around major access doors, else they may be impossible to close because of a minor accident with small mobile equipment.

It is best to enclose all crushing, milling, and materials handling equipment inside heated buildings. A heated mill allows the use of water spray for dust supression at its source. A heated building eliminates the need for auxiliary heaters for grease, grease lines and bearings. Radiant heaters are sometimes used in cold buildings, but are not desirable as they can cause injuries to careless workers. Heated buildings insure that operators function at the desired efficiency and that repairs can be performed in a reasonable length of time and in reasonable comfort.

Foundations

The foundation of an arctic building is exceedingly important. Some builders may be fortunate enough to be able to place foundations on bedrock or gravel which will be structurally sound whether frozen or not. The usual situation finds the builder faced with a site underlain by fine grained frozen ground that contains much ground ice. Thawing of this ground will result in differential settlement and loss of building usefulness. Solutions to this problem vary with site geology. In some cases, it is practical to remove the fine grained or silty frozen material and replace it with free draining granular material which is stable either frozen or thawed. Otherwise, the solution lies in keeping the permafrost frozen by preventing heat flow into the ground or by providing for refreezing. Light weight buildings such as living quarters are often elevated on piles to prevent heat flow from the building to the ground and to allow the cold winter to refreeze the summer thaw. Heavier buildings can be built on a thick gravel pad in which culvert pipes are buried (Rice, 1975). These pipes are left open and the cold winter air will refreeze the ground thawed during the summer. In the warm summer months, these pipes are blocked to reduce thaw rate. Some systems like this will require fans to improve the circulation, and will require protection from snow drifting over the outlets.

Systems have been designed to refreeze the ground in the winter with a series of frost tubes placed beneath the foundation or in the pile formation. The ground is thus maintained in a frozen and stable state (Galate, 1976). A frost tube is a simple device consisting of a small diameter pipe with one end buried in the ground and the other end exposed to the cold winter air. The tube is sealed on each end and filled with a refrigerant, typically freon or ammonia, under pressure (Galate, 1976). During winter when the air temperature is colder than the ground temperature, this gas condenses at the top of the tube and then flows to the base where it is again vaporized by the "warm" ground which is typically a few degrees below freezing. This cycling extracts heat from the ground keeping the ground frozen. During the warm days of spring and summer, the gas does not condense and the system is inoperative. With the proper selection of tube gas and pressure, the temperature of condensation can be controlled.

The ground can also be kept frozen by a conventional refrigeration system with pipes in the foundation. However, this system is subject to human error and mechanical breakdown and requires an energy source.

The use of insulation alone beneath a heat source will not prevent permafrost from thawing (Rice, 1975). Insulation only slows the thawing process. The use of insulation can improve the efficiency of the refreeze system chosen to protect the permafrost.

If it is necessary to construct a dam for a water reservoir or tailings pond on permafrost, the dam should be designed so that it will function as it settles and can be repaired during settlement.

The best results will be obtained by hiring an experienced frozen ground foundation consultant. He will recommend an extensive soils investigation program to determine the physical properties of the soil, and design a foundation adequate for the design loads.

Water Supply

The developer planning a town and industrial facility in the north may find that providing an adequate water supply is challenging and expensive. An adequate system provides the convenience that people in temperate climates take for granted, that is, a system capable of providing an uninterrupted supply of clear, clean, and good tasting water in sufficient quantity for daily use and for fire protection. A good first estimate of water use would be 80 gallons per man day plus fire protection and extras such as street and vehicle washing, lawn watering, or industrial consumption (Rice, 1975).

Water in the arctic is supplied from wells, lakes, rivers, sea water, reservoirs and melted snow and ice. Arctic water must be carefully treated, stored and distributed to prevent freezing and disease transmission. The difficulty and expense in obtaining and distributing water encourages water conservation practices.

It is highly unlikely that water of sufficient quality and quantity for community and industrial purposes can be obtained from a well drilled to below the permafrost level. The permafrost layer is thick, 540 meters (1770 feet) at Asbestos Hill, Quebec (Stewart, 1976), 350 meters (1150 feet) at Barrow (Rice, 1975), and often thicker (Brown and Pewe, 1973). The well pipe will be subject to freezing and is difficult and expensive to thaw. More often than not, the well casing in permanently frozen ground will pass through layers of ice-rich fine grained soil. Damage to the casing may result because of loss of soil strength if heat were applied to keep the well flowing. Subpermafrost water is often difficult to locate, expensive to develop and highly mineralized (Alter, 1969). Iron and salt are the most common problem minerals found (Rice, 1975).

The surface ice on arctic lakes typically reaches a maximum thickness of 1.8 to 2.4 meters (6 to 8 feet) (Alter, 1969). Small shallow lakes freeze to the bottom, but larger, deeper lakes do not. Many, including the oil industry, the developers of the Distant Early Warning Line radar stations, and residents of Barrow have utilized these deep lakes for winter water supply (Alter, 1969 and Grundy, 1977). Problems result if a lake is heavily pumped and not sufficiently recharged from below. The lake water may become unpotable because impurities tend not to freeze in the ice (Grundy, 1977). Large water users are forced to move from lake to lake at increasingly longer haulage distances to ensure adequate water supply. Water supplied in this manner is labor intensive and therefore expensive.

Large lakes and some large rivers which do not freeze to the bottom develop a thaw bulb underneath. It may be possible to drill into such a thaw bulb for water. Lakes can be located with Landsat photographs or by making use of side looking radar (Grundy, 1977).

Fresh water from sea water is possible although expensive. The Alaska Native Health Service Hospital complex at Kotzebue, Alaska uses salt water for toilet flushing and desalted sea water for all other uses (Alter, 1969). The developers of the Polaris Project on Little Cornwallis Island, N.W.T. used a desalinization unit to supply fresh water for camp use (Redpath, 1974). Nuclear power plant waste heat is utilized at McMurdo Station, Antarctica to produce fresh water from sea water (Alter, 1969).

The melting of snow and ice can be used to supply limited quantities of fresh water. Waste heat from power generators can be utilized for melting snow and ice, as at Byrd Station, Antarctica (Alter, 1969). Oil exploration crews in the arctic use oil fired snow melters as a water source at a cost of $1 per barrel of water (Grundy, 1977). Snow can be collected by snow fences thus using the winds for snow transportation. These methods are not practical for community use. Over 400 pounds of ice would be required each day. Snow and ice are often contaminated by animals, birds, community refuse and collection equipment.

Due to the impermeable nature of the frozen ground and low evaporation rate, summer water flows are high despite the low precipitation rates (Johnson and Hartman, 1971). This abundant water supply during the summer months is stored by some people for winter use. One storage method is a reservoir. Reservoirs can be made by deepening and diking an existing lake, by excavating a reservoir in a river flood plain, or by excavating one near the community. A reservoir must be deep enough to hold a season's requirements beneath the surface ice. Reservoirs are being successfully used by the oil industry on the Alaskan north slope, and the North Slope Borough is developing a reservoir for community use (Grundy, 1977). Summer water can also be stored in heated tanks or indoor pools as British Petroleum is doing on the Alaskan North Slopes. B.P. Alaska has five, one million gallon heated storage tanks (Grundy, 1977). As a part of B.P. Alaska's fire protection system for their permanent camp at Prudhoe Bay, water is stored in a swimming pool where it serves a useful function while in storage (Rice, 1975).

Water treatment is accomplished by utilizing normal temperate zone techniques in heated buildings. Arctic water must often be clarified, softened, deionized, aerated, chlorinated, fluoridated, or desalinized (Rice, 1975, Alter, 1969). A practical conservation practice is to reuse shower and laundry waste water for toilet flushing (Rice, 1975). This requires storage and dual piping systems and care must be taken to prevent drinking water contamination. Toilets that require less water than conventional units are available and should be used.

Sewage Disposal

Many organisms in sewage are not killed by freezing and pathogens persist in a viable state for long periods of time in a cold environment (Alter, 1973). The slow rate of dilution of waste in the arctic further increases the likelihood of disease transmission (Alter, 1969a) from improperly handled sewage.

Sewage collection and treatment systems in the subarctic are little different from systems used in the northern tier of states of the United States. Care is taken to prevent line freezeup by either heat addition or deep burial, and treatment plants are enclosed and heated. Arctic systems are limited by the permanently frozen ground, shortage of water, cold weather, lack of experienced operating and repair personnel and cost of energy and transportation.

The collection systems presently on the market can be classed in four groups: the dry type, the self-contained wet type, the flow-through wet type, and the recirculating wet type (Alter, 1969b). The dry type includes the old privy and the chamber pot which are unacceptable. Chemical and incinerator toilets are dry type commodes which have odor and disposal problems. The wet type self-contained units flush to a holding tank that must be emptied, but less often than chemical or incinerator toilets and the odor problem is more easily controlled. The wet type, flow-through units include the typical system found in most modern homes and systems that use combustible fluids for flushing and transporting waste directly to an incinerator or boiler. Water transport units require large quantities of, and a collection system that is protected from freezing, and collection methods using combustible fluids that present a fire hazard. The most promising units for the water poor arctic are the circulating wet type commodes. They represent the next step past the wet self-contained type by treating the waste with biological, chemical or physical processes at the point of origin. The residue is then infrequently removed and discarded. There are many variations of these systems, including vacuum transport and collection and positive pressure systems.

Central community sewage treatment can be done by biological methods, physical-chemical methods, or incineration (Rice, 1975). Biological treatment, while common in warmer areas, is retarded by the cold, and the frozen state of the ground precludes adequate septic systems. The cold retards anaerobic decomposition (septic) more so than aerobic processes that work well at warm indoor temperatures. These "activated sludge" and "extended aeration" processes produce a sludge which can be incinerated. Physical-chemical treatment is a complex, expensive, water treatment technique. Incineration is a practical alternative for the disposal of the sludge produced by other treatment methods.

In the future, techniques may be developed to use the wastes for the supply of nitrogen to the nitrogen poor arctic landscape (Rice and Alter, 1975).

Water Lines

Water lines used for fresh water distribution, sewage collection and tailings disposal are very susceptible to freezing. Once frozen, a buried line is difficult to excavate, replace or thaw. Pipe in the nonpermafrost areas may be buried below the frost layer, continuously circulated, insulated or heated. In permafrost areas, best results are obtained with the use of heated, elevated utilidors. A utilidor system is employed at the United Keno Hill Company town of Elsa in the Yukon Territory for water, sewer, steam heat, and electricity distribution with no problems. Burying the utilidor may result in permafrost thaw, utilidor settlement and pipe breakage. Clinton Creek, Yukon Territory buried utilidors above ground whenever permafrost thaw failures were discovered.

At some northern locations, insulated water supply lines are laid on the ground. Pipes laid on the ground are insulated with either foam type or fiberglass insulation and have a protective covering. A rule of thumb at the Anvil Mine is to keep water flowing at seven feet per second to prevent freeze up on the coldest days. The need for insulated pipe has prompted DuPont of Canada to develop a plastic preinsulated pipe (O'Brien, 1976). Early indications are that this pipe is well suited for the job. The pipe comes in many different sizes and insulation thickness for use as water, sewer or corrosive materials lines. The insulation, polyurethane foam, is jacketed with either a plastic or steel outer layer. The pipe has thermostatically controlled heat tracing cables to prevent freeze up and faciliate thaw. In tests where the line was frozen and then thawed by heat trace, no repairs were required because the plastic expanded with the ice. This pipe (Solaircor) is presently in use at the Anvil Mine, in the Yukon Territory.

Tailings Disposal

Special attention must be taken in the design of tailings ponds. Merely extending the discharge line to the pond will result in a buildup of frozen tailings at the end of the pipe. The accumulated frozen material will not melt completely during the short summer and over several seasons will prevent the tailings pond from functioning effectively. A successful design includes sufficient pond depth to insure discharge of tailings below the surface ice. One such design at Whitehorse Copper utilizes a pond 9 to 12 meters (30 to 40 feet) deep which is completely successful.

Belt Conveyor Design and Operation

At times, designers find it necessary to run conveyors from a warm building to a cold outside location. Ideally though, conveyors should be run entirely in the cold or entirely in the warm. The freeze-thaw cycle of the material being handled will cause problems at transfer points and will build up on rollers, pulleys and on the belt. A belt operated in the cold may take 25 percent more power to operate than in the warm summer months (Osztar, 1965). Additional power is needed because of the stiffness of the belt, increased viscosity of the lubricants, increased roller weight from build up, increased stiffness of the load and rubbing on the belt by built up material on skirting. The Whitehorse Copper Mine uses heat to solve these problems. The conveyors are enclosed and the enclosures are used to distribute hot air from one building to the next. Another solution could include larger transfer points, thereby reducing buildup and the need for cold weather lubricants, spot heating or the addition of chemicals. Chemicals may prevent freezing, but will increase corrosion and may affect process chemicals in the mill. Spot heating creates hazards to operators and mechanics and is usually inadequate. Material will freeze to conventional rubber lagging more readily than to a steel pulley. A thicker lagging will flex, breaking this frozen material. The use of proper cold weather greases and oils is essential. A belt with summer grease that is stopped on a cold day may not restart until spring. At Clinton Creek Mine, idler grease was changed four times a year to insure continuous operation.

Scheduling

The long cold winter months exert a control over transportation and construction schedules not seen in warmer areas. Rarely will an all weather highway or railroad be found anywhere near an arctic project site. Most likely men and small supplies will be transported by plane and a seasonal shipping mode will be used for construction materials. During the cold winter months, sleds pulled by crawler tractors (cat trains) provide access. These trains leave few permanent scars on the country and are less expensive than air freight. Frozen rivers and lakes provide a good running surface for most of the winter. During the summer months, barges can navigate many arctic rivers, and ships can travel the arctic coast. During the spring and fall months, many locations are restricted to air travel only.

Development is usually done on a tight schedule for cost or product need. Unexpected problems can severely hamper construction schedules and projected start up dates. Disaster struck the developers of the Asbestos Hill Mine when on Nov. 1, 1972 the last barge from the last cargo ship overturned in 160 feet of water. Over 150 tons of cargo were lost (Thurner, 1976). The material consisted of conveying equipment, process machinery and structural steel. Salvage was out of the question, and the next ship could not arrive until summer. The material had to be reordered and flown to the site. The value of the lost goods was recovered through insurance, but the added cost of air freight was not.

Limited outside construction work in cold weather also plays a part in the scheduling of materials shipments. The ideal situation is to complete the foundation and basic structure in the warm months, and then finish inside work during the winter. Construction companies in Fairbanks would, in the past, rush all summer to complete projects only to have men and tools idle all winter. Recently a great deal of effort has gone into planning projects so that the men work all year. Basic foundation work is performed in the warm months, but construction proceeds through the winter by working men in the cold until productivity falls below 85 percent. Beyond this point, work proceeds in enclosures built of two by four lumber and polyethelene plastic. Plywood, insulation, and vapor barriers are sometimes used. In windy areas, gusset plates are added to the framing. The building can then be heated by temporarily installed hot air furnaces. The costs of heating these structures is estimated to add about two percent to the bid cost. However, utilizing workers in a year—round nonovertime basis more than offsets the cost of heating.

The concept of an enclosed work area is carried another step by the operators of the Usibelli Coal Mine at Healy, Alaska. The erection of a new dragline is being accomplished inside a fabricated steel building to insure proper welding environment. The building is split so that it can be slid apart to allow a crane to lower large components into place. The construction schedule calls for the dragline to outgrow the building by April, at which time it will be removed and the remainder of the work completed in the warmer spring weather.

CHAPTER 6

BLASTING FROZEN GROUND

When water in rock freezes it changes phase, altering the physical character of rock, and therefore its reaction to blasting. Failure to consider the changed character of frozen rock may result in the creation of large blocks and slabs which are difficult to load. The velocity at which shock waves travel through the rocks, the dynamic Young's modulus of elasticity, Poisson's ratio, modulus of volume elasticity, and other shear modulus are all affected. Laboratory testing can determine the values of these parameters to insure that the blast is properly designed.

Rock Breakage

Land (1972) describes the shock type breakage process in three stages, briefly as follows: Stage one consists of a shock wave traveling at from 3,000 to 5,000 meters per second outward from the hole. This shock creates radial cracks from the tangential stresses. The second stage consists of a rebound shock from the free face that creates a tension wave and since rock is weak in tension, primary failure cracks develop. These first two stages condition the rocks for stage three whereby expanding gases push the rock outward. This outward expansion produces tension stress and breakage occurs along cracks produced in stages one and two.

Rocks fail by shock type failure or shear type failure depending upon the relationship between the dynamic loading velocity or shock wave velocity, and the seismic velocity of the rock. Shock failure occurs when the shock wave velocity is greater than the seismic velocity, and shear failure occurs when it is less (Lang, 1978). Shear failure results in the rock absorbing the explosive energy in plastic deformation rather than fragmentation. The rock then breaks in large blocks and slabs. Therefore a well designed blast will produce a shock wave velocity greater than the seismic velocity.

Blasting Frozen Ground

The seismic velocities of frozen ground are increased over those of thawed ground (Lang, 1976, Garg, 1973); the amount of increase depends upon the moisture content of the rock. Dry frozen rocks show only a slight increase in velocity. Serious blasting problems occur when the moisture content of the frozen rock exceeds eight percent (Lang, 1976). Tests at Knob Lake showed that the greatest problems occur at a moisture content of 15 to 18 percent (Lang, 1976).

Table 6-1 displays the elastic contrasts for the middle iron formation (MIF) at Knob Lake, Quebec, at varying temperatures. The MIF ore is essentially fine to medium grained blue hematite and silica with a moisture content generally from 5 to 8 percent. The MIF ore makes up the bulk of the ore at Knob Lake, and has a density of 3.6 grams per cubic centimeter (224 pounds per cubic foot). Poisson's ratio is the ratio of lateral to longitudinal strain when longitudinal stress is applied. This is an energy storage value, and better fragmentation can be expected if the value is low (Lang and Farreau, 1972). Young's modulus relates load to compression or expansion in the direction of the load. If Young's modulus is high, more energy must be supplied to fracture the rock (Lang, 1972). The marked increase in all values in Table 6-1 for frozen ore has a detrimental effect on blasting. The increase in seismic velocity will require explosives with shock wave velocities sufficiently high to ensure shock type failure. The increases in elasticity and Poisson's ratio indicate an increased capacity to absorb energy when frozen. This energy absorption further hampers proper fragmentation. Results similar to those presented in Table 6-1 were found by testing the ore at the Asbestos Hill Mine, Quebec (Lang, 1976).

Failing to compensate for these rock properties will result in the ore being broken into big blocks and slabs. Excessive back break can also be expected, which can be controlled with preshearing. Computer evaluation of rock properties and explosive characteristics will optimize blasting practice in frozen ground.

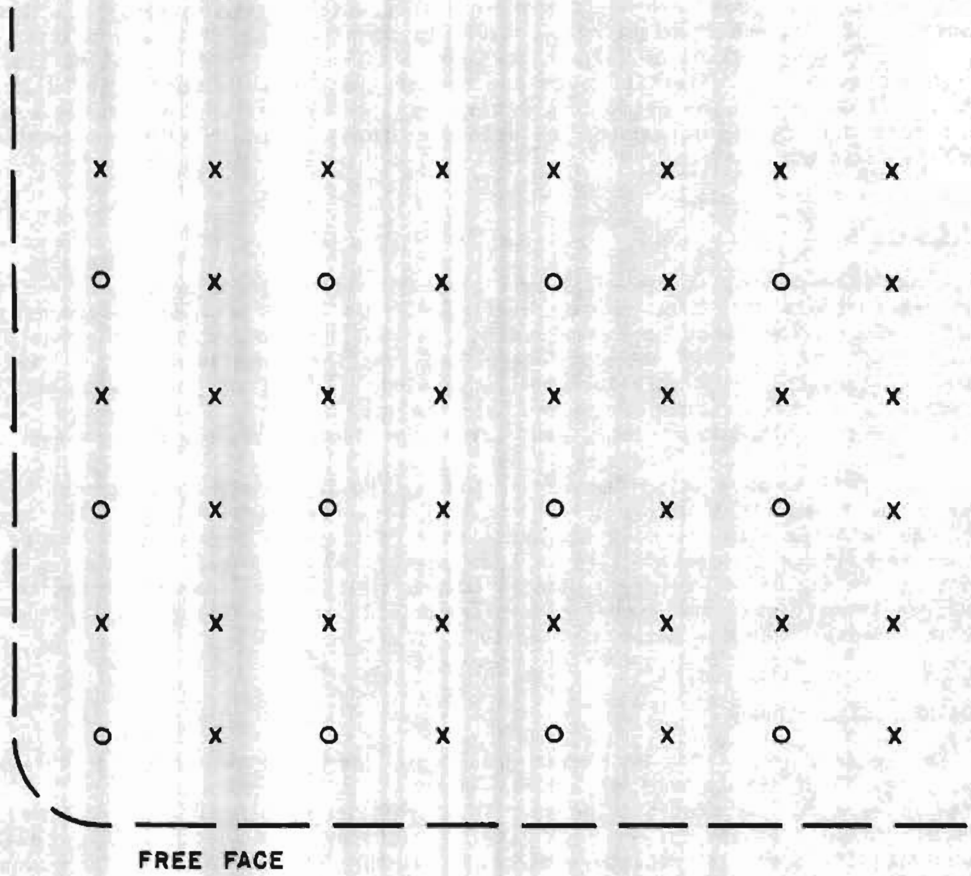


FIGURE 6-1

DRILLING PATTERN FOR SEASONAL FROST

Source - Champagne (1977)

The seasonal frost layer can be a problem in nonpermafrost areas. This seasonal frost extends to eight feet at Knob Lake, Quebec, and requires the use of frost holes for satisfactory results. Frost holes are drilled between standard full depth holes to the depth of frost. If such holes are not used, large slabs of ore with high ice content remain after the blast. A deck charge, which is a charge suspended at the frost level in a full depth hole, does not provide adequate fragmentation (Champagne, 1977). Frost holes at Knob Lake are loaded with about thirty pounds of AN/FO (Champagne, 1977). Figure 6-1 shows a common frost hole pattern.

Freezing of slurry and other water base explosives occasion other blasting problems related to cold. Unless these products are stored in heated buildings they will be frozen, which can damage the primer, and the slurry will not adequately fill the hole. Canadian Industries Ltd. developed a low temperature slurry in response to this need at Asbestos Hill, Quebec. This slurry, Polar Hydromex, remained flexible at minus 29°C (-20°F), warmed to rock temperature quickly and produced adequate detonation velocity at Asbestos Hill when the rock temperature was minus 7°C (+19°F) (Lang, 1976).

TABLE 8-1

Elastic Constant	Unfrozen 0°C	Marginally Frozen 0° to 0.6°C	Frozen 0.6°C
Seismic compressional wave velocity	2,103 m/s	3,383 m/s	6,096 m/s
Seismic shear wave velocity	1,098 m/s	1,823 m/s	2,033 m/s
Dynamic Young's Modulus of elasticity	1.16×10^5 $\frac{kg}{cm^2}$	2.16×10^5 $\frac{kg}{cm^2}$	4.36×10^5 $\frac{kg}{cm^2}$
Poisson's ratio	0.13	0.35	0.44
Modulus of volume elasticity (Bulk Modulus)	1.03×10^5 $\frac{kg}{cm^2}$	2.91×10^5 $\frac{kg}{cm^2}$	11.8×10^5 $\frac{kg}{cm^2}$
Shear modulus	0.44×10^5 $\frac{kg}{cm^2}$	0.97×10^5 $\frac{kg}{cm^2}$	1.52×10^5 $\frac{kg}{cm^2}$

Source: Garg 1973.

Drilling cuttings used for stemming refreeze before blast time. Iron Ore Company of Canada has had some trouble with frozen stemmings breaking the primacord when the ground moves from a preceeding detonation. One solution is to use dry crushed rock for stemming which results in better containment, better fragmentation, a lower powder factor, better back break control, and less fly rock (Lang, 1966).

CHAPTER 7

COLD WEATHER OPERATION AND MAINTENANCE OF PLANT AND EQUIPMENT

The operation of a community or industrial installation in the north is complicated by remoteness and long cold winters. Cold weather changes the characteristics of metals, increases the viscosity of liquids, stiffens hoses and cables, and decreases employee productivity and morale. High winds decrease the wind chill temperature causing warm objects to cool rapidly. High winds also cause snow to drift around buildings, roads, portals and working areas. The remoteness of these locations dictates a large inventory of repair parts and provisions for back-up systems. The weather, combined with the remoteness, results in a very high turnover rate and difficulty in recruiting employees with desired skills. Employee problems are dealt with in Chapter 8 of this report.

Solutions

The solutions to these problems are many and varying according to need, operator preference and experience. Meticulous planning, innovative solutions and extensive employee training by management are keys to success. But, the ultimate success of cold weather operations rests with the employees.

In the fall of each year, maintenance supervisors concentrate on preparing equipment for the winter months. Components that are likely to need replacement during the winter are replaced before winter sets in. At Pine Point N.W.T., dipper sticks, booms and shafts that are known to fail in the cold are magnifluxed, and replaced if cracks are found (Scarborough, 1986). Lubrication systems are checked for worn components and to see that proper cold weather products are being used. All protective equipment and heaters are checked and replaced or repaired. The first cold spell of the season will reveal areas overlooked and any weak link in a system. This results in a flurry of activity by the maintenance department.

During long cold spells it is necessary to provide heated storage for all equipment not operating around the clock. Whenever possible, routine maintenance and repairs are performed in heated shops. An alternative to a heated service building is a service truck with a heated section for all oil and grease storage, pumps and hoses (see Appendix J). If a breakdown occurs in the field, temporary repairs are made to allow the disabled equipment to be towed to the heated shop for proper repairs and warm up before starting. Repairs undertaken in the open on a sub-zero day with a strong wind will take much longer to complete and run a higher risk of being improperly performed. It is especially difficult to make successful major welding repairs because of the need to apply large quantities of heat to relieve stress.

The importance of on-site maintenance capability can not be overemphasized. Maintenance departments, of necessity, develop the capability to do any repair or rebuilding needed. For example, the maintenance shop at Whitehorse Copper Mine can build replacement hydraulic cylinders less expensively on site than they can buy them (Jutronich, 1977). These homemade cylinders are often better than new because they have been redesigned and modified to withstand operating stresses actually experienced. Such practices produce a maintenance crew with a high level of proficiency and confidence.

When ordering new equipment, all available cold weather options are specified, including high impact T-1 steel components, insulated and heated cabs, antifreeze systems for airlines, heaters for coolants and oils and motor protection devices. To the greatest extent possible, equipment should be selected to be compatible with the existing fleet. Repair is simplified and inventories are reduced if all trucks have motors and transmissions of the same make and model.

Some operators reduce loads during winter operations. Six yard shovel buckets are replaced by five yard buckets and trucks carry lighter loads (Scarborough, 1986). Operators of railroads have found that trains need to be shortened because drawbars break in the cold, and it is difficult to keep the long air lines from freezing.

Another solution used by some northern operators is to shut down during the coldest weeks, allowing extended vacations and leaves. This period is used for plant and equipment maintenance. Asbestos Hill in Arctic Quebec follows this plan, shutting down for six weeks (Demers, 1976).

The strong winds encountered at many arctic locations may necessitate snow fences, special layouts or snow removal crews. Oil well drilling crews in the arctic use snow fences as far as 6 miles up wind to keep drill pads clear enough for work to proceed. Elevating roadways 6 to 8 feet above the surrounding terrain will keep the surface reasonably clear (Luciani, 1976).

Extensive modifications are necessary for equipment to function properly in very cold weather (Burrows, 1974). Door seals may shatter in the cold if they loose their flexibility. Possible suitable materials include buna N, colorprene, EPDM and silicones. Plastic becomes brittle in the cold and breaks easily. Plastic seatcovers become stiff and split; fabric seatcovers are more durable and are warmer to sit on. Vehicle hoses for oil, coolant, air etc. need to remain flexible at the expected lower temperatures. Many manufacturers make hoses suitable for cold region use. Teflon, nylon, fiberglass, silicones and polycarbonates are acceptable for such hoses and other components. Operator's cabs require extra heaters, insulation and work lights, and the equipment should have auxiliary lights to illuminate the work area. Electrical wiring must remain flexible in the cold or insulation will break and cause shorts. Batteries, alternators and starters need to be heavy duty to hold up to the increased demands of cold weather. Tubeless tires require tubes of natural rubber to prevent leakage. Synthetic hydrocarbons perform well for lubricating fluids and greases and arctic type SAE 1707E brake fluid is satisfactory. A higher brake pressure is needed to overcome the cold stiffness. Fire extinguishers with CO_2 propellant will not function in the cold, but nitrogen charged units work well at minus 54°C (-65°F).

Cold Weather Steel

Normal mild steel in machine frames and components becomes brittle when exposed to cold weather and may fracture when subjected to normal loads. Figure 7-1 depicts this change in stress strain response. The information in Figure 7-1 is presented without scale since the values depend on steel type, loading rate and component geometry (Van Vlack, 1976). Temperature-induced brittleness when combined with a stress riser (notch, crack, other area of stress concentration) increases the probability of a failure. A major structural failure in the coldest part of the winter means a very difficult repair job. Figure 7-2 indicates the behavior of a bar in tension with a small crack. At room temperature, the stress concentration at the base of the crack is relieved by plastic flow (see Figure 7-1). At very cold temperatures the stress is not relieved and failure is rapid as the ultimate strain capability is exceeded. Operators in cold regions specify alloy steel with acceptable cold weather characteristics to solve this problem. USS T-1 is a quenched tempered, low carbon, low nickel alloy steel, with proven good service in sub-zero temperatures to minus 46°C (-50°F). T-1 steel is often specified on new equipment and for replacement parts. For high stress parts, A.S.T.M. specification A-203, A-300 (2 1/4 percent nickel alloy) is suitable for temperatures to minus 57°C (-70°F) (Oszter, 1965). Other steels that perform well to minus 48°C (-55°F) are I.N. 787, 4130, 4140, and 1018, A36-FGP-K-N, LTM. A-537A, A-537B and A-516-70-N (Burrows, 1974).

Gears of forged medium-carbon steel have excessive failures in cold weather. Forged steel gears have a grain orientation parallel to the gear circumference. The use of cast manganese-molybdenum alloy, which has a random grain orientation with greater strength combined with an improved tooth design, has reduced failures for the Iron Ore Company of Canada to acceptable levels (Ritcey and Kilburn, 1969).

Areas of stress concentration can be identified from past failures, strain gauge testing or design analysis. Once identified, these areas can be reinforced or redesigned. During Fall inspection these areas should be included in an inspection program so that any cracks can be repaired (Woodle, et. al., 1963).

Operator training for cold weather operation is the most important factor in successful winter operation. The key word is "gently". Operators must avoid dumping large boulders or frozen chunks into an empty truck bed. A large boulder dropped from a loader bucket can cause an impact load on loader components because of the rapid unloading. Using a loader as a dozer

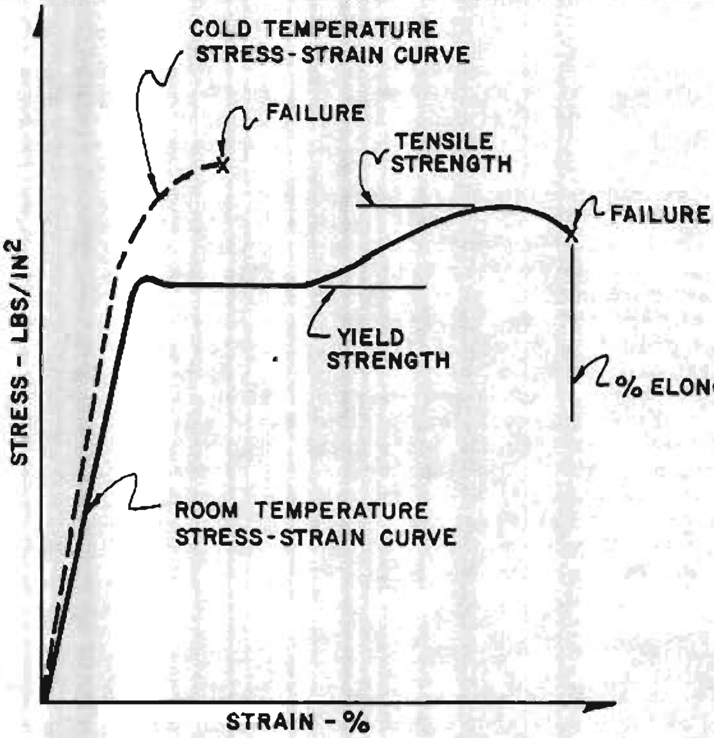


FIGURE 7-1

STRAIN CHARACTERISTICS OF STEEL AT WARM AND COLD TEMPERATURES

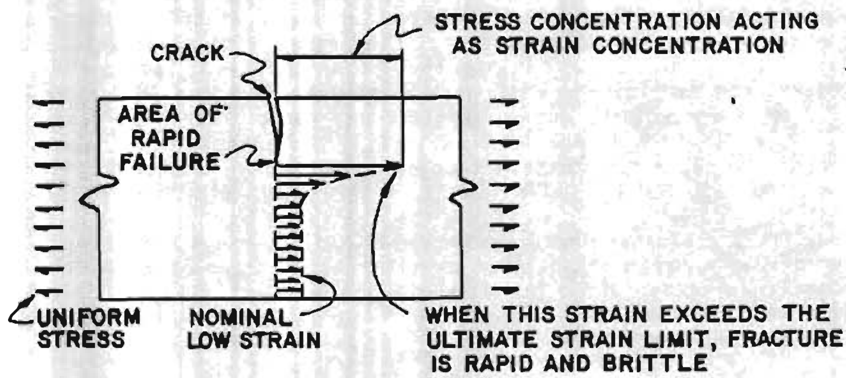


FIGURE 7-2

STRAIN DIAGRAM - COLD BAR WITH CRACK

Source-Thompson (1973)

or ramming the bucket into a frozen pile may cause bucket failure (DeMelt, 1973). Careless and thoughtless operators have no place at any mine, but can be doubly damaging to equipment in the cold regions.

Rock Drills

Drills cause special problems for pit operators because their size and limited travel speed precludes the use of heated storage and service areas. To insure that drills which are continuously exposed to the cold remain operative, certain modifications are made. Crews at the Iron Ore Company of Canada at Schefferville strip new drills to the frame and rebuild them for local winter conditons. The frame is extended two feet and a machine house built around all of the components. The machine house and cab are pressurized by attaching a culvert pipe to the drill mast. A fan is fitted at the top (See Figure F-2 of Appendix F). The incoming air is heated, and additional heaters are installed in the cab for operator comfort. Compressor coolant and lubrication oil are heated to ensure proper operation at start up (Carr et. al., 1964). These heaters shut off when the compressor is on, and remain on when the compressor is off. Radiant heaters keep the hydraulic and automatic lubrication systems working properly.

Gear boxes that are subjected only to occasional use are often fitted with electric immersion heaters to keep the oil warm enough to provide proper lubrication. Thermostats should not be used on these heaters because they increase the chances of failure and add to maintenance costs. Most lubricants can tolerate continuous heating all winter without carbonizing if energy output is kept below eight watts per square inch of heating surface (Carr et. al., 1964).

Electric powered drills are used whenever sufficient power is available. Movement of the drill then requires movement of a trailing cable. Neoprene cable covers become brittle and break in the cold. Satisfactory cable life is attained with the use of a 60 percent natural rubber jacket meeting ASTM specification D532 (Carr, et.al., 1964). Natural rubber is used because the temperature at which brittleness occurs can be modified. Natural rubber is susceptible to deterioration from sunlight and oil contamination, but this is less of a problem than the cold.

Shovels

Whenever practical, shovels should be replabed by large rubber tired front-end loaders. Loaders can utilize heated storage and service areas along with the other mobile equipment. The lower capital cost of a loader fleet may make a back up unit practical for the small operator, insuring greater availability. If the use of shovels cannot be avoided they should be ordered with cold weather steel components.

The ore and waste at the Iron Ore Company of Canada mines at Schefferville, Quebec are wet and sticky, resulting in material freezing to the sides of cold shovel buckets. Thawing this material by burning oil-soaked straw may damage the manganese steel bucket. Electric heaters on the buckets have solved the sticking problem (See Figures F-3 and F-4 of Appendix F). Eight 1500 watt heaters were placed, two in each side and four on the bottom of the bucket (Carr, 1964). Vibration, moisture and power supply problems have been solved by mounting the heaters in blocks with a special heat resisting resillient compound around the connection and covering them with a 1/2" plate of abrasion resistant high strength steel. Thicker wear plates have experienced expansion and contraction problems.

Shovel sticks have been broken in cold weather for reasons outlined above under steel response to cold. Failure of the automatic lubrication system on the stick causes damage that results in areas of stress concentration. Iron Ore Company of Canada solved this problem by ordering shovel sticks made from an AISI 4620 alloy steel centrifugally cast tube, machined to a 1/32" tolerance (Ritcey and Kilburn, 1969). An automatic spray lubrication system combined with strip heating also solved this problem. Strip heating of structural components should be applied with caution since it may contribute to differential expansion and contraction and cause failure (DeMelt, 1973).

Rapid wear and failure of swing-rack gears and pinions at Schefferville, Quebec, required that the forged swing-rack gears be replaced with cast manganese molybdenum alloy gears. The design of the teeth was changed (see Figure 7-3) to achieve a larger radius of curvature at the root of the teeth, thereby reducing stress concentration (Carr, et.al., 1964).

Shafts subjected to high impact loads develop backlash and failure in the spline. Iron Ore Company of Canada solved this problem by using chrome-molybdenum or chrome-nickel-molybdenum alloys along with a redesign of the spline (see Figure 7-3). Use of an involute design resulted in reduced stress concentration and greater shear area at the spline root (Carr, et.al., 1964).

Proper lubrication of shovel components is essential for continuous operation. Iron Ore Company of Canada found it necessary to redesign the automatic lubrication system on their shovels at Schefferville, Quebec. Number one grease was too thick to pump through automatic grease lines in cold weather. The use of gear oil did not provide adequate lubrication for antifriction bearings. Gear oil is now pumped to all open and sleeve type bearings and bushings. Antifriction bearings are greased by hand once each month. The open gear spray lubrication systems repeatedly froze, resulting in inadequate lubrication. This system has been replaced by a drip system that is satisfactory. At Pine Point Mines, heated Eddolube HDX30 is brushed onto the exposed gears and hood rollers several times each shift on very cold days (Scarborough, 1966). All metal lubrication tubes are replaced with large diameter metal-braid Areoquip high-pressure hose (Scarborough, 1966).

Track frames on shovels at Schefferville and Pine Point break repeatedly during cold spells. Iron Ore Company of Canada has not had much success repairing the frames in the field, therefore new or repaired frames are used as replacements. The broken frame is taken to the heated shop, repaired and left for one year out in the elements. Apparently a one year rest allows stresses built up during the welding to dissipate. Repaired frames, not allowed to rest, fail shortly after reinstallation.

Limiting the stress on components is another means of insuring cold weather operation. At Pine Point, the wooden bumper blocks were replaced with rubber, and bucket size was reduced from 5 to 4 cubic yards (Scarborough, 1966). Iron Ore Company of Canada is experimenting with limit switches to protect the shovels from stresses occasioned by inexperienced or careless operators. Stress on track frames can be reduced by using a dozer to clean up the working area. To avoid running over large rocks, someone is employed to direct movements when relocating a shovel.

Truck and Loaders

The impact of the cold on highly mobile equipment such as trucks, rubber tired loaders and dozers is reduced by the use of heated buildings, proper lubricants and careful operation and maintenance. Cabs fitted with extra insulation and heaters insure that operators can work in comfort. Cabs at Schefferville, Quebec have two hot water heaters totaling 50,000 BTU capacity for operator comfort and adequate defrosting of windows (Mayer, 1966).

Haulage trucks universally have double walled boxes made of T-1 steel with motor exhaust passed through the space between the box walls. Special steel is necessary to stand up to the impact of chunks during cold weather loading. The exhaust gases heat the box so that moist material will not freeze to the steel.

Protection of motors is of special importance in cold weather. Many operators use only water as an engine coolant based on the belief that bearing failure results should antifreeze leak into the motor oil. Since water freezes quickly, an emergency shutdown in the field requires immediate drainage of the system. Refilling before restarting can be troublesome and the chance of damage from human error increases. Radiators of large capacity that are filled with water may freeze during normal winter operation, as happened at Schefferville, Quebec one winter (Carr, et.al., 1964). The motor cooling system should have a thermostatically controlled fan and radiator shutters. Iron Ore Company of Canada sets shutters at 82°C (185°F) with the temperature sensor located at the bottom of the radiator tank. If the motor temperature is allowed to fluctuate over a wide range, the heads will develop cracks (Carr, et.al., 1964). When antifreeze is used it should meet equipment manufacturers specification and be compatable

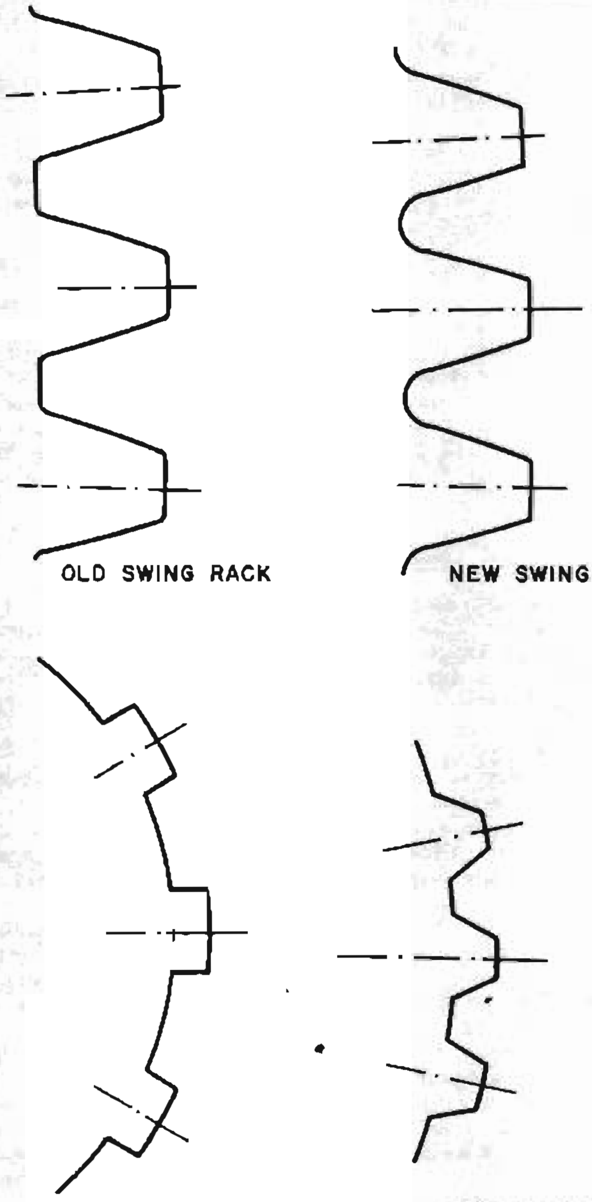


FIGURE 7-3
SHAFT & SWING RACK TEETH DESIGN CHANGES

Source - Carr (1964)

with the chemicals on the coolant filters. Antifreeze should be mixed with a volumetric ratio of 68 percent antifreeze to 32 percent water to insure maximum protection (see Figure 7-4).

Diesel motors should be equipped with shutdown protection for engine overspeed, overheat and low oil pressure. These devices should be inspected daily to insure their proper operation. Early detection of antifreeze and air filter leaks and of component wear is possible if motor oil is sampled and analyzed periodically.

Rubber tired equipment has certain operating advantages in the cold months. Haulage roads are frozen hard by the cold and rolling resistance is reduced. Cold weather prevents tires from overheating and reduces ply separation. Tires that are too worn for summer use or retreading are put back on in the winter and worn out.

Haulage roads are usually slippery in the Spring and Fall requiring trucks to be fitted with a pressure limiting valve on the front brakes to prevent skidding.

Truck loaders may need to have immersion heaters placed in the hydraulic tanks because the large volume of oil will not stay warm under winter use. As an alternative, hydraulic oil can be diluted with kerosene or fuel oil. Diluted oil should always be replaced when the coldest winter weather is over to prevent system damage. A better solution is the use of type A automatic transmission fluid (Scarborough, 1966), or Conoco Dn-600 synthetic fluid (Burrows, 1974).

Bulldozers, Graders and Diesel Motors

Many of the factors discussed above for drills, shovels, trucks and loaders apply equally well to bulldozers, graders and diesel motors. Bulldozers, graders, and other machines that have hydraulic cylinders exposed to the weather are subject to repeated seal failure. The use of oil soaked leather (rawhide) seals reduces the incidence of failure (Carr, et.al., 1964 and Burrows, 1974). Most manufacturers of hoses make products for low temperatures (Burrows, 1974).

Cabs are fitted with extra heaters to keep the operator comfortable and the frost off the windows. Motor radiator fans can be ordered with reversing capability so that warm radiator and motor air can be blown toward the operator. Fabric radiator covers are available to cut down the air flow over the radiator to help maintain proper operating temperature. Care must be taken that motors do not overheat because the cover is still in place during a warm period.

Refineries make diesel fuel for local conditions and ambient temperatures. It is important to specify fuel with a cloud point at least 10^0 below minimum expected temperature. The cloud point is the temperature at which wax precipitates from the fuel. Wax forms a matrix that will plug screens, filter lines, valves, pumps and injectors. This is an important consideration if an entire year's supply of diesel must be delivered at one time. A diesel motor fuel system may have to be redesigned to include the following factors: no restrictive components, components positioned near the motor heat, fuel recirculation to reduce wax buildup in filters, side curtains or enclosures to hold engine heat near accessories, removable fuel tank screens, large fuel lines with large radius bends, large water drain taps, and fuel tank vent extended to heated area to prevent frost plugging. The fuel tank should be kept full to prevent condensation. Fuel should have a cloud point of at least -65^oF (MIR-F-451212, MIL-F-46005) and a sulfur content less than 0.2 percent (Carr, et.al., 1964). The application of heat to fuel should be approached with caution. If the heating system remains on during summer, viscosity of the fuel could be lowered to the point where metering could be incorrect. The heated fuel may also form thermal decomposition products that plug filters. There are flow improvement and moisture absorbing fuel additives available to help insure satisfactory winter operation (Burrows, 1974).

Many operators keep equipment in heated storage or run it continuously. Equipment to be idled for several hours should be left at fast idle to reduce carbon build-up and to maintain proper temperature and oil pressure.

Cold weather starting may require the use of low viscosity SAE 10W (series 3) motor oil (Kidman, 1971). For ease of operation, mechanical controls should be lubricated with a winter

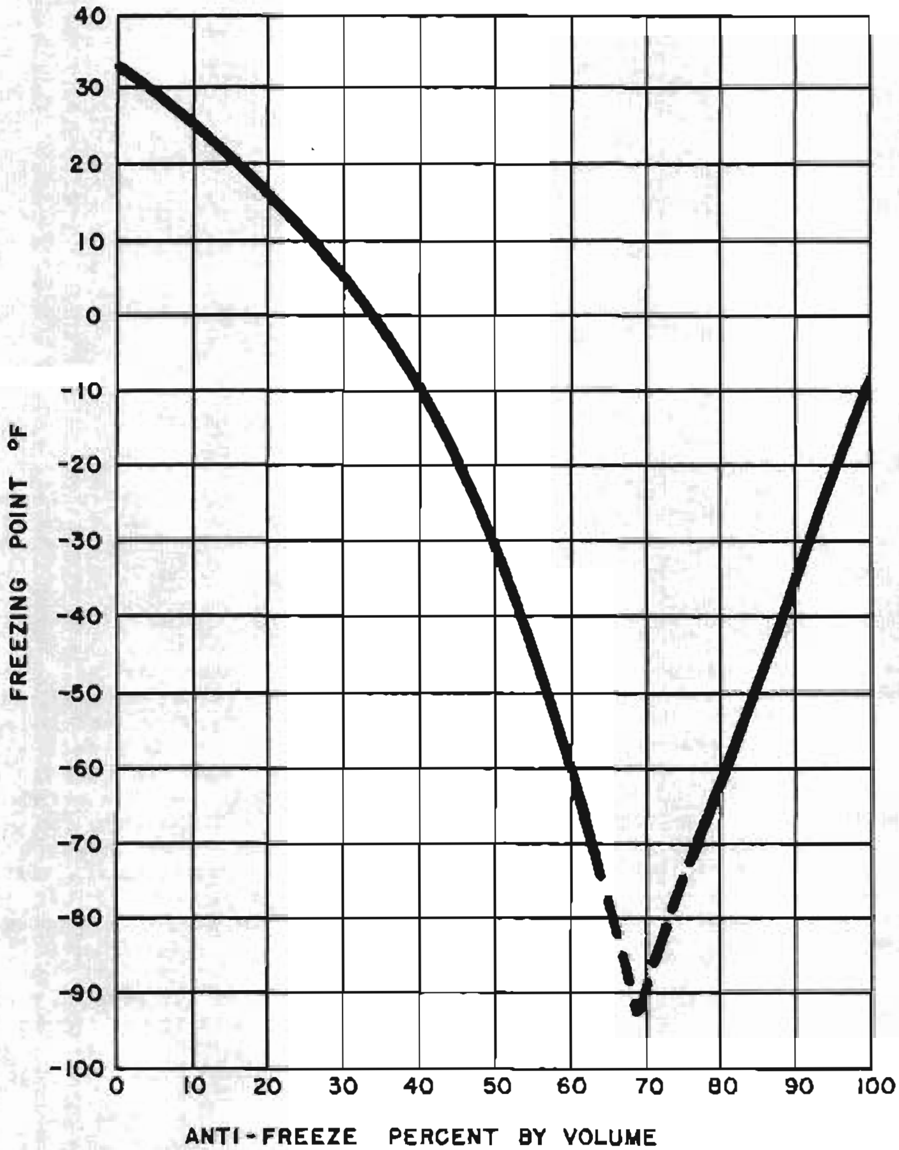


FIGURE 7-4

FREEZING POINT DEPRESSION OF COOLANT AS A FUNCTION OF PERCENT ANTI-FREEZE

Source - Bly (1971)

grade grease (Kidman, 1971). Once operating, the motor oil should be checked every two hours and a good preventive maintenance and inspection schedule followed (Kidman, 1971).

TABLE 7-1

Battery Temperature	Efficiency
+ 80°F	100%
50	82
30	66
20	58
10	50
0	42
- 10	33
- 20	21
- 30	13
- 40	5
- 60	0

Source - Rice, E.L., Personal Communication, 1975.

At the end of each shift, or more often if necessary, bulldozer tracks should be thoroughly cleaned to prevent the buildup of frozen material. Operators must be careful that frozen chunks do not fall over the blade and jam between the hoist and blade causing hoist failure.

Railroad Operation

Special modifications and procedures are necessary for winter operation of railroad equipment. Cabs and cabooses must be insulated, fitted with auxiliary heaters, defrosters, and double pane windows (Woodle, et.al., 1963). Diesel motors require fuel and motor housing modification for low temperatures to insure proper motor operating temperatures (Woodle, et.al., 1963). Air dryer have proven to be inadequate to keep moisture from freezing air brake lines (Woodle, et.al, 1963). Methane alcohol is injected into the main air reservoir at the rate of one quart each day for each locomotive (Carr, et.al., 1964). The use of water cooled compressors which operate at a lower temperature than air cooled compressors allows after-coolers to do a more efficient job of eliminating moisture (Woodle, et.al., 1963). Air reservoirs can be fitted with automatic water drain valves (Carr, et.al., 1964). Despite these precautions and because of the reduced draw bar strength, train lengths are reduced in the cold months (Johnson, 1977).

Track sanders tend to fill with snow and ice and should be fitted with flap type nozzles (Woodle, et.al., 1963). Wheels must be closely watched since it is not uncommon to see a car that had been sitting idle being pulled to the ore loading point with wheels sliding. A sliding wheel will develop a flat spot that will pound the track, possibly fracturing a rail (Woodle, et.al., 1963).

Most ore and concentrates transported by rail are moved in open gondola cars. These cars fill with snow, causing the material to freeze during transport. The moisture in warm ore loaded into cold railroad cars will migrate to the outside of the load and freeze making a "halo" of frozen ore which is difficult to break (MacLellan, 1973). Ore with an average moisture content of seven percent when loaded may arrive at the destination with twenty percent moisture content at the edges, ten percent moisture near the edge and three percent moisture at the center. Not only is unloading complicated, but accurate sampling is difficult. Moist ore frozen into a railroad car must be heated before it is unloaded. Usually ore cars need to be placed in a heated building and thawed out before unloading. At Noranda, cars from Flin Flon are stored in heated buildings one day for each day they are exposed to freezing temperatures (MacLellan, 1973). Car thawing time at Flin Flon is based on both exposure time and outside temperature. The Flin Flon building can thaw fifty cars with six 2 million BTU/hr. oil fired and four 2 million BTU/hr. propane fired heaters. Ore cars arriving at Sept-Isles are thawed in a four car shed with infrared heaters of six million BTU/hr. total capacity (Carr, et.al., 1964). The use of wooden car liners only makes cars more difficult to thaw and unload (MacLellan, 1973). Operators may spray the inside surfaces of the car with oil, antifreeze or salt solution to facilitate unloading if the cars are rotary dumped. If the car is to travel through a range of temperatures as when shipped from Lynn Lake to Vancouver, it is covered to prevent moisture build-up from rain and snow (MacLellan, 1973). Cars are also covered with reinforced plastic throwaway tarpaulins. Concentrate is also protected from precipitation and dust loss with a sprayed latex mixture (MacLellan, 1973).

Cars that sit exposed over a winter or have filled with snow on a return trip are emptied before ore loading. A returning car may have gone through several freezing and thawing cycles and must be emptied by manual labor. Snow can be removed with a hand operated snow blower and shovel. When Iron Ore Company of Canada halts ore shipments at Knob Lake during the winter months of December to March, the ore cars fill with snow (Carr, et.al., 1964). To efficiently empty these cars of snow for start up, two surplus J47-19 jet engines are mounted above the tracks with the exhaust pointing into the cars. The cars are passed under these engines which blow out the snow and melt the ice accumulation. The engines are surplus from B-36 airplanes, and are modified to operate on diesel fuel. The exhaust temperature of these engines is 1276°F. Each engine burns 35 gallons of fuel per hour at 40 percent speed; 245 gallons per hour at 70 percent speed; and 505 gallons per hour at 85 percent speed. Seventy percent speed was found to be most efficient.

Snow accumulation around car wheels, tracks, and switches may create continuous problems. *Reserve Mining Company* uses electric heaters to keep switches operating (Woodle, et.al., 1963). Iron Ore Company of Canada at Schefferville built snow sheds for switches and car storage (Carr, et.al., 1964). The 3400 feet of sheds were replaced by a J47-19 jet engine mounted in a flatcar with the exhaust pointed down toward the track.

CHAPTER 8

PERSONNEL AND INDUSTRIAL RELATIONS

Introduction

Technical problems associated with cold weather operation are rapidly being solved with sound engineering and management practices. The personnel problems are not as easily solved, and represent the biggest deterrent to development of the north. The labor skills required often can not be found among the local residents, and labor must be recruited from the south. Imported workers and their families can have trouble adjusting to the short daylight hours in the winter, the long periods of cold and wind, the long daylight hours in the summer, the swarms of mosquitos and flies, and the isolation. Work in the arctic then, becomes something temporary that one does before he moves on to something else. For some, the north country is challenging and they learn to deal with the hardships in order to enjoy the excitement, the changing seasons, the year round recreation opportunities, beautiful scenery, and the natural setting.

Local Labor

The cultural differences of the native people make it difficult to integrate them into the work force. Colin Alexander (1976) quotes the former Canadian Northern Affairs Minister, Jean Chretien as saying that employers should adjust their standards to allow native people to take leave for hunting or to come and go when they like. He further quotes Ewan Cotterill, former Assistant Commissioner of the Northwest Territories, who studied personnel policy in the government of the N.W.T. His conclusion was that the lowering of standards for native people represented a form of paternalism which branded the natives as inferior and encouraged low standards. Murray Watts (1965), who has been employing Eskimos since 1931, has complete faith in their integrity, adaptability, and capacity to become first class workers. Because of the outdoor nature of Mr. Watt's exploration work, many of these Eskimos have become better workers than imported labor. The native northerner is a task-oriented person interested in completing a job, the results of which can be seen (Lotz, 1968). He has difficulty with the employment oriented concept of industrial society where often no finished product is produced.

No easy solution has been found to the native employment problem. Possibly the long term solution lies in improved education opportunities for young natives.

The native population has not participated in many developments in the north. Many Eskimos live near Asbestos Hill Mine in northern Quebec, yet none work there. The Canadian government built a new community adjacent to the company town of Schefferville, Quebec, for the Montagnais and Naskap Indians, yet only a few work at the mine. Despite the favorable work schedule of one week on and one week off, few Alaskan natives work in the north slope oil fields. Much work and cooperation between industry, government and native leaders is required before the natives can be successfully integrated into the work force.

Imported Labor

Workers for northern development often come from the south bringing their required skills and experience to the job. Unfortunately, many find that life in the north is not for them and leave within a short time. A Mining Association of Canada study of labor turnover and shortage in Canadian mining industry (Cawsey and Richardson, 1975) reported that average cost per new employee for recruitment and training is one thousand dollars. The high turnover rate associated with northern mines is expensive. This study also showed a relationship between both employee age and geographic location with turnover. The turnover rate for young skilled workers remained high but dropped sharply after age forty. Labor turnover problems increase the further one gets from a major city, up to about 250 miles. Beyond 250 miles, turnover becomes less of a problem. This Canadian study also showed a higher turnover rate for the western provinces and northern territories.

The management at the Whitehorse Copper mine in the Yukon Territory dealt with the lack of skilled workers by hiring people as laborers and training them in the skills for which they show an aptitude or interest. Most northern operations have a training program of some kind but find that many employees, when trained, move south to take skilled jobs. The Schefferville mine has recently lost many skilled workers to the government subsidized jobs at the Syncrude, Athapascan Tar Sands project and the James Bay Hydroelectric projects.

Incentives

The first incentive that comes to mind to entice workers to the north is pay. In fact wages are generally much higher in the north than in urban centers. Professionals working on the north slope receive a percentage of their monthly salary as a bonus. This bonus is typically 45 percent for Alaska cost of living and up to an additional 25 percent for north slope duty.

The cost of living is correspondingly high in the north, negating much of what is gained by the higher wages. U.S. Department of Labor figures (1975) indicate the cost of living in Anchorage, Alaska to be 28 to 48 percent above the U.S. urban average, depending on the living standing. Fairbanks, Alaska is another 15.2 percent higher than Anchorage (Dixon, 1975). The Federal Government pays its employees a nontaxable cost of living adjustment of 22 percent in Anchorage and 25 percent on Fairbanks. Most companies in small resource-centered communities in the north subsidize the employee's rent, food, transportation and services to reduce this high cost of living to a level below those found in the south. Residents of Fermont, Quebec buy their homes from the company but pay only about one quarter of the cost (Fish, 1975). The Cyprus Anvil Company subsidizes each employee in the form of rent, medical services, groceries, and transportation costs (Marr, 1977). Single workers at the United Keno Hill Mines pay only $2.75 per day for room and board (Dundas, 1977).

A further incentive found at many northern operations is liberal vacation and leave of absence benefits. The best example is the oil industry with the week on - week off schedule for production workers. An employee at United Keno Hill Mines is entitled to two weeks paid vacation after the first year, and increasing up to a maximum of 35 days at the end of fourteen years. Three weeks leave without pay are also allowed each year (Dunbar, 1977). At the Wabush Mine, Quebec, an employee is eligible for five weeks vacation by the fifth year of work (McGrath, 1977). After five years at the Anvil mine, an employee receives a one month holiday bonus (Marr, 1977).

Other incentives include subsidized or free trips to population centers, including auto shipment. At Schefferville, employees are entitled to free passage for their auto to Sept-Iles on the train (Garg, 1977). A married employee at Anvil can use up to $1,100 in tax-free air fare each year (Marr, 1977).

Despite all of these incentives, the turnover rate remains high at most northern sites. Table 8-1 gives turnover rates for several locations studied.

TABLE 8-1

Location	Company	Turnover Rate	Date
Southcentral Alaska	Union Oil Co.	5.4 1st half	1975
		1.8 2nd half	1975
		3.6 1st half	1976
		*19.6 2nd half	1976
		10.7 1st half	1977
North Slope, Alaska	British Petroleum	10	1977
Healy, Alaska	Usibelli	5	1977
Whitehorse, Y.T.	Whitehorse Copper	10-20 skilled 200 laborers	1977
Faro, Y.T.	Cyprus Anvil	19.7 1st half	1977
Elsa, Y.T.	United Keno Hill	14 each month	1977
Schefferville Quebec	Iron Ore Company of Canada	30 per year	1977
Wabush Labrador	Wabush Mines	10 per year	1977
Asbestos Hill Quebec	Asbestos Hill	8-9 per month	1977

* British Petroleum started hiring for north slope work.

The Mining Association of Canada report quoted earlier (Cawsey, 1975) concludes with the observation that the chronic labor turnover and shortage situation is an industry-wide problem requiring union, government and industry cooperation. The M.A.C. report lists the following reasons given by young people for not entering or not staying in the mining industry: the competition from welfare, the remote location of most mines, little inducement to stay in the industry, lack of accomodations and amenities for nonmarried workers at the mine sites and the poor image of the mining industry. Much is yet to be done to stabilize the work force in the mining industry in the north.

Dealing With the Cold

A stiff wind on a cold day creates a dangerous work situation. The wind does not make it colder but does increase the rate of cooling. Table K-2 (Rice, 1975) lists ambient temperature versus wind speed and the resulting wind chill temperature. The wind chill temperature is the equivalent temperature under calm conditions. Proper protective clothing is necessary, and a buddy system is best for spotting frost bite on exposed flesh. The protective clothing is of necessity bulky and can become tangled in moving machinery that is improperly guarded.

Should a worker freeze an extremity, it should be left frozen until bed care is available. If a foot is frozen, the victim will become a stretcher case when it is thawed. If frozen, thawed and refrozen during evacuation, severe damage will result. The first indication of frostbite is a grey or yellow-white spot on the skin which appears before anything is felt, but the buddy can see it on exposed flesh. The first sensation is numbness rather than pain. Frozen skin should never be rubbed to warm it, as tissue damage may result. Warm water is the best means of thawing frozen tissue. Blankets and heat packs are also used. Snow, ice or petroleum products should never be used (Crippen and Davis, 1970). Frostbitten lungs during strenuous work in the cold is simply not true (Rice, 1975). Best results are obtained when workmen are properly trained, properly equipped and use the training and equipment provided.

Personnel Problems

The stress of working and living in the cold together with the remoteness of location often results in personality problems. Furthermore, emotional problems are a major contributing factor to industrial accidents (Vincent, 1969).

The small town atmosphere of the company town is difficult for wives especially. Gossip travels quickly. If a family has some problem, everyone knows about it (Bowman, 1977). Many wives have trouble developing a sense of belonging in the new community and feel isolated from their families back home due to the distance (Vincent, 1969). This feeling of isolation and loneliness is often compounded when the husband goes out with the boys to utilize the company provided recreation facilities after shift (Vincent, 1969). These problems lead to alcoholism, drug abuse, and severe emotional problems which result in divorce and employee turnover. Vincent (1969) found, when studying the Schefferville mental health problems, that fully one third of the admissions to the local hospital were basically emotional maladjustment. One solution lies in providing work or community project choices for the wives, and baby sitting services so they can take advantage of the opportunities (Bowman, 1977).

CHAPTER 9

NORTHERN ACCOMODATIONS AND COMMUNITIES

Introduction

The population in the North American Arctic is sparse. Mining companies considering development of a prospect will in all likelihood find no established community for employee residence. The choice will likely be a camp or some type of a company sponsored town. Oil field activity in Arctic Alaska has adopted exclusively a basic camp setup with a rotating crew schedule. The mining industry utilizes camp facilities for hourly workers combined with family housing for staff. However, in the Canadian subarctic the trend is toward the integrated company town. A few operations may be close enough to take advantage of an established local community. Whitehorse Copper Mines Ltd. is an example.

Camps

In developing the oil deposits at Prudhoe Bay, single status housing was provided for all employees. Employees normally work alternate weeks of seven days, twelve hours per day, which allows them a week with their families. Transportation to Prudhoe Bay is by aircraft from Anchorage (625 air miles to the south). This schedule has resulted in a turnover rate of less than ten percent.

The camps are usually constructed of prefabricated units which are ready for use once placed on a foundation and connected to utilities. Units come in a wide variety: bunkhouses, kitchens, dining halls, recreation rooms or storage areas. Larger buildings are available that fold away for shipment. Anvil Mines Ltd., used two 40 foot by 100 foot ATCO foldaway units for a service building and standby power house while driving decline at the Polaris Project on Little Corwallis Island. Foldaway buildings are easy to ship, and the assembly time required to become operational is relatively short.

Camps With Homes

A camp facility can be augmented by family quarters for staff, omitting the usual town services such as schools, stores and churches. This approach is used at the Asbestos Hill mine in Northern Quebec. The Canada Tungsten mine in the Northwest Territories utilizes a similar approach by providing a few stores and expanding recreation facilities and other services in stages. With the continued success of the mine, the town of Tungsten will develop into a fully integrated community.

Company Town

The most common practice for a long term development in a remote region is a modified company town. The objective is to provide a subsidized and suitable place for a worker to bring his family together with a pride of ownership and property rights. Carving a complete community out of the wilderness is expensive as all infrastructure cost is borne directly or indirectly by the developer.

A company town is planned around the whole family (Lotz, 1968). It is essential that wives have an opportunity for activities, both work and social (Bowman, 1977). Wives from Quebec Cartier's first company town, Gagnon, were consulted during the design stage of the town of Fermont, which was built to serve the new Mount Wright mine in Quebec. As a result, homes in Fermont have mud rooms, basements, ample storage, plenty of electrical outlets, modern bathroom and kitchen fixtures (Fisher, 1977, Fish, 1975b). It is important that homes are built with a view of the yard from the kitchen, because much of the wife's time is spent preparing meals, while supervising the children (Lotz, 1968).

In an effort to instill a sense of belonging, many companies are attempting to de-emphasize the "company town" feeling of the community. At Fermont, the homes are sold to employees at less than cost. When an employee leaves, the company guarantees to buy back the house if no other buyer can be found. At other towns such as Schefferville and Faro, the company makes a special effort to stay out of the affairs of the town. The "company town" attitude can be reduced if supply concessions are granted to outside firms for groceries, merchandise and community services. Townspeople will be most proud of a facility if they have built it themselves rather than relying on the company to provide their every need.

The staff at Clinton Creek provided the author with many suggestions for an ideal company town. It was pointed out that it is not a good situation when a worker socializes exclusively with his co-workers. The solution may be for the town to serve more than one employer. Women adjust to the company town life much better if they have employment or social opportunities available to them. Often, single workers are housed in dormitories and eat at a central cafeteria, isolated from the married families. Possibly, single employees should be offered small apartments that are situated near the married employees housing. This arrangement would more closely duplicate that of the outside world.

The Established Town

The majority of communities in the north are quite small, and would not be capable of absorbing the large influx of residents associated with a mine development. Therefore, the developer may find it necessary to build additional homes and subsidize the utility services and school systems.

General Considerations

Protection of the residents of a town or camp is the most important consideration when planning a community. Fire is the greatest threat to a remote arctic location. The low humidity creates extremely well dried wood and fiber which can act as a tinder (Rice, 1975). Fire fighting is more difficult because of frozen water lines, the risk of frostbite, lack of water, and the need for a larger than normal crew for warm up rotation (Rice, 1975). Fire prevention and detection are also important. Alternative systems must be provided for that time when a vital utility fails or is destroyed by fire. Each support system must be evaluated with respect to a course of action to take if fire should destroy that system. The uppermost question is, how will we feed and house the residents until the repairs are completed or evacuation takes place?

In laying out a town or camp, the prevailing winter winds need to be considered. The Quebec Cartier town or Fermont, Quebec is protected from the prevailing wind by a five story wind break building (see Figure 9-1). Drifting snow can be reduced by positioning buildings with the narrow side toward the wind.

An economic analysis of fuel costs versus wall thickness will indicate the optimum amount of insulation needed. It is very important to install a good vapor barrier on the warm side of the insulation. Moisture migration into the insulation will condense and freeze at the 0°C isotherm, and reduce the insulating value of the wall, not to mention the water that will run into the room when spring arrives.

Windows in the Arctic are expensive. Dr. Elbert F. Rice of the Civil Engineering Department of the University of Alaska estimates that the total cost per square foot of a window is ten to fifteen times that of a wall. Windows need to be large enough to be used as fire escapes and to keep the occupants content.

Conclusions

Unless a rotating crew arrangement is adopted, a developer will be faced with the planning of a complete community or an equivalent addition to an existing community. This village must be a people-centered community providing most of the amenities found in temperate regions. The developer must expect to heavily subsidize the community to insure its success.

FIGURE 9-1 FERMONT, QUEBEC (Photo: Quebec Cartier)

APPENDICES

APPENDIX A

CYPRUS ANVIL MINING CORPORATION LIMITED

The Anvil Mine, the largest mine in the Yukon Territory, is an example of government cooperation with private enterprise in developing a mineral deposit in a remote region. Today the city of Faro, twelve miles from the Anvil mine, is the second largest community in the Yukon. The Anvil lead zinc mine lies 130 miles north northeast of Whitehorse in a picturesque area of rolling hills and beautiful lakes in the Anvil mountain range. The climate is subarctic with winter low temperatures near minus 46°C (-50°F) and midsummer high temperatures near 29°C (85°F). Average precipitation amounts to a scant fifteen inches per year, half of which is snow.

Mine

The mine is a single large open pit operated six days per week and three shifts per day. Daily production is nearly 11,000 tons of ore and 27,500 cubic yards of waste. Both ore and waste are loaded with five and fifteen cubic yard electric shovels into 85 and 120 ton trucks. Drilling is done with three electric drills, drilling nine inch diameter holes on an 18 foot by 18 foot grid in ore and a 22 foot by 22 foot grid in waste rock.

Mine equipment is ordered with the cold weather options offered by the manufacturers, and further modified by the Anvil maintenance department, based on past experience. These modifications include engine block heaters, engine oil heaters, differential oil heaters, transmission oil heaters and large cab heaters. Heaters help keep the oil temperature in transmission, differentials or gear boxes above outside temperature, but heated storage gives the best results.

Shovels and drills however, cannot be stored in heated buildings. Strip heaters are placed on the stick and boom; radiant heaters are positioned for external gears. Booms and dipper sticks of T-1 steel are specified when shovels are ordered. When wet ore freezes to the shovel bucket, straw is burned in the bucket to melt the frozen material.

Welding repairs must at times be performed in the cold. At the Anvil mine, an enclosure is first constructed around the work area and then heated. The welded piece is preheated and slowly brought back to ambient temperature so that stresses are properly relieved. The enclosure also provides a more comfortable working environment to insure efficient repairs and the proper attention to detail.

Mineral Processing

Three products are produced at Anvil: lead concentrate, zinc concentrate, and mixed lead-zinc concentrate. Lead recovery is 81.3 percent, producing a 68 percent lead concentrate with 20 ounces of silver per ton. Zinc recovery is 80 percent, producing a 54 percent zinc concentrate. The mixed concentrate contains 29 percent lead and 30 percent zinc.

The entire concentrator is in a heated building including fine ore storage and concentrate thickeners. Process water for the mill is supplied from the one billion gallon reservoir built in Rose Creek, and is pumped one and one-half miles through an insulated 24" steel pipe. Temperatures of the process water is between 1.1°C (34°F) and 4.4°C (40°F). This low temperature hinders the flotation process, but is compensated for with additional flotation plant throughput or special reagent combinations.

Transportation

The dried concentrates are loaded into thirty ton capacity "teardrop" containers which are trucked to Whitehorse 235 miles away. ("Teardrop" is suggested by the parabolic shape of the aluminum containers). At Whitehorse, the containers are loaded onto trains for shipment to Skagway, Alaska. The White Pass is a 110 mile long narrow-gauge railroad built early in the century to serve the Klondike gold fields. The containers are covered to prevent dust loss or snow accumulation. At Skagway, the containers are dumped and the concentrate stored in a 100,000 ton capacity building to await shipment to Japan and several European nations.

Supplies for the Anvil mine are brought to the site via several routes. White Pass container ships sail weekly from Vancouver to Skagway, then freight moves by rail to Whitehorse. Supplies are also brought by truck via the Alaska Highway. Goods are also flown to Whitehorse or to Faro. There are daily flights from Vancouver and Edmonton to Whitehorse and regular flights to Faro. There is also daily bus service from Faro to Whitehorse. The long supply lines dictate a warehouse inventory twice what is common in less remote areas.

Personnel

The problems of attracting employees with the needed skills, and of providing an environment in which they will stay, are as serious at Faro as at other remote mine sites. In the early months of operation, employee turnover rate ranged up to 25 percent per month. By 1971, this figure had dropped to 7 percent per month and to 3.3 percent per month by 1977. The turnover is disproportionately high among the single employees, prompting the company to emphasize family housing units, schools, and family facilities.

The company subsidizes each employee to the extent of about seven thousand dollars each year. Subsidies include rent, medical expenses and food cost. Each married employee receives $1,100 each year in tax free air fare. Employees are eligible to take twenty-two days vacation with pay and twenty-two days leave without pay each year. After five years of service, an additional one month's vacation is received as a bonus.

Government Aid

Government cooperation made possible the development of the Anvil prospect into the Anvil Mine, thus providing employment for over 450 people. The Canadian Federal Government built a road to the mine site, expanded electrical generating capacity of the Whitehorse Rapids power plant and built the power delivery network.

The Department of Manpower also set up trade training schools. The objective was to provide job opportunities for the local natives. About thirty have become stable employees.

Faro

The town of Faro represents the company's determination to create a modern family environment for their workers. Since the Anvil deposit is in a remote location, a complete community was built where none had existed before. Construction began in 1968 but the town was destroyed by a fire started by lightning before the first families could move in. The town was rebuilt, and families began moving in three months later. Today Faro is the second largest community in the Yukon, with a population of fifteen hundred.

Faro has many modern conveniences including a school to grade twelve, a well equipped community recreation center, church facilities, medical services including dental, regular bus and air service, and recreation and service organizations. The town is located twelve miles from the mine. Concentration trucks do not pass through town enroute to Whitehorse. Thus mine operations have little effect on town life.

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APPENDIX B

ASBESTOS HILL, ASBESTOS CORPORATION LIMITED

Introduction

In a remote, wind swept, treeless, tundra area of the Ungava Peninsula in Northern Quebec, a rich asbestos deposit has been brought into full production. The mine, operated by the Asbestos Company of Canada, is located on the south side of Hudson Strait, 1,130 miles north of Montreal. Even though it is located 300 miles south of the Arctic Circle, (61°49 north latitude, 73°58' west longitude) the climate and weather are arctic.

This area of Northern Quebec is largely underdeveloped with no roads, airports, railroads or sizeable settlements. To bring the property into production, virtually all infrastructure was supplied by the developers. This factor necessitated a larger than normal capital expenditure.

The mine is on a plateau, 1,700 feet above sea level, with frequent winds that reach extremes in excess of 100 miles per hour. Winter temperatures from November to April are in the range of 0 to minus 55°F with wind chill factors 20° to 40° colder. Mean summer temperatures are in the upper forties with a few days reaching the seventies. The cold climate results in permafrost to a depth of 540 meters (1800 feet). The rock temperatue is +19°F in the pit and +24°F at a depth of 700 feet. The active layer is about 12 inches thick.

Operations

The ore mined at the Asbestos Hill mine is processed to an upgraded fiber at the mine site. The fiber is hauled 42 miles in 50 ton trucks to Deception Bay where it is stored in a building capable of holding 90 percent of one year's production. The fiber is then loaded on ships of up to 50,000 DWT capacity during the three month shipping season (20 July through 20 Oct.) for shipment to the finishing mill at Nordenham, Germany. This arrangement is cost effective because the plant construction costs were lower in Europe than in the Canadian Arctic and because the bulk shipment cost for ungraded fiber is one thrid that for containerized finished fiber. The three fiber grades produced are equivalent to Canadian 4J, 4T and 4Z. The European location has enabled customers to reduce inventories that were necessary in the past due to the long supply lines from South Africa, Russia or Canada.

The Mine

More than 1.5 million tons of 18 to 20 percent asbestos ore are mined each year to produce the 250,000 tons per year of fiber exported to Europe. Ore is produced from a surface mine with a stripping ratio of about three to one. Production will come from underground mining when the surface pit is exhaused in 1982. The development work for the underground mine was begun in July, 1975 by contractors. The first phase entails driving 8000 feet of 15 by 10 foot decline at -20 percent grade; 1,300 feet of 13 by 10 foot cross cuts; cutting 25 drill stations, and drilling 30,000 to 40,000 feet of diamond drill holes. Timbering and rock bolting are necessary for ground control.

Due to the harsh winter weather, the pit operations are shut down from mid-December to early February. All repairs that can be scheduled are performed during this six weeks shut down, and maintenance crews carry out mechnaicial checks to insure that the equipment is ready for start up.

Drilling

Blast holes are drilled with two rubber tired Ingersoll-Rand Drillmaster T-4 drills and two crawler mounted DM-4 models. Bit diameter is 6.5 inches. Holes are drilled on a 9 by 11 foot spacing pattern in ore (a powder factor of 1.23 lb. ton) and 15 by 17 foot pattern in waste (a powder factor of 0.48 lb/ton). The average powder factor for the mine is 0.66 lb/ton.

Bench height is forty feet and is usually three rows wide with three feet of subgrade drilling necessary for proper floor control. At Thetford Asbestos Mine, about 1250 miles to the south, the same size holes are drilled on a 20 by 22 foot pattern which requires 50 percent less drilling per ton of ore produced. The difference is due to the fact that Asbestos Hill ore is frozen and Thetford ore is not. Despite the frozen ground at Asbestos Hill, water seeps into drill holes and freezes, necessitating loading the holes immediately after drilling.

Blasting (see also Chapter 6)

Early in the operation of the pit, it was found that blasting frozen ore resulted in many oversized chunks, requiring secondary blasting and caused crusher feed problems. There was also extensive back breakage, complicating the drilling of the next shot. L.C. Lang, Research Engineer from Canadian Industries Ltd., was assigned the task of thoroughly studying the problem and recommending a solution. He found that the package slurry, Hydromex T-3, used in the holes was inadequate. The 5-1/2" diameter cartridge, being frozen, would not fill the 6-1/2" hole, and when dropped into the hole would damage the lower primer. Detonation of the explosive charge was usually initiated by the second primer in the upper part of the hole, resulting in poor blasting results. Canadian Industries Ltd. developed a special cold weather slurry designated Polar Hydromex which is soft and easy to handle at -20°F. The confined velocity of detonation for Polar Hydromex at the temperatue of the ore, (+19°F), is 19,000 feet per second. Polar Hydromex, even when chilled to -60°F in cold weather, will warm up to rock temperature in 24 minutes after charging, insuring proper velocity and density upon detonation. In the same 24 minutes, Hydromex T-3 had warmed to only -40°F.

Rock subjected to dynamic loading will break in either shock or shear type failure. Shock failure occurs when the disturbance or shock velocity is greater than the sonic velocity of the material, and results in good fragmentation. If the disturbance velocity is less than the sonic velocity, the material absorbs energy in plastic deformation rather than fragmentation. Large blocks and slabs result from the plastic shear-type failure. The mechanical properties of the rock to be blasted must be determined to insure that an explosive is selected with detonation properties to match the rock. Tests on dry materials showed little correlation between temperature and sonic velocities of compressional (longitudinal) and shear (transverse) waves. However, tests on saturated samples show a sharp increase in sonic velocities of compressional and shear waves at temperatures below freezing. Also, with decreasing temperature there was an increase in Young's modulus. Experiments at Iron Ore Company of Canada's Schefferville Mine indicated that at a moisture content of eight percent the velocity increase became a problem and was most serious between 15 and 18 percent. After measurements of in-situ rock properties, a computer model can examine the important variables of rock type, the explosives and the distribution, the energy density, spacing, burden, collar, subgrade, delay patterns, and times. Application of the computer design resulted in good fragmentation, good pit floor and good loading conditions. Preshearing is used to control back-break.

Loading and Hauling

Eight rubber tired front end loaders with 9 cubic yard buckets are used in the pit. Five are used on production; three are in reserve or are used for odd jobs. Although subject to decreased production when fragmentation is poor, the loaders have several advantages over shovels. Loaders can be quickly removed from the work area prior to blasting, driven to heated garages for service and repairs, and quickly replaced by a spare unit. Thus breakdowns have had little effect on production. Loader buckets are "V" tipped with interchangeable teeth to improve lip wearability and better rock pile penetration.

Small drills are used for floor control and secondary blasting. Where possible, the floor is leveled off with a D-8 tractor and ripper. A Caterpillar 824B rubber tired dozer is used for pit road maintenance and clean up around loaders.

Ore and waste are hauled from the mine in thirteen 45 ton capacity trucks with an average load of 40 tons. Three trucks are used for ore haulage, nine for waste, and two are held in reserve.

All rubber tired equipment is fitted with tire chains to reduce tire wear and increase traction on slippery roads. Road sanding requirements have been reduced since the chains were installed. Another important advantage of chains is the reduction in the contamination of the ore by rubber.

Equipment operators are selected and trained on site. Careful operation is emphasized to insure against breakdowns caused by misuse in cold weather.

Mill

The mill has the capacity to process 6,600 tons of ore per (24 hr) day yielding 1,200 tons of ungraded fiber. Ore from the pit is dumped into a heated sluice and fed by a pan feeder to a 48 by 60 inch jaw crusher with an open setting of 8.5 inches. The ore is then passed through a closed secondary crushing circuit and discharged to three rotary dryers. Two 80 inch by 50 foot dryers are rated at 22 x 10^8 BTU and one 120 inch by 50 foot unit is rated at 60 x 10^8 BTU. All are oil fired, and reduce the moisture content to less than one percent. The dry ore is then stored in a 30,000 ton storage dome. This dome is a laminated wood beam structure sheathed with plywood and asphalt paper.

The asbestos mill circuit is of standard airlift separation design. The ungraded fiber is stored in a 300,000 ton storage dome. Both the dry ore and ungraded fiber storage domes are 190 feet in diameter by 80 feet high. Each has sixteen laminated wooden arches containing 40,000 board feet of lumber and 25,000 square feet of plywood decking and sheathing.

The mill is operated by twelve men each shift, including four process controllers. A ten man clean up crew works on the day shift only.

The mill is not heated and the large quantities of air (40,000 cubic feet per minute) used for drying, aspiration and dust control create low wind chill temperatures near the inlet louvers. The warm ore, when exposed to the cold mill air, causes condensation in the dust control system. Hot air is added to the dust hoods to solve or minimize this problem. Jaw crusher grease and grease lines are also heated, and injectors on the pressure lubrication system are warmed with radiant heating. Trouble with frozen chutes is reduced by the use of abrasion resistant plastic liners such as steel-liner or ultraclad. Rotary rubber brushes prevent carry-back on conveyor belts.

Trucking Fiber

The fiber is trucked 42 miles to Deception Bay in specially designed Kenworth trucks with a capacity of 50 tons. The frames are made of manganese steel and are laminated in three layers. This frame, more flexible than standard, is necessary to stand up to the rough road and cold weather. Each of these trucks has a 25 ton box on the bed and pulls a 25 ton trailer. The boxes are fitted with hinged covers to prevent loss of fiber.

The trucks are loaded with a front end loader inside the fiber storage dome. The loader operator is protected from breathing fiber by a filtered and pressurized cab.

The road to Deception Bay is elevated six to eight feet and built along the high ground which allows the strong winds to keep the surface blown free of snow. When snow is cleared from the roadway, it is pushed at least 200 feet downwind.

A quarry was opened in 1974 to supply the fill material to elevate the road. This quarry has its own portable crusher and screening plant and in two years supplied 250,000 tons of road material. The quarry is operated only in the summer months.

The trucks are unloaded inside a 225,000 ton storage building at Deception Bay. The building is 760 feet long, 305 feet wide and 145 feet high and covers 5.3 acres without any intermediate columns. The framework uses 36 glue-laminated arches and contains 1,800,000 board feet of wood plus 600,000 board feet of laminated struts and sawn purlins. The covering consists of 400,000 square feet of corrugated steel.

The storage buildings are of laminated wood because this size of building could not have been designed of steel, fabricated and delivered in the required length of time.

Shipment of Fibers

The fiber is reclaimed by conveyor belt and loaded on ships of up to 50,000 ton capacity. The wharf consists of three rock filled steel pipe cells 70 feet in diameter and 80 feet high for protection against the large ice forces generated by incoming tides carrying sea ice.

The loaded ships travel to Nordenham, Germany where the fiber is stored in a 225,000 ton shed. The ungraded fiber is then classified and marketed in Europe.

Accomodations

The original plan called for an integrated townsite at Asbestos Hill, but this idea was dropped when it was decided to build the finishing mill at Nordenham, Germany. ATCO-type portable camp buildings are used at Deception Bay and Asbestos Hill. These buildings are elevated four feet above the ground to protect the permafrost, and avoid the damage that would result from permafrost degradation.

During peak activity in the summer months when ships bring in supplies for the year and an entire year's fiber production is loaded out, the terminal crew totals 45 workers, but reduces to ten during the quiet winter months. Deception Bay has a landing strip, communication radio, a 1 mw diesel power station, a 6.5 million gallon tank farm and two maintenance ships in addition to the cargo and handling facilities and camp.

25,000 gallons of water per week are trucked 27 miles from a deep water lake. A Pres-O-Ject system collects sewage. The system has a holding tank which when full, is emptied by compressed air, in a rapid flushing action, through the sewage discharge line.

The camp which accomodates the mine and mill crew houses an average of 350 men for the 45 production weeks. The power station at the mine site has a capacity of 4850 kw. Water is hauled ten miles in a 5,000 gallon capacity exhaust heated tank truck from a deep water lake. Two tanks, with a combined capacity of 450,000 gallons, hold water sufficient for 12 to 15 days. This water can be used for fire protection. Water is heated and recirculated in insulated pipes through heated utilidors for domestic, plant, and fire protection. Long utilidors which are susceptible to freezing are heated by circulating ethylene glycol. Sewage lines run through these utilidors. The sewage treatment plant is an oxygenation type using chlorine to reduce all remaining bacteria.

The main repair shop, the plant shop, the warehouse and pump house, are all centrally heated by a circulating glycol system which is warmed by heat exchangers on the diesel generators or by fuel fired furnaces of which there are nearly 100.

Asbestos Hill has a nurse on site and Twin Otter medi-vac service to the Frobisher Bay hospital 250 miles away.

Senior staff are supplied with family housing and their families often spend the summer at Asbestos Hill. This has contributed to a very low staff turnover rate.

Manpower

Even though there is a sizeable Eskimo population in the area, none work for the company, and only a few took jobs during construction. This is a problem common to northern operations.

Turnover rates are rather high despite good wages and liberal benefits. In 1975, the maintenance department hired 216 men to fill 105 jobs. The foreman level of supervision is the most difficult to fill. Foremen from Thetford Mines are frequently used until men can be trained for the job. The turnover rate for foremen is still 25 percent per year. Employee turnover rate holds steady at 10 percent per month. Each person reacts to life in a remote camp differently and high turnover must be expected to continue. When camp employees live, eat, work and spend recreation hours with the same people, personalities are likely to clash and emotional weaknesses will become apparent.

Workers spend 38 weeks each year on the job with a guarantee of 60 hours work each week. The remaining 14 weeks are used for compensation leave and annual vacation. Employees are normally expected to work on site for ninety day periods of time. Only a minimum necessary staff is located at Asbestos Hill, with all possible staff located in Montreal. Most engineering services are performed from the company offices at the Thetford Mines.

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APPENDIX C

THE BLACK ANGEL MINE

Introduction

Named for a dark rock structure shaped like an angel high above the Marmorilik Fjord, the Black Angel mine is the first large-scale industrial development in Greenland. The mine is located at the junction of the Marmorilik and Ouamarujuk Fjords and the portal is 2000 feet up a nearly vertical face overlooking the Marmorilik Fjord.

Located 71° North latitude, the mine is owned by Greenex A/S, a Danish company which is a wholly owned subsidiary of Vestgron Mines Ltd. of Canada. Cominco Ltd. is the operations manager and has a 62.5 percent interest in Vestgron.

Lead and zinc sulfides were identified in the talus at the foot of the cliff circa 1930, but it was not until a mountaineering team scaled the cliff in the mid-sixties that the outcropings were discovered.

This area in West Greenland has an arctic climate and although the mine is located on tide water, shipping is prevented from December to June by sea ice.

Development

When development began, the refitted former Canadian Arctic patrol vessel S.S. C.D. Howe was anchored in Marmorilik Fjord. This ship was used as a floating camp and warehouse for the sixty man work crew.

Two portals were collared 2000 feet up the cliff with the help of helicopters and Swiss climbers. Each portal is now fitted with a cableway, one for men and materials; the other for ore. The cableways stretch across the fjord to the concentrator.

The remote site required all infrastructure to be built where nothing existed before, including a town site, concentrator, concentrate storage and handling facilities, docks, power plant and sea water desalinization plant. The total investment to bring this property into production was $61.2 million.

Mine

A room and pillar mining method is used. Approximately fifteen percent of the ore is left in pillars. Ore is hauled to the mainline transport tunnel by diesel powered load-haul-dump units. Haulage in the mainline tunnel itself is by diesel locomotive with Grandby type mine cars. All primary and secondary crushing facilities, repair shops and other main service functions are located underground. Waste rock is discarded into the fjord through openings blasted in the rock face.

Wet drilling is with jumbos and conventional handheld drills. Salt water is used to prevent freezing of the drill water. Calcium chloride or sodium chloride is added to the water in sufficient quantity to depress the freezing point to about 22°F. Drilling with salt water causes corrosion and skin irritation.

Mill

The concentrator was originally located at the Douglas Creek Mine of Cominco American Inc. in Montana. There it was disassembled and shipped to Greenland. Sea water is used in the flotation process requiring alteration of some concentrator components to minimize corrosion. The filter cake is washed with fresh water to reduce the chlorine content in the concentrate.

Facilities are provided to store seven months' of concentrate production since ice blocks the fjord from December through June.

Personnel and Accomodations

After start up, Canadian employees were replaced with Greenlandic and Danish workers. Technical and professional employees are drawn from Scandinavian mining and technical schools.

Most of the 250 employees are housed in bunkhouses. There is also a recreation center with a resident doctor.

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APPENDIX D

Canada Tungsten Mining Corporation Ltd.

Introduction

Canada's only producing tungsten mine is located on the Flat River in Northwest Territories 130 air miles north of Watson Lake, Yukon Territory. The mine is two miles from the Yukon border and 190 miles by road from the nearest town of Watson Lake. The road is maintained by the Yukon Government to within forty miles of the mine. Canada Tungsten maintains the last forty miles.

Located at 62° North latitude in the Selwyn Mountains, the site has a subarctic climate, with recorded temperature extremes from minus 49°F to plus 90°F. The ground is snow free from late May to late September. During an average winter, five feet of snow can be expected.

Mine

The open pit mine produced 1.35 million tons of ore averaging 1.64 percent WO_3. The mine was located at 5000 foot elevation in a cirque on the west side of the Flat River Valley. Mill feed for the full year was mined during the snow free period from mid June to late September. Ore for winter milling was crushed and stockpiled. The stockpile was reclaimed with a Northwest 1 1/2 cubic yard shovel.

The underground deposit was found as a result of a stepout drilling program. Reserves are estimated at 4.5 million tons of 1.60 percent WO_3 and 0.25 percent copper. The extent of the ore has not been fully delineated. The ore body is mined by room and pillar methods. The pillars are 50 by 60 feet; rooms are 30 feet wide. The ore is taken in 20 foot benches. Up to four benches are planned where the deposit is thickest. The method will be changed in areas where the ore body dips at an angle greater than 25 percent. Mined areas are to be filled with waste and the pillars recovered by longhole methods from below. Ground control is with rock bolts with straps and fencing where necessary. The ventilation air is heated to plus 50°F by a 12 million B.T.U. per hour propane burner. In December, 15,000 gallons of propane are burned to heat an average of 140,000 cubic feet of air per minute.

Mill

Flotation, gravity separation, roasting and magnetic separation processes are all used at the concentrator. The concentrate, averaging in excess of 75 percent WO_3, is placed in two ton plywood crates which are trucked directly to Vancouver or to Fort Nelson for transfer to rail car.

Waste heat from diesel electric units is utilized to heat the concentrating process water. Also, water from the thickeners and settling tanks is recirculated.

Personnel and Accomodations

The work force presently numbers 189 men including staff and summer help. Single employees live in Atco style trailer bunkhouse units. Twenty-eight families are accomodated in houses and townhouses. There are plans to build more, since family workers are being encouraged.

Fringe benefits include subsidized retail grocery stores, recreation facilities and a medical clinic. The normal work week is 48 hours with overtime for hours over forty. Single status employees are allowed four round trip air fares to Vancouver or Edmonton each year. Employees are eligible for two weeks paid vacation after one year of service. In addition, ten days to two weeks of leave without pay are allowed after each three months served. Longevity is rewarded with additional pay and vacation bonuses.

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APPENDIX E

CASSIAR ASBESTOS CORPORATION LIMITED
CLINTON CREEK MINE

The farthest north open pit mine in North America was the Clinton Creek mine in the Yukon Territory. Located at latitude 64° 30' North, Clinton Creek, only 140 miles south of the Arctic Circle, has a subarctic climate. Clinton Creek is about 64 miles from Dawson and four hundred miles from Whitehorse by road.

Temperatures range from 30°C (86°F) in the summer to minus 52°C (-62°F) in the winter. Eight months of freezing weather insures widespread permafrost with depths of about 200 feet in some places. Average annual precipitation is twelve inches, nine of which are rain.

The mine and mill were shut down in 1978 due to depletion of economically recoverable ore.

Clinton Creek Mine

Mining was by open pit from two pits producing 2,110,000 tons of ore each year. Production was scheduled three shifts each day, six days per week. Ore from the pit was trucked to a primary crusher near the mine and then transported to the fiber mill via a 5,281 foot tramway.

Holes were drilled on a 20 foot by 20 foot grid (9" holes) or 22 foot by 23 foot grid (9-7/8" holes) in ore. Waste was drilled on a pattern of from 18 by 18 foot to 26 by 34 foot. Burden and spacing depended upon rock type and drill diameter. In areas of permafrost, the burden and spacing were reduced one half. All production was from below the permafrost level.

The ore was loaded into trucks with either a five cubic yard electric shovel or ten cubic yard front-end loader and hauled directly to the primary crusher located near the pit perimeter.

Mine Equipment

Equipment was modified for cold operation, and operators were instructed in cold weather procedures. Success at Clinton Creek depended upon employee knowledge of conditions and procedures thus eliminating high stress on vulnerable parts. Regular checks were made of vulnerable parts for cracks and signs of wear.

Strip heaters for shovel components were not used at Clinton Creek, because management believed that they caused differential expansion and contraction. Wet ore that freezes to shovel buckets is thawed by fuel oil poured over the frozen ore, and ignited.

To keep hydraulic systems functioning, special oil was used or the summer oil was diluted. The hydraulic oil in the drills was replaced with Imperial Univis J43 which was an aircraft undercarriage hydraulic oil. The hydraulic oil for ten cubic yard loaders was diluted with up to thirty percent kerosene.

During the weeks of extreme cold the shovels and loaders was assigned to load the easily dug ore. The harder digging was left until the temperature was above minus 29°C (-20°F). In this way, components were not highly stressed when the metal was brittle. No shovel sticks were broken at the Clinton Creek mine.

One way stresses were reduced on truck components at the Clinton Creek mine was to insure that the haulage roads were graded. To prevent the parking brake from freezing in the braked position, the trucks were parked in a depression in the service area with the brake off. Diesel motors were equipped with emergency shut off devices which activated in the event of engine overspeed, overheating or loss of lubrication pressure. These shut off devices were checked each day.

The primary crushing plant was located near the pit and included a 122 centimeter (48 inch) by 152 centimeter (60 inch) overhead eccentric jaw crusher, screen and secondary crusher in a heated building. A heavy curtain of belting was suspended above the feeder between the building and the dump bin, to keep the dust and cold air out of the crusher building, (see Figure E-1). This curtain had a reinforced window which allowed the crusher operator to observe the trucks while dumping.

All heavy equipment was serviced and repaired in the centrally located garage. The service garage was heated by a hot water circulation system located in the floor. This proved to be a very effective method of heating a service garage.

Ore Tram

The crushed ore was loaded into buckets of 1900 kilograms (1.6 tons) capacity, and trammed 1610 meters (5,280 feet) to the mill which was 150 meters (500 feet) above the crusher building (see Figure E-2). The longest unsupported span was 670 meters (2,200 feet) and the maximum height above the ground was 76 meters (250 feet). During the winter months the moist ore froze to the bucket wall and trap door. This frozen ore continued to build up, reducing the capacity of the bucket and overloaded the return cable. Therefore, twelve of the eighty-four buckets were removed from the line each day and stored in a heated building for 24 hours to allow the ore to thaw.

The tram buckets dumped the ore into a screening and crushing circuit where rock and fiber were first separated. Thirty percent of the mill feed was removed as waste in this circuit and sent to the tailings pile. The rock containing the fiber was dried to three percent moisture, and stored for mill feed. The mill produced three grades of fiber CT, CY and CZ. The mill was heated by the waste heat from the electrical motors that drove the process air fans.

The conveyor belts that transport ore to and from the dry ore storage building, and the waste to the tailings dump, operated at ambient temperature. The lubricants in the bearings and gear boxes were changed four times each year to insure proper lubrication. DN600 was used during the cold weeks. If the lubricants were not changed, a stopped belt would prove extremely difficult to restart. The increased tension caused by the cold on improperly lubricated conveyors resulted in belts being pulled apart at the factory splice.

Transportation

Graded fiber was trucked to Whitehorse where it was loaded onto the White Pass and Yukon narrow guage railroad for shipment to Skagway, Alaska. In Skagway the fiber was loaded aboard container ships for transport to Vancouver, British Columbia. Traffic to and from the mine crossed the Yukon River at Dawson City. This was accomplished in the ice-free summer months by a government ferry and by an ice bridge when the Yukon was frozen. During breakup and freeze up of the river both of these methods were precluded.

An airport with a 1615 meter (5,300 foot) runway served the mine and had twice weekly scheduled service to Whitehorse.

Power

Electrical power was generated by five 1,400 kilowatt Ruston and Hornsby Diesel electric units. There was also one 500 kw Caterpillar Diesel electric unit. Waste heat from the power house was used to heat the larger buildings in town.

The Town of Clinton Creek

Five miles from the mine, on the banks of the Fortymile River, the company built a community with a population of 445. Clinton Creek was a modern town laid out in a wilderness setting with many services, including a four bed hospital.

FIGURE E-1
CURTAIN ABOVE PAN FEEDER

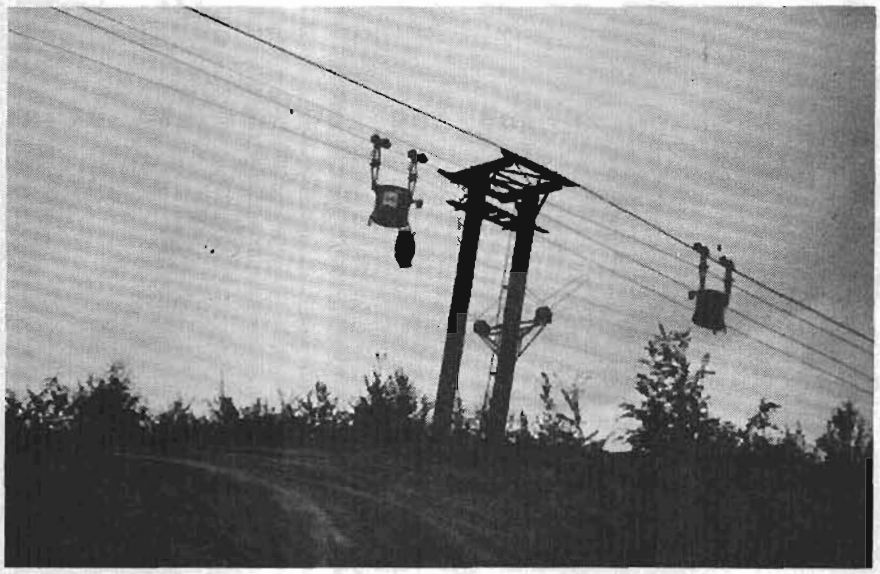

FIGURE E-2
ORE TRAM

The buildings in the town were all built on pile foundations because of the permafrost. These piles are placed in 6.7 meter (22 foot) drilled holes and are backfilled. Utilities were brought to homes in utilidors which were originally underground but were relocated above ground when problems arose. The residents often skirted the buildings for aesthetic reasons or for increased storage capacity (see Figure E-3). Skirting the buildings prevented proper freeze back of the ground during the winter and permafrost degradation resulted. Other problems developed from thawing of ground around the utilidors. Not only did the utilidors fail but they thawed the support of the foundation piles (see Figure E-4).

Company policy was to sell the houses to the employees, but after the mine was shut down, the company bought the homes to insure that the employees did not lose money.

Personnel

Labor turnover was a problem just as it was at any remote northern location. To insure that the best available men were hired, prospective employees were put through a selective hiring process and a selective probationary period. New unskilled employees were also given an extensive training program. Many of the workers were from foreign countries, often as many as twenty-five different nationalities were represented at one time, among them, many Yugoslavians. To help these employees succeed, the company offerd classes in English and trade qualifications, and assisted in transfer to new jobs when the mine closed.

The town was laid out with dormitories for single workers in one area and married family housing in another which discouraged mixing. It would create a more natural living environment to integrate the housing, and offer small apartments to the single employees along with the regular family housing.

Despite the fact that the employees socialized with the same people with whom they work, there was little trouble. There were no police in Clinton Creek and the nearest Canadian Royal Mounted Police Post was in Dawson.

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Vincent, 1977

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FIGURE E-3
HOMES ON PILE FOUNDATION, NOTE SKIRTING

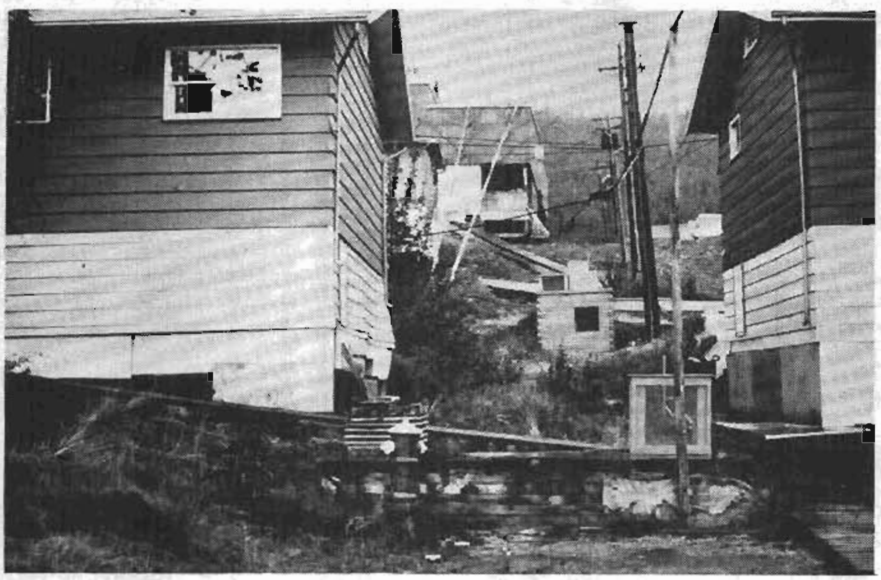

FIGURE E-4
BURIED UTILIDOR CAUSED THAWING OF FROZEN GROUND
SUPPORT FOR FOUNDATION PILE AND PILE MOVEMENT RESULTED

APPENDIX F

IRON ORE COMPANY OF CANADA

The Iron Ore Company of Canada was formed in 1949 by Canadian and U.S. steel companies with a capital investment of 258 million dollars to develop the iron ore deposits near Knob Lake, Quebec. The company began construction in 1950 of a 357 mile railroad, two hydroelectric power plants, a permanent town and a 10 million ton per year ore terminal at Sept-Iles on the Saint Lawrence River and town and mine facilites at Schefferville (see Figure F-1). Highgrade ore at Knob Lake is crushed and loaded directly into railroad cars for shipment to Sept-Iles where it is loaded for shipment directly to the smelter. Currently this direct shipping ore, principally nonbessemer and manganiferous, averages 54 percent iron. Low grade (50 percent iron) ore mined at Knob Lake is concentrated and pellitized at Sept-Iles.

Knob Lake Mines

Mining in the Knob Lake area is by open pit from seven pits at five locations spread 24 miles along the Quebec-Labrador border. Production in 1976 was 8,870,000 long tons of which 3,528,000 long tons were processed into pellets. The individual pits are not permanent. The desired production level is maintained by opening new pits as older pits are mined out (see Figure F-1 a).

The Ferriman North and Fleming Number Three mines are in Quebec, whereas the two pits at Redmond and the two at Timmins are located in Labrador. The Rowe pit straddles the border which complicates record keeping. Each of the five mines has its own crushing, screening and loading plant, its own maintenance shop and its own engineering and supervision staff. Blast holes are drilled with 9 7/8" electric powered drills. Shot rock is loaded by five 10 cubic yard and five 6 cubic yard shovels into thirty-four 120 ton diesel electric haulage trucks. Ore production extends from April to mid-November, and waste removal is scheduled 12 months of the year. The overall stripping ratio is two tons of waste to each ton of ore. Each drill hole is sampled by a laboratory technician for iron content to delineate ore from waste for the production shovels.

In 1973 a concentrator and pelletizing plant came on stream at Sept-Iles to process Schefferville lean ore. Knob Lake reserves now total 370 million tons. Ore is in forty-six separate deposits ranging in size from one million to fifty million tons.

These deposits are located on the continental divide in an area of rolling hills with many lakes. Schefferville is on the southern edge of the discontinuous permafrost zone and has a subarctic climate. The mean annual temperature is 24°F, and precipitation amounts to 29.3 inches per year. Snow fall amounts to about 130 inches. The high elevation of the area exposes the mines to high winds all year. In most months, the average wind velocity is ten miles per hour.

Due to the remoteness of the location, warehouse inventory is higher and approximates five to six million dollars. An extensive inventory of drill and shovel components is kept on hand for rapid repairs. Components such as motors or track frames can be repaired in a heated shop more efficiently than in the field under winter conditions.

Mine Dewatering

Water in the ore causes many problems in this subarctic location. Water in blast holes requires the use of expensive slurry explosives, and wet holes tend to cave. During the winter months, the wet ore freezes on the ground after a shot, and also freezes to the shovel bucket. Wet ore loaded into railroad cars compacts and freezes and is difficult to unload. Water also causes muddy roads in the pit, increasing wear on tires and brakes. Holding pit slopes at an acceptable angle is quite difficult when the walls are saturated.

It is important to dewater the ore before mining. This is accomplished by controlling surface water and by drilling wells in and around the periphery of the pit. Well location is

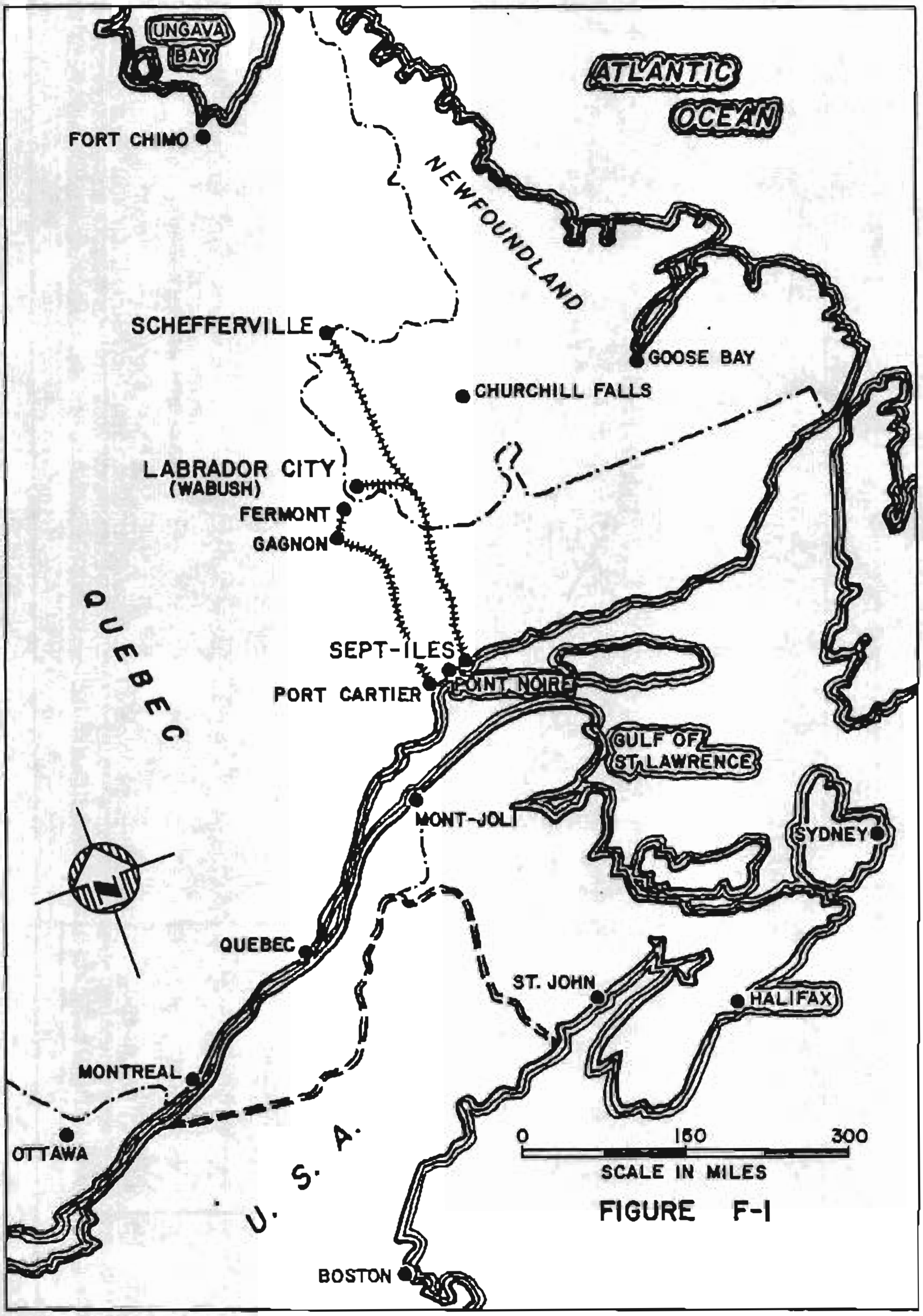
UNGAVA
BAY
ATLANTIC
OCEAN
FORT CHIMO
NEWFOUNDLAND
SCHEFFERVILLE
GOOSE BAY
CHURCHILL FALLS
LABRADOR CITY
(WABUSH)
FERMONT
GAGNON
QUEBEC
SEPT-ILES
POINT NOIRE
PORT CARTIER
GULF OF
ST. LAWRENCE
MONT-JOLI
SYDNEY
QUEBEC
ST. JOHN
HALIFAX
MONTREAL
OTTAWA
U. S. A.
0
150
300
SCALE IN MILES
BOSTON

FIGURE F-1

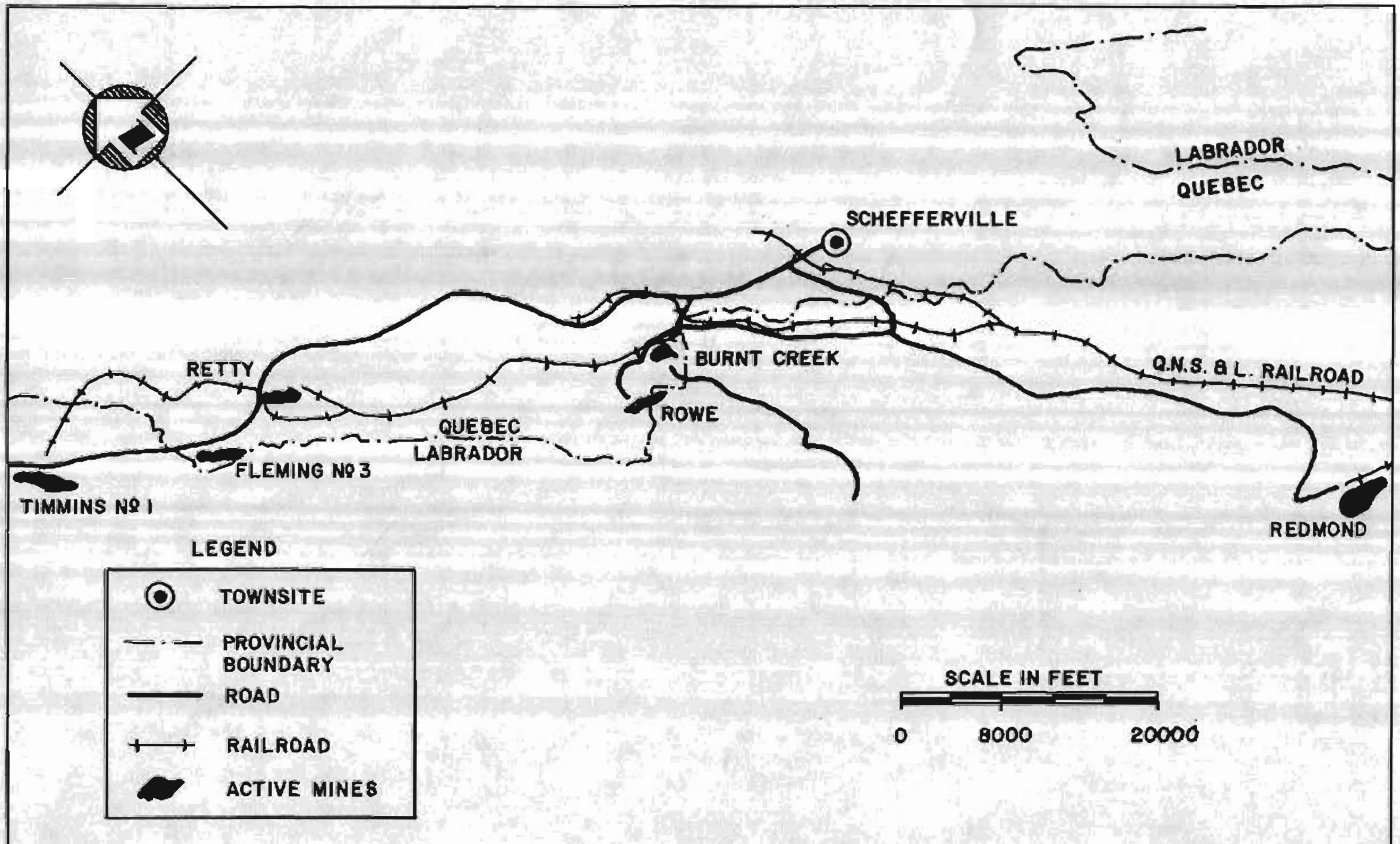

FIGURE F-1a

ACTIVE MINING AREAS – KNOB LAKE (1975)

determined by pit design, geology, hydrology, field tests, a finite element analysis computer program and by the evaluation of well performance. There are presently thirty-seven wells in operation with a total pumping capacity of 27,042 U.S. gallons per minute. Wells vary in depth from 200 to 700 feet and have 12 inch diameter casings. Discharge lines are carefully laid to insure proper drainage when shut down because of cold. The low point in the line has a tee gate valve which is enclosed, insulated and heated. Pumps normally run continuously, and the steady flow of water prevents freezing. Pumps are protected from fly rock and cold with an insulated and heated metal enclosure.

Although wells are usually quite effective in lowering the water table on the pit, other measures are taken to cope with the wet conditions. These include holding shots to a small size in the winter to insure that ore can be loaded out before it freezes solid, and shovel buckets that are heated to prevent ore or waste buildup. Drainage ditches and sumps help to control water and keep haulage roads dry.

Alteration has a varying affect on the porosity and permeability of the various rock layers. One third of the ore rocks are porous but drain poorly, the other two thirds drain readily. The altered slates are relatively impermeable. These conditions complicate pit dewatering, and discontinuous permafrost further complicates the job. When permafrost is encountered, wells are drilled to below the frost level and sand points are used for the water above the frozen layer.

Blasting

Drill holes in unfrozen rock are spaced on a 27 x 27 foot grid. Bench height is 38 feet with six feet of subgrade drilling. During the winter months, frost holes are used to break up the seasonal frost layer. A frost hole is a short hole drilled only to the depth of frost penetration. Frost holes break up the seasonal frost layer without the necessity of closing the normal hole spacing. Without frost holes, large slabs of frozen ore are prevalent in the blasted rock. Frost holes are drilled between each full depth hole and between rows of holes, for a total of three frost holes for each depth hole (see Chapter 6). A row of frost holes is placed at the shot perimeter to control back break and prevent frozen chunks from hanging on the edge. The mine supervisor varies the burden, spacing, subgrade and location of frost holes with the weather and geology. Dry holes are bulk loaded from mixing truck capable of discharging AN/FO or AL/AN/FO. Although more expensive, AL/AN/FO is preferred because of its greater weight strength. Wet holes are loaded with a slurry in 50 lb. bags which increases the explosive cost by a factor of three or four. The Hydromex slurry is stored in a heated building to insure proper plastic qualities when loaded in cold weather.

Shots are primed with primacord and the holes are stemmed with cuttings. Often the stemming will freeze between loading time and detonation. If delays are longer than 15 milliseconds the first hole to go will move the frozen stemming material in later holes far enough to cause misfires. The use of dry crushed rock for stemming eliminates this problem and results in better containment, better fragmentation, a lower powder factor, better break control, and less fly rock.

Drills

The nine electrically powered blast hole drills were extensively rebuilt for cold weather before being put in service. The drill is stripped to the frame which is then extended two feet so that a machine house can be built to enclose the machinery and provide a walkway inside. A 24" culvert pipe is run to the top of the mast and fitted with a fan to force dust free air into the machine house (see Figure F-2). During cold months, the air is heated to insure proper operation of drill components. Radiant heaters above the lubrication and hydraulic storage tanks and pumps supplement the heated air. The compressor oil and coolant have immersion heaters that stay on when the unit is not operating and switch off during operation. The compressor main bearing lubrication system is changed from splash type to pressure type to insure proper lubrication. Cuttings and ice which pack around the stem wrenches below-deck cause a never ending operating problem. The installation of a notched drill collar and the use of two wedges not only eliminates the problem, but reduces the danger of losing a stem down the hole. The dust collector is replaced with a fan and curtain arrangement to prevent freeze up

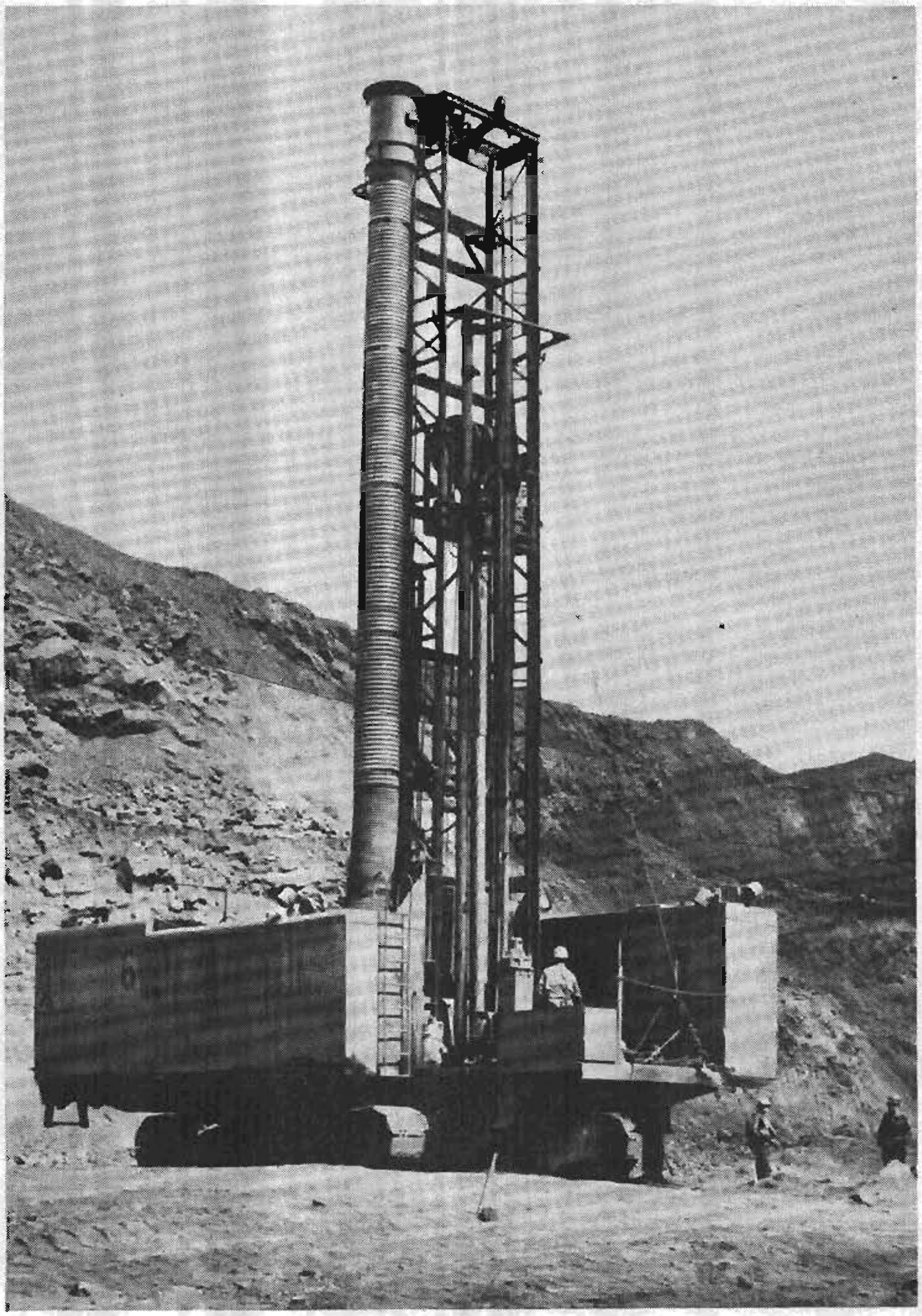

FIGURE F-2 MODIFIED BLAST HOLE DRILL

of the collector. Tanner gas is injected in the air system to prevent air line freeze up. Trailing cables are 60 percent natural rubber to prevent the cracking associated with neoprene in the cold.

Shovels

Five 10 cubic yard and five 6 cubic yard electric shovels are used to load ore and waste. These shovels are modified for cold weather operation. The operator's cab is insulated and fitted with heaters. To prevent wet ore from freezing on the bucket, electric heaters are attached to the bucket sides and bottom. The capacity of these heaters totals 12 kw (see Figures F-3 and F-4).

To prevent failure of a dipper stick in cold weather, the standard stick is replaced with a centrifugally cast tube of AISI 4620 alloy machined to a tolerance of 1/32 of an inch and warmed with trace heaters. The company is experimenting with limit switches, to protect the stick from inexperienced or careless operators. The forged swingrack gear is replaced with a cast rack of manganese-molybdenum alloy with an improved tooth design. Shafts subject to high impact loads are replaced with shafts of chrome-molybdenum or chrome-nickel-molybdenum alloys, and the splines are changed to an involute design (see Chapter 7).

Proper lubrication of the shovels was a difficult problem. The open gear and stick spray nozzles were replaced with a drip system. The automatic system now pumps lightweight oil to the stick, open gears and sleeve type bushings. Antifriction bearings are hand lubricated with grease once each month.

The side frames on the shovels break on an average of one set each winter season. Repair results have been so poor that new or rebuilt frames are allowed to sit for a year before being reused.

Mobile Equipment

Mobile equipment is kept running all winter except when brought to a heated building for service and repair. Operator cabs are insulated and fitted with larger heaters. Equipment fitted with air activiated devices have systems to remove moisture to prevent freeze up. Air heaters, automatic tank drainages valves or alcohol injectors serve this purpose. Hydraulic systems that do not generate operating heat are diluted with kerosene (as on the graders), heated (as on the loaders), or changed to a lighter weight (as on the bulldozers).

Permafrost at Knob Lake

As mentioned elsewhere, the area is at the southern edge of the discontinuous permafrost zone. Although the town of Schefferville is not located on permafrost, many of the pits have encountered permafrost to depths of 290 feet.

Due to the saturated conditions of the rocks in the area, the permafrost areas have layers of ice in the ore. The frozen ore is difficult to mine economically since it will not drain when wells are drilled nearby, and its mechanical properties require more explosives on a closer pattern for good breakage. During drilling, compressed air is used to clear the hole of cuttings. Compressed air is hot after compression and thaws the walls of the holes during drilling which results in sloughing. Wet sloughing holes are loaded promptly with the more expensive slurry to insure proper detonation.

Due to the added expenses of mining frozen ore, it is often left in favor of unfrozen ore. However, as new pits are opened along the wind-swept ridges toward the north, the proportion of frozen ore increases. It has therefore become important to know the three dimensional distribution of permafrost in a pit during the planning stage. Om Garg, of Iron Ore Company of Canada, has written several papers describing the research done at Knob Lake to predict permafrost distribution. Predictions are made on the basis of measurements of ground temperature, topography, drainage, vegetation, snow depth and geophysical properties. There is a signifi-

FIGURE F-3
HEATED SHOVEL BUCKET

FIGURE F-4
HEATED SHOVEL BUCKET

cant increase in seismic velocity and electrical resistivity in frozen ground which can be used to delineate permafrost boundaries.

The knowledge of permafrost distribution is used to predict drilling and explosive costs, to avoid setting a dewatering well in permafrost, and in design of the pit slopes. The geophysical data also show depths to bedrock which are necessary for foundation design and estimates of amount of overburden that must be removed.

Town of Schefferville

Located at the latitude 54°49' north and longitude 66°50' west, Schefferville is in the subarctic area of northern Quebec. The town was built solely for the iron ore development in the Knob Lake area. The population is about 4,500 including some 600 Montagnais (French speaking) and Naskap (English speaking) Indians. The homes are company owned, and are rented to employees for from $65 to $100 per month.

The affairs of the town are directed by an elected mayor and four aldermen who are responsible to the Quebec government under the Towns Act. Although the company attempts to stay out of town affairs, they did support the town when they overspent for the Arctic Winter Games held at Schefferville, in 1976.

Schefferville has three churches, three schools, two banks, a theatre, two hotels, restaurants, hardware store, service station, department stores and grocery store. There are also two commercial buildings housing numerous small shops. The town also has a police and fire station, post office, and town hall. The thirty-nine bed hospital is staffed with two doctors. Two commercial airlines serve Schefferville on a daily basis. The town operates a sports and cultural center which provides hockey, skating, broombakk, bowling, swimming pool, curling, library and workshops for paining, sculpture, acting, photography and handicrafts. Outdoor activities include baseball, soccer, tennis, down hill and cross country skiing. The Canadian Broadcasting Corporation provides radio and television in both French and English. Since there is no road connection to Schefferville, residents ship their automobiles via railroad to Sept-Iles for use on vacations. The schools provide classes in French and English through grade eleven. Students must attend boarding school to finish their high school education.

In 1972 the Canadian Government built a 106 unit settlement adjacent to the company town to house the local Indian population. The Indians formerly lived in an inadequate village a few miles from town.

Schefferville has become the service center of many groups engaged in mineral exploration in northern Quebec and Labrador. McGill University operates a subarctic research laboratory at Schefferville to study permafrost and to conduct anthropological studies.

Power for Schefferville comes from a company owned hydroelectric plant at Menihek, 30 miles south of Schefferville. Each sluice gate is protected from freezing by electric heaters of 144 watts total capacity. The transmission line spacing was increased from 17 inches to 12 inches and then to 31 inches and in some cases 51 inches because of the high winds. There are three 1,000 kw standby diesel generators located at Menihek. These units are kept ready for quick starts with coolant and lubricant heaters.

Personnel and Labor Relations

Recruiting and training an adequate work force is a most difficult problem. Vincent, in studying the work force in 1969 states that virtually all workers came from small villages along the Saint Lawrence or from the Maritime Provinces. Only at the management level can individuals be found who came from cities. Although the wages are high for eastern Canada ($5 to $8 per hour) the turnover rate has risen to 30 percent (as opposed to 15 percent in 1967) as the skilled workers find better paying jobs at the tar sands project in Alberta or the hydro-electric project near James Bay. Both of these projects are government financed and pay higher wages.

To insure an adequate supply of skilled workers, there are training and apprenticeship programs for the young unskilled workers. Often, however, these skilled employees move south when trained. There are some Portugese workers who work for twenty years and then retire to Portugal. Because of government support and the cultural differences, very few Indians work at the mine, although those who do are good workers.

In 1978 the average work force was 1115. The men work fourteen days and then have two days off. The mine operates three shifts, seven days per week. Premium pay is time and one half for the first four hours over forty and double time over forty-four.

Most winter work is performed in heated buildings or from heated cabs. One big exception is major repairs on drills and shovels which cannot be brought inside. Temporary enclosures of flameproof canvas are erected and heated. These serve to protect against wind and low temperatures, but are, at most, marginally effective because of the size of equipment to be repaired. Mechanics have been supplied with mobile repair trucks that are fitted with heated lunch rooms.

<u>References Cited</u>:

Champagne, 1977

Garg, 1977

Mamen, 1962

Morrison, 1977

Vincent, 1977

APPENDIX G

PINE POINT MINES

Introduction

Pine Point Mines is a recently developed lead-zinc open pit mine in the subarctic. Figure G-1 shows the location on the south shore of the Great Slave Lake between the towns of Hay River and Fort Resolution in the Mackenzie District of the Northwest Territories, Canada. The topography is gently rolling with scrub jack pine, black spruce and willow with large areas of open swamp. Situated 60°52' North, Pine Point experiences subarctic conditions with an average temperature for January and February of minus 25°F. The area is in the discontinuous permafrost zone with minimum winter temperatures near minus 50°F.

Operation

Two of the first three ore bodies uncovered during development contained very high grade ore in the centers. In November and December of 1964, 14,080 tons of high grade ore were shipped to Comonco smelters at Trail and Kimberly. The ore graded 18.6 percent lead and 25.8 percent zinc, netting Pine Point $1 million. High grade ore, grading 22.5 percent lead and 29.1 percent zinc and amounting to 364,000 tons, was shipped in 1965. In 1965, shipments of concentrate and high grade ore netted Pine Point $22 million, enabling the investment in the mine and mill to be paid off during the tune up period. The 1966 earnings were $34.2 million, and on March 1, 1965, the mine qualified for the three year tax exemption on all income. Further, the property acquired from Pyramid qualified as a separate mine and was granted a three year exemption on the condition that the mine was suitably expanded or a new mill constructed. The expansion came on line in 1969, bringing capacity to 8,000 tons per day and by 1972, capacity was up to 11,000 t.p.d.

The production schedule is four million tons of ore each year, with a stripping ratio of two to one. The stripping consists of five million tons of waste rock and three million tons of overburden. Before mining begins, wells are drilled around the perimeter of each ore body. These wells are 250 to 350 feet deep with 60 to 100 horsepower pumps producing 200 to 1000 gallons per minute. The low cost hydropower allows this extensive dewatering system to be economically feasible. The ore is soft and friable, so drilling and blasting present few problems. Mining is done in 35 foot benches using shovels, loaders and trucks.

The ore is dumped directly into a 42 inch by 65 inch gyratory primary crusher, where it is crushed to minus 5.5 inches. The ore is then screened to plus and minus 3.4 inch with the oversize going to two secondary crushers. Mr. R.J. Johnson presents a detailed description of the frozen ore thawing process which is briefly outlined below. From mid-December until the end of March one-half of the ore (475 tons per hour) passes through a thawer and the other half bypasses it. The thawer is a cylinder 10 feet in diameter and 60 feet long. It rotates at 3.85 rpm and has a maximum capacity of 650 tons per hour. The thawer burns butane at 100 to 120 U.S. gallons per hour equivalent to 10 million BTU/hr which is one-fourth its maximum heating capacity. The unit is fitted with four scrubbers to remove the dust from the exhaust. This system has worked with no problems, and there is no curtailment of production during winter months. Once thawed, ore is mixed and stored in the fine ore bins. The ore is then concentrated by conventional methods, yielding a lead concentrate that is 80 percent lead and a zinc concentrate that is 60 percent zinc.

Cold Weather Precautions

J.W.B. Scarborough describes the steps taken at Pine Point to deal with the weather conditions to insure year round, uninterrupted operation. When new equipment is ordered it is fitted with cold weather options and all mobile equipment is stored in heated buildings.

The power shovels have booms and dipper sticks made of T-1 steel, insuring good impact strength to -40°. Wooden bumpers have been replaced with rubber to reduce impact. The cabs are well insulated and fitted with good heaters. All metal lubrication tubes and air lines are

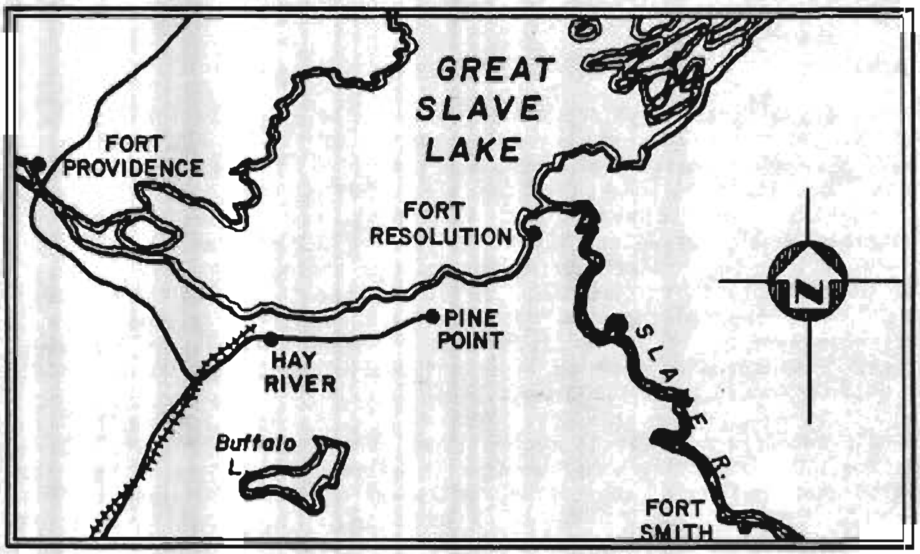

FIGURE G-1

LOCATION MAP, PINE POINT AREA

Source- Homulos (1966)

replaced with large diameter, metal-braided, Aeroquip high-pressure hose. During the winter months, the five cubic yard buckets are exchanged for four cubic yard buckets. Several track frame castings were broken as a result of the extreme cold and difficult digging conditions. To avoid such costly breakdowns during cold weather, areas of difficult digging are leveled by dozer prior to moving the shovel to the face. In the fall, all critical shafts, booms and sticks are "magna-fluxed" to detect cracks so that repairs can be made before cold weather arrives.

The twelve Euclid quarry trucks are equipped with quarry-type exhaust heated T-1 steel boxes. The cabs are fitted with extra insulation and extra heaters. The motor is kept at the proper operating temperature by a thermostatically controlled fan and radiator shutter and by engine hood side guards. The crawler tractors are equipped with reversible radiator fans to help keep operators warm. Tractors that are not in use are stored in a heated building and those used outside are kept running 24 hours per day. The only winter maintenance problem on the tractors is the hydraulic fluid seals which leak in cold weather. The rotary drill has a heated cab, and the drill machinery is enclosed to protect the air and hydraulic systems from the cold.

Special precautions are taken to insure that the equipment is properly lubricated in the critical cold months. Imperial Oil Van Eaten is used for the sticks, slides and hook rollers on the shovels. During periods of extreme cold, heated Essolube HDX30 is brushed on to the exposed rotating gears and hook rollers several times each shift. Bushings are lubricated with Esso Lotemp Molly grease. The hydraulic systems on most equipment use Esso automatic Transmission Fluid Type A. If the hydraulic system does not build up heat during operation, such as on the "air-trac" drills, the fluid is diluted with P-40 diesel fuel. Trucks use ATF type A in the transmission as well as in the hydraulic system and G.P. 80 gear lube is used in the gear boxes. The tractors use D-3-30 oil in the motors, hydraulics, transmission and final drives.

The Pine Point formula for successful winter operation is to order cold weather options, use T-1 steel, reduce loads, (including those on quarry trucks), utilize heated storage, insure the proper lubrication and thaw the frozen ore.

Conclusion

It required government subsidies for power and transportation to change this property from a prospect to an operating mine. This operation has made a significant contribution to the development of northern Canada and to the strength of the Canadian economy. There is a strong possibility that the increased production will nearly pay for the railroad extension to the Great Slave Lake through greater than anticipated freight volume. The history of this property illustrates the role that mineral development can play in the north.

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Scarborough, 1966

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APPENDIX H

UNITED KENO HILL MINES LIMITED

The United Keno Hill Mines are located in central Yukon Territory, Canada, near the towns of Elsa and Keno. Elsa is 285 miles north of Whitehorse and 200 miles south of the Arctic circle. The climate is subarctic. Temperature extremes of minus 62°C (-80°F) to plus 35°C (95°F) have been recorded at the town of Mayo, which lies twenty-eight miles to the south (see Figure H-1). Temperature extremes at Elsa vary from minus 51°C (-60°F) to 27°C (80°F). The mean annual temperature is minus 1°C (30°F). Much of the area is underlain by permafrost, often several hundred feet thick. A few places on south facing slopes are free of permafrost.

Silver, lead, zinc and cadmium are mined from several small deposits by underground methods. The ore is concentrated at Elsa and trucked to Whitehorse where it is loaded on railroad cars for shipment to Skagway, Alaska, then by ship to Vancouver, British Columbia, where it is transpoted by rail to various smelters depending on which metal is in the shipment.

History

The first silver ore was discovered in the area in 1906 by gold prospectors leaving the declining Dawson area.

The Ferriman North and Fleming Number Three mines were mined out in the winter of 1914-1915, and interest in the area ran high. In 1919 more discoveries were made and activity increased as the Treadwell Yukon Company and Keno Hill Mining Company worked in the area. All production stopped in 1942 when reserves were exhausted. In 1945 Keno Hill Mining Company purchased the Treadwell holdings and later reorganized as United Keno Hill Mines Limited. Production has continued since then.

Exploration is a major part of the operation, as the ore lies in small pockets and veins. Reserves are rarely sufficient for more than one year. The high price and expanding demand for silver insures continued exploration and mining in this area.

Keno Hill Mines

All ore comes from underground mines located on Galena Hill and Keno Hill. Presently, production is from the Husky, No Cash, Elsa, Dixie, and Keno Mines. The mining methods used vary with ground conditions but are mainly cut and fill at the Husky and square set stopping at the other locations. Experiments are underway to determine the feasibility of mining near-surface ore by pit methods. The test site is near the Keno Mine and appears to be successful. However, this surface ore is oxidized and therefore difficult to concentrate.

All mining takes place in frozen ground, requiring special techniques. Drilling is not interrupted until the hole is complete, otherwise the rod will freeze in place. Holes are loaded soon after they are drilled or ice would fill the hole. Salt is added to the drill water and air lines are heated with heat tape. The frozen rock requires more explosives and closer hole spacing to insure proper breakage. Shots are kept small to insure that they can be loaded before freezing.

Openings in the frozen rocks quickly fill with water which freezes, closing the opening. Areas that are not being worked soon become impassable. In the areas being actively mined, salt is used on the tracks and care is taken to have pumps remove water before it can freeze. Much of this water comes from the rocks but some condenses out of the air. Warm ventilation air quickly cools to its dew point and ice crystals form on the walls and timbers (see Figure H-2). This frost builds up until it interferes with rail car passage. As new areas are mined, the geologist must keep the mine map up to date before the frost covers the rock.

The frozen rocks contain veins of ice several inches thick (see Figure H-3). The ice in this photo was found in the Keno mine among rock layers in a recently worked area more than 100 feet below the ground surface.

FIGURE H-1
SIGN OUTSIDE MAYO

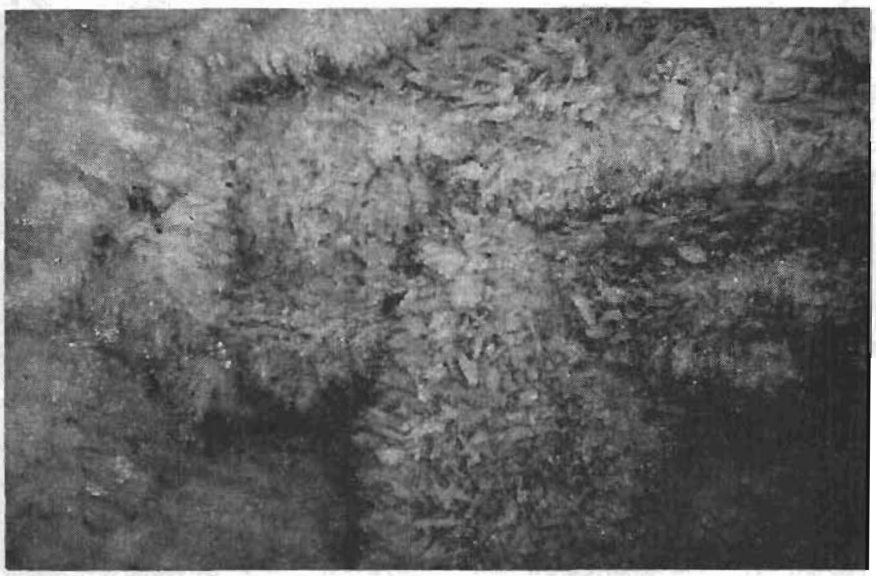

FIGURE H-2
ICE CRYSTAL BUILDUP ON MINE TIMBERS

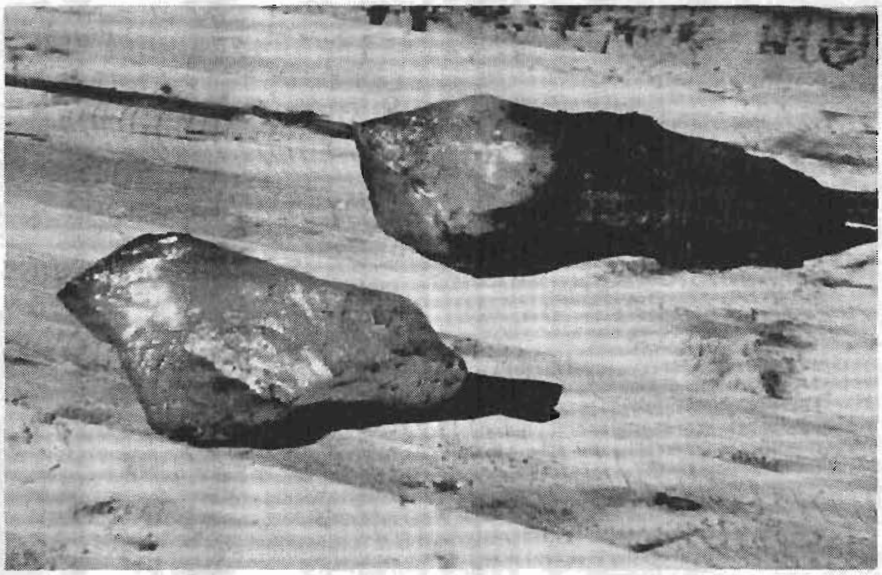

FIGURE H-3
ICE LENSES FOUND IN BEDROCK
(PHOTOGRAPHED OUTSIDE OF PORTAL)

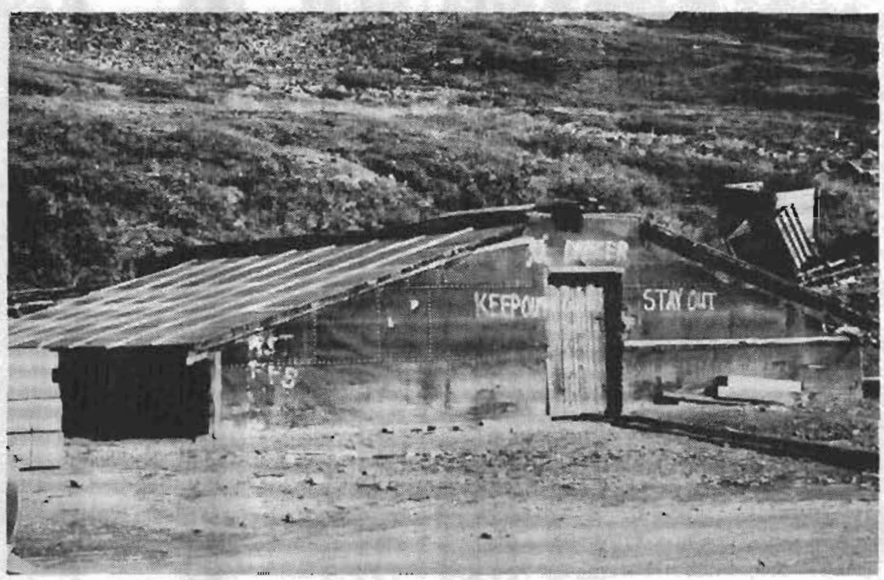

FIGURE H-4
SNOW SHED OVER KENO MINE PORTAL

Despite the high wages, liberal benefits and [illegible] remains quite high, nearly fourteen percent per month. Wages effective September 1977 range from over $6.50 per hour to over $10.00 per hour. Benefits include a yearly air fare to Edmonton or Vancouver for both employees and spouses, liberal leave privileges and vacation benefits, eleven paid holidays, good insurance and pension plans.

<u>References Cited</u>:

Dundas, 1977	"Collective Labor Agreement...", 1976
Godfrey, 1977	"Current Operations At United Keno Hill", 1961
Holzupfel, 1977	"United Keno Hill Mines Limited...", 1976

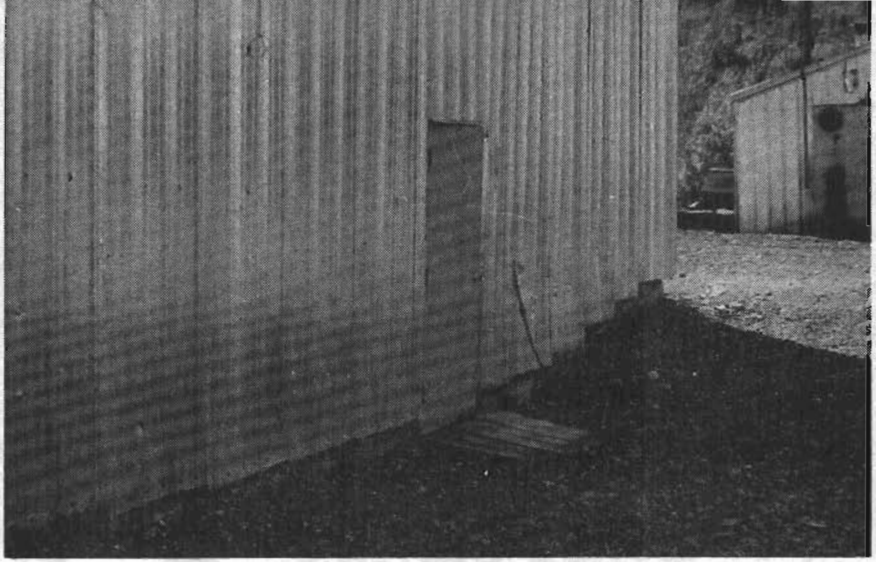

FIGURE H-6
FLOOR SETTLEMENT AS PERMAFROST MELTS

APPENDIX I

USIBELLI COAL MINE INC.

Many aspects of Alaska's only year round mine were covered in the Mineral Industry Research Laboratory Report to the United States Department of the Interior Bureau of Mines by Lynch, Johansen, Lambert and Wolff on June 30, 1976. Although Alaska has a tremendous potential for mineral and fuel development, problems with land ownership, land freezes, governmental discouragement, taxation, transportation and labor costs have prevented new mines from opening. Except for a few seasonal gold mines, the Usibelli Coal Mine is the only full scale year round mining venture in Alaska now.

The Usibelli location, just seven miles from the Alaska Railroad and 120 miles from Fairbanks, has contributed to its success. The mine is located in the Healy Creek Valley near the community of Healy. Rail, auto and air transportation are available, insuring adequate connection with Fairbanks and Anchorage.

Healy, at 63°52'N latitude, is in the subarctic. Temperatures range down to minus 54°C (-65°F). The cold is compounded by high winds to 80 kilometers (50 miles) per hour.

Coal from the Usibelli Mine provides the base load power for most of central Alaska. The coal is burned for heat and electricty by the University of Alaska, community of Fairbanks, Fort Wainwright, Eileson Air Force Base and Clear Air Force Base. Some coal is burned at a power plant near the mine owned by Golden Valley Electric Association, and electricity is transmitted to Fairbanks over a 138 kv line.

Geology

The coal beds dip from 45° north in the Healy Creek area to flat lying between Healy and Lignite Creeks, just to the north. In the Healy Creek area, Number One bed ranges from 12 to 31 meters (40 to 100 feet) in thickness; Number Two bed 3 to 9 meters (10 to 30 feet); and Number Three bed 2.4 to 5 meters (8 to 16 feet). In the Lignite Creek area Number One seam is 15 to 25 feet in thickness, Number Two seam, 6 to 10 feet, Number Three seam, 12 to 25 feet, Number Four seam, 20 to 31 feet, Number Five seam, 0 to 9 feet and Number six seam, 20 to 29 feet. The coal beds lie in the Tertiary Coal Bering Group which consists of poorly consolidated sandstones, conglomerates, siltstones and clays. This group is overlain by poorly consolidated gravels which are unconformably overlain by glaciofluvial gravels. The thirteen recognized coal seams of the Nenana Coal Field are estimated to contain approximately seven billion tons, down to a depth of 3000 feet.

The coal is ranked subbituminous "C" with a heating value of 7500 to 9000 BTU per pound. It has approximately 20 to 25 percent moisture and 8 to 15 percent ash. Like most Alaskan coal, the coal mined at Healy is very low in sulfur (about 0.1% to 0.3%) and thus is environmentally acceptable. Stripping of the gravel layers is hampered by permafrost. The coal, however, is mostly unfrozen or ice free, and does not present special mining problems.

Mining

Coal mining in this area has been continuous since 1918, by both underground and open pit methods. Since 1960, all production has come from surface mines. Consumer demand for coal is greatest in the winter months at 90,000 tons per month, dropping to 40,000 tons in midsummer.

Early stripping was done by hydraulicking. Later the overburden was removed by a variety of methods. Most commonly it was ripped or bulldozed to a pile, then loaded onto trucks with front end loaders. After the coal was uncovered, it was loaded into trucks by front end loaders. The International Payhauler trucks have interchangeable boxes, one for hauling coal and one for hauling waste. The coal and waste trucks are loaded by ten cubic yard Payloaders. Eight trucks are assigned to winter coal production and two to waste haulage. Coal is hauled to the Healy Mine Mouth power plant or to the rail tipple. No coal washing is being done now, and none is planned for the future.

Mined out areas are filled with waste from new pits, contoured and seeded. Seeding and fertilizing is done from an airplane and has proven quite successful. A herd of Dall sheep come to these reclaimed sites to feed and are often seen grazing adjacent to areas where noisy equipment is working. Moose are also common in the area.

During cold weather all equipment is housed in heated buildings when not operating. 40,000 square feet of heated storage is available for this purpose. Equipment is serviced twice daily from a mobile service truck. This truck is specially designed and built for the mine. It has a heated box section that houses all grease, oil, pumps and hoses (see Figure I-1).

The cold weather actually has some advantages; roads are smooth and hard, reducing truck rolling resistance, and are easily maintained. In the spring and during the rainy periods the roads become soft and material may slide down from cut banks, partially blocking passage. For these reasons the mine uses International Payhauler fifty ton trucks because of their four wheel drive feature.

On the other hand, the cold reduces worker efficiency and the useful life of equipment. Construction of large mining machines, such as Usibelli's 33 yard walking dragline, may require special measures because of the cold winter weather. Construction of Usibelli's dragline was started in a heated building that was split at the center and could be opened for installation of large components and then closed and reheated during cold weather. This allowed critical welds to be made under proper conditions and kept worker efficiency at an acceptable level.

The town of Usibelli is also the location of the company offices, shops, heated storage buildings and some company housing. In 1977 Usibelli coal mine leased a section of land from the Alaska Railroad which was subdivided and improved with roads, telephone and electrical lines. Usibelli has subleased the property to both mine employees and other local people who have constructed permanent dwellings. This subdivision is known as Tri-Valley Subdivision and now forms the nucleus of the residential development in the Healy area. Numerous state land disposals in the area recently, along with the development of Tri-Valley subdivision, ensures the future availability of suitable residential land.

Personnel

The Usibelli Coal Mine has a very low turnover rate when compared to other cold region operations. The rate increased during the Alyeska pipeline construction period but has stabilized since. Wages at this Alaskan mine average twenty-five percent above western mines and forty percent above eastern mines. Most employees work fifty hours per week, which contributes to high yearly wages.

Workers are able to associate with employees from the railroad maintenance crews, highway maintenance crews, and power plant workers in Healy. This gives a needed variety that may not be found at other northern mining towns, and contributes to the low employee turnover rate.

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Conwell, 1976

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Usibelli, 1977

Correspondence with Chief Manager, Steve Denton, August 1982.

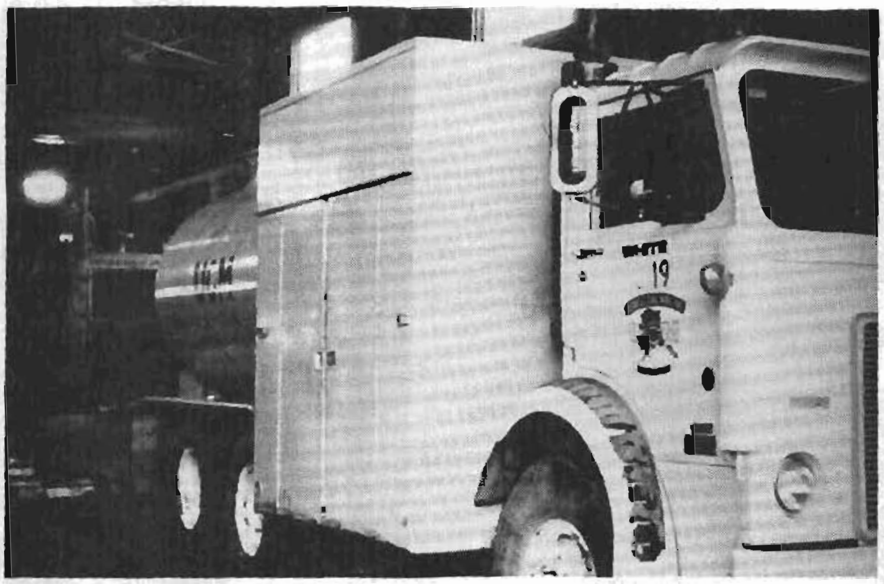

FIGURE I-1
SERVICE TRUCK WITH HEATED SERVICE COMPARTMENT

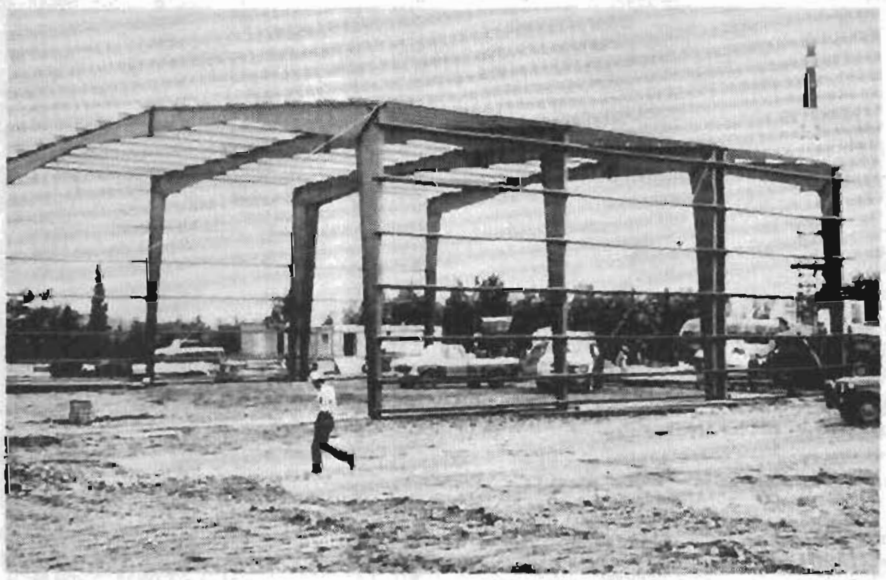

FIGURE I-2
ERECTION OF HEATED BUILDING FOR
WINTER DRAGLINE CONSTRUCTION

APPENDIX J

WHITEHORSE COPPER MINES LIMITED

Introduction

Seven miles from Whitehorse in the Yukon River Valley, Whitehorse Copper Mines Ltd. produces copper, gold and silver from an underground mine. Whitehorse, Yukon Territory is in the subarctic with a mean annual temperature of minus 1°C (30.5°F). Usual high temperatures in the summer are 18°C to 21°C (65°F to 70°F) with extremes of 27°C (80°F). Winter temperatures range to minus 40°C (-40°F) with a record low of minus 52°C (-61°F). The average total precipitation is 42 centimeters (16.5 inches) per year including approximately 127 centimeters (50 inches) snow. Although located in the discontinuous permafrost zone, the mine is not affected by frozen ground.

The Mine

The method of underground mining is sublevel blasthole stopping. The primary crusher is located underground. The ore is trammed to the ore chutes by nine cubic yard, low profile, load haul dump units which enter the mine via a decline. The crushed ore and waste are hoisted to the surface in a fourteen foot diameter circular shaft.

The ventilation air is heated in the winter months to insure comfortable working conditions. The large air volume (123,000 cubic feet per minute) required by the use of diesel equipment dictates heaters of 12 million BTU per hour capacity. The air is heated by propane, then circulated down the shaft through the mine and exhausted up the decline. The oil fired furnaces formerly used were replaced by propane burners when rising oil prices made it cheaper to truck propane from Alberta. As a bonus, savings are made on maintenance costs. The cost of maintaining the oil burners was high; the propane burners are cheaper to maintain. The propane must be pumped from the storage tanks when temperatures fall below minus 26°C (-15°F). Figure J-1 shows the propane tanks, burner and duct to the head frame.

Concentrator

The crusher building and mill were not heated during the period of open pit ore production. This situation created maintenance, dust control and operating problems. In a cold environment, maintenance people do not work as carefully or as rapidly as in a warm environment. With a cold mill, water spray cannot be used for dust control, and crushing frozen ore often creates more dust than crushing unfrozen ore. Problem spots that require heat, such as a grease pump, were heated by infrared heaters. These heaters proved to be a hazard to mill operations and to maintenance personnel.

At the same time that the mill was restarted in 1972, using warm underground ore, insulation and heaters were installed in the crusher building, mill and conveyor galleries. Sixty thousand cubic feet of air per minute is heated by a 7 million BTU capacity propane furnace, and circulated through the mill, crushing plant, coarse ore stockpile and fine ore bin. The conveyor galleries are enclosed and utilized for warm air distribution. The temperature is kept above 5°C (41°F) at all times, providing comfort for operators and maintenance personnel, and allowing for successful dust supression with water spray.

The milling circuit includes a 5000 ton live capacity coarse ore stockpile (see Figure J-2). This stockpile is protected from freezing by an insulated and heated "tent" which was constructed from material on hand by plant maintenance personnel. It consists of a rigid center pole with cables strung to anchors located at the perimeter of the stockpile. The cables support corrugated metal roofing and three inches of fiberglass insulation. Heat is supplied to the enclosure through the ore reclaiming conveyor tunnel. This saves having to deal with frozen ore in the storage pile.

Minus 0.95 centimeter (3/8 inch) ore is stored in a cylindrical, 5000 ton live capacity, fine ore bin. In the past, ore would freeze in the bin during the cold months. Retrieval

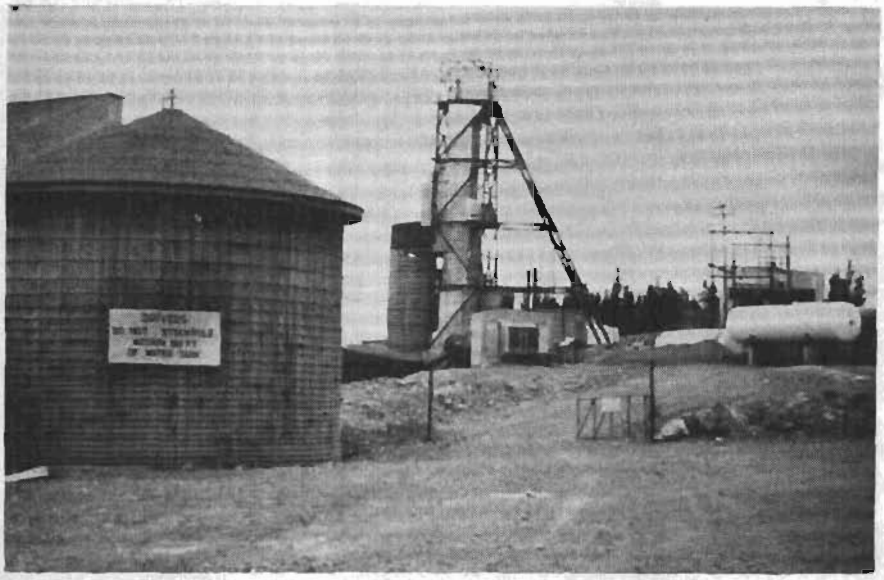

FIGURE J-1
MILL WATER STORAGE TANK (LEFT), HEADFRAME AND VENTILATION AIR HEATER (CENTER) AND PROPANE STORAGE TANK (RIGHT)

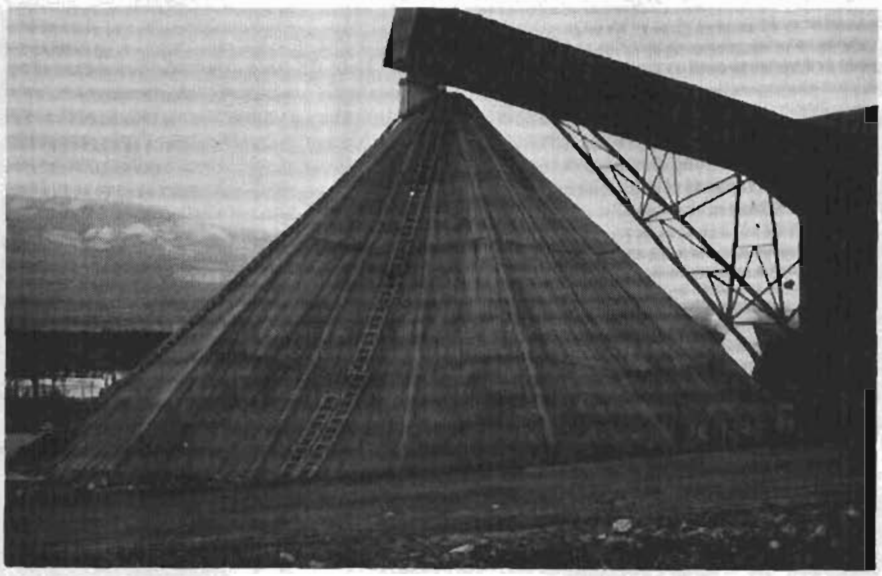

FIGURE J-2
COVERED COARSE ORE STOCKPILE

required a crew of up to twelve laborers working from beneath the bin. Since the bins have been insulated and heated, reclaiming is an automatic operation (see Figure J-3). This was accomplished by installing 7.6 centimeters of fiberglass insulation on the outside of the bin and covering that with corrugated metal siding. A 7.6 centimeter (3 inch) air space was left between the insulation and the original outside wall, (now inside the insulation). Warm air is spiraled around the bin in this air space to maintain the temperature above freezing.

One hundred to one hundred twenty tons of concentrate grading from 35 to 45 percent copper are recovered from a mill feed of 2,400 tons per day. The concentrate is shipped in 25 ton containers on the White Pass and Yukon Railroad to Skagway, Alaska and then by freighter to Vancouver, B.C., where it is transferred to gondola cars for rail shipment to Flin Flon, Manitoba.

Smelter credits are received for the precious metal recovered in the concentrate. The average concentrate grade is 0.8 ounce gold and 7.0 ounce silver. Coarse gold is also recovered from the grinding circuit, mill liners and dump boxes; nuggets are hand-picked. Fine gold concentrate is sold to an independent precious metals refinery. Approximately 1300 ounces of coarse gold were recovered by this method in the first six months of 1977.

Mill Tailings

The large but shallow tailings pond proved to be inefficient because of ice buildup at the discharge line. In 1975, the maintenance department began construction of an earth filled dam in a steep sided valley downstream from the original pond. By keeping the pond depth in the 9 to 12 meters (30 to 40 feet) range the icing problem has been eliminated. During the winter months tailings are discharged below the ice level, insuring that the solids will settle out and not be frozen in a block of ice.

Eighty percent of the tailings water is reclaimed from a pond below the dam. Water from the Yukon River and the mine drainage system supplies the remaining 20 percent. The pumphose is floated in the reclaim pond on styrofoam blocks (see Figure J-4). Water is circulated to underwater heaters to keep the area around the pumphouse ice free.

Water pumped at Whitehorse Copper is carried to steel pipes laid on the ground surface, insulated with foil-backed fiberglass insulation and covered with fabrene for weather protection. Surface lines are used for ease of thawing and repair. Approximately 1,200,000 gallons per day are pumped to an unheated uninsulated wood stove tank (see Figure J-1) for mill use.

Warehousing and Supply

The remote location of this mine, together with the lack of services available in Whitehorse, necessitates a large warehouse inventory. The value of goods stored at the mine was $1,087,000 on June 1, 1978. Transportation costs to Whitehorse are presented in Table J-1.

TABLE J-1

Ship From	Cost	Shipping Time
Edmonton (truck)	$17/cwt (hundred weight)	3 days
Vancouver (truck)	$18/cwt	3 days
Vancouver (ship & rail)	$ 6/cwt	7 days
Air Express	$33/cwt	4 days

Warehouse inventory is being computerized to better control the large inventory.

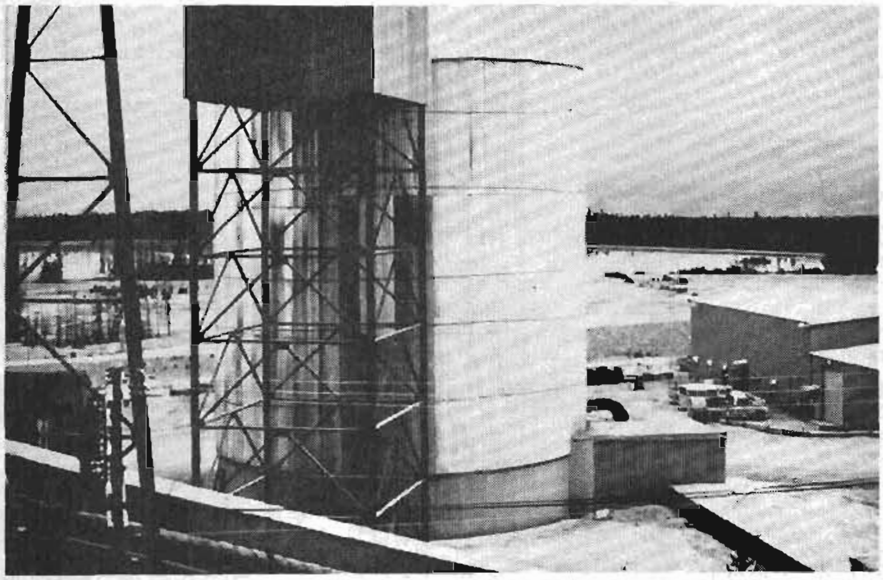

FIGURE J-3
HEATED AND INSULATED FINE ORE BIN

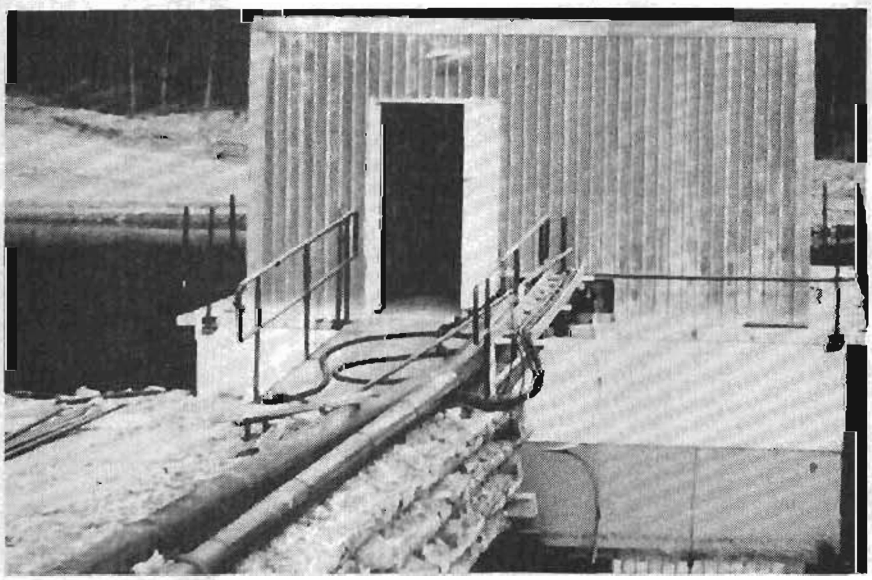

FIGURE J-4
RECLAIM POND FLOATING PUMP HOUSE

Power

Electrical power is generated locally at the Whitehorse Rapids hydroelectric plant on the Yukon River by the Northern Canada Power Commission. Average monthly consumption in 1975 was 2,584,000 kwh. The requirements for crushing, milling and recycling of water average 24.7 kwh per ton of ore. The power cost in 1977 was approximately three cents per kilowatt hour.

Maintenance

Maintenance can be provided by bringing skilled people from outside an organization on an as needed basis or by keeping men with the required skills on the payroll. Whitehorse Copper management believes the latter method is most effective. An employee centered approach is taken in developing the required in-house skills through apprenticeship training programs. They also give liberal incentives for cost saving ideas. This attitude has paid off as the maintenance department can do nearly every repair required from building hydraulic cylinders to rebuilding diesel motors. The department also performs construction work such as installing a new underground crusher, building a cover for the coarse ore stockpile and moving 120,000 cubic yards of material each year for tailings dam construction. Underground loading units could be traded for new models, but for about the same price the loader can be rebuilt by company personnel.

Personnel

The Whitehorse Copper mine is fortunate to be located on the Alaska Highway and only eleven kilometers (7 miles) from Whitehorse, the largest city in the Yukon Territory. Although not many skilled workers are available in Whitehorse (pop. 12,000) there are young men available to start as laborers and gain the required skills. Laborers earn $6.50 per hour but can advance rapidly as skills are learned and earn more. For example, the flotation operators earn $9.10 per hour. This emphasis on training plus the proximity to a relatively large city has resulted in a turnover rate of 10 to 20 percent for skilled classes, which is low for a northern operation.

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APPENDIX K

OTHER CANADIAN MINES

Introduction

In this section several other mining properties located in the cold regions of North America are briefly described. These properties were chosen for inclusion because each has some unique or significant characteristic. Other northern mines were omitted from this discussion because not enough information is available for them.

Arvik Mine

The farthest north mine in North America is the Polaris Mine owned by Arvik Mines and managed by Cominco. This rich lead zinc mine is located on Little Cornwallis Island sixty miles north of Resolute, Northwest Territories (see Figure K-1). The climate is arctic with a mean annual temperature of 2.8°F. Twenty million tons of 20 percent combined lead zinc ore has been identified.

The shipping season at Arvik is limited to six weeks, but even so the ships have strengthened hulls for ice loads and, at times, rely on ice breaker support. All buildings were prefabricated. A desalinization unit provides fresh water. Drilling is with salt water at a concentration of one pound of calcium chloride per gallon of sea water.

In 1973, a dock was built from ice for use in shipping a large bulk sample obtained during development work. The dock was constructed by building layers of waste rock and fresh water ice. The fresh water ice does not melt in the cold salt water of the Arctic Ocean. The waste rock prevents the dock from floating.

During development of the underground mine, a record was set by J.S. Redpath, Ltd. for decline driving. In one month, the 24 man crew advanced 1302 equivalent feet and in 85 days, 3387 feet. Two low profile two cubic yard loaders and one low profile 13 ton dump truck were used in driving the nine by fifteen foot opening.

Cassiar Asbestos

The Cassiar Asbestos mine is located near the summit of McDame Mountain in northern British Columbia. The mine is owned and operated by Cassiar Asbestos Corporation Ltd. It is located 100 miles southwest of Watson Lake, Yukon Territory (see Figure K-1). The remote mountain location and the fact that the town is shaded by the mountains gives Cassiar many characteristics of a subarctic location. Ore is brought from the mountain mine to the mill on an aerial tramway 2.9 miles long with a 2500 foot drop in elevation.

Like many other remote mine locations, Cassiar experiences a high labor turnover which at times approaches 200 percent per year. To help cope with this problem the company has an extensive training program to adapt the newcomers.

Exploration in the Coppermine River Area

Coppermine is a small town on the Arctic coast of the Northwest Territories (see Figure K-1). Many companies are active in mineral exploration in this area, but the only surface access is a winter road from Hay River, which crosses many lakes. Deposits of copper ore have been found which may develop into mineable ore.

Several exploration techniques and ideas adaptable to permafrost areas have been developed or verified in the Coppermine River area. The use of induced polarization methods has proven effective as they did at Pine Point (see Appendix G). Permafrost may indeed limit weathering and leaching but geochemical exploration methods are nevertheless useful. Continuous permafrost in the arctic contains thaw bulbs around larger lakes and rivers, allowing cation move-

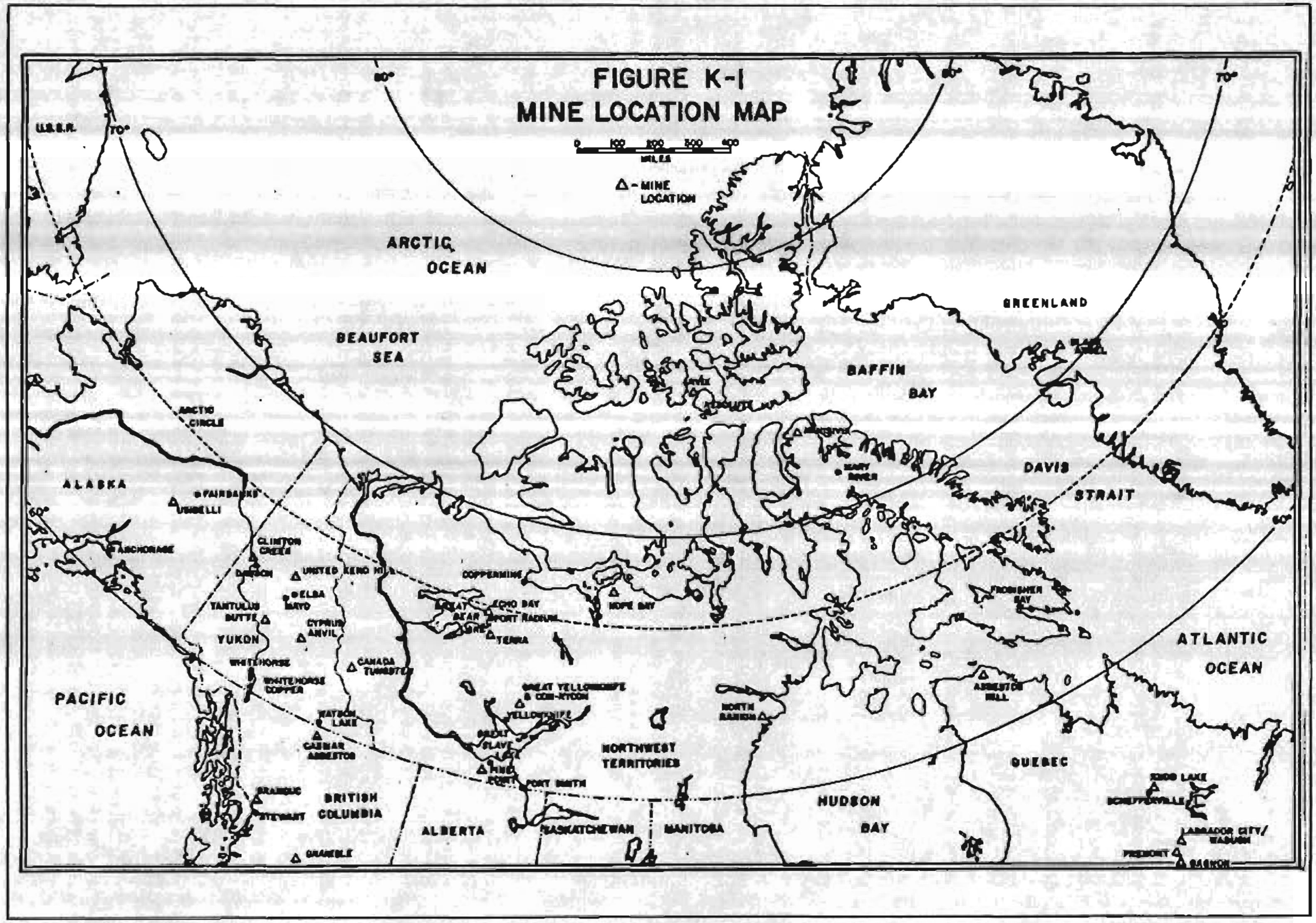

FIGURE K-I
MINE LOCATION MAP

ment. Frost heave, solifluction and frost boils also act as physical dispersion agents. A sample from a frost boil gives a sample from the B soil horizon. Work in the Coppermine River Area indicates that buried deposits in the Arctic may be detectable if they intersect the thaw bulb of a lake or river.

Great Bear Lake Area

Great Bear Lake, Northwest Territories, is the site for two neighboring mines, the Echo Bay and the Eldorado (see Figure K-1). Prior to World War II, radium oxide was mined in this area. Later, the emphasis switched to uranium. Until 1960, the Eldorado Mining and Refining Company mined uranium. When reserves were depleted the mine was closed. In search of silver the Echo Bay mine was opened nearby in 1964, and the Eldorado Mill was reactiviated to concentrate the silver ore. The concentrator recovered 98 percent of the silver from the ore averaging 50 to 100 ounces of silver per ton. The Echo Bay mine was depleted in 1974. Since then the Eldorado mine has reopened as a silver mine.

The shipping season for the Eldorado Mine is by water routes for two and one half months in the summer and two and one half months by truck over a winter road.

Giant Yellow Knife

Gold has been mined near Yellowknife, Northwest Territories, since 1938. Mining is presently being conducted on Great Slave Lake by Cominco at the Con and Rycon Mines and by Giant Yellowknife Gold Mines Ltd. All mining is by underground methods.

At the Giant Yellowknife mine, gold is concentrated in a roasting process that leaves an arsenic trioxide byproduct. The permafrost, which extends to 270 feet, is utilized for the storage of this arsenic trioxide. Large rooms are excavated in permafrost in the greenstone hanging wall. The permafrost prevents ground water movement.

The temperature of the ventilation air is controlled by oil fired heaters. When it is necessary to extend a stope to the overburden level, cold air is circulated to the stope until it is mined out to prevent roof collapse due to thawing of the overburden. Once mined out the stope is sealed.

Granduc

Newmont mining and American Smelting and Refining own the Granduc Operating Company which operates the Graduc Copper Mine, 25 air miles north of Stewart, British Columbia (see Figure K-1). The mine is located high in the Coast Mountains in an area of permafrost, ice fields and heavy snows. The average snow fall at the mill site is 700 inches of wet heavy snow each year. Access to the mine is in two adits; one 7000 feet long and the other 54,500 feet long. In 1969 reserves were estimated at 43 million tons of 1.73 percent copper.

The heavy snowfall creats an avalanche danger that was not recognized until 1965 when an avalanche destroyed the mine camp and took twenty-six lives. The camp was rebuilt but is used only during the months of March 1 to November 15 when the avalanche danger is low.

Granisle Copper

The Gransile Copper Mine is located on McDonald Island in Babine Lake, British Columbia (see Figure K-1). The mine is operated by Granby Mining Company Ltd. Here the tailings disposal problem has been solved by constructing two dikes between two small islands and filling the resulting pond. Eighty percent of the tailings water is reclaimed for reuse in the mill.

Access to the island, 6,500 feet from shore, is by barge. The barge route is kept open in the winter when lake ice grows to 24 inches by suspending 6,500 feet of perforated pipe to near the lake bottom and pumping air through the pipe. The rising column of air bubbles brings warm water from the lake bottom to the surface, creating an ice free channel.

Mary Island, Baffin Island Iron Mines

A large-scale high-grade iron deposit exists 350 miles north of the Arctic Circle on Baffin Island, Northwest Territories (see Figure K-1). Reserves are estimated to be 127 million tons of 68 percent iron. Although the property is awaiting better market conditions, much detailed exploration work has been carried out. During this period the operation has been supported by aircraft landing on a frozen lake adjacent to the camp. The lake airfield is usable until early July each year. Many local Eskimos were hired and trained for the work. The project managers are well pleased with the performance of these workers.

Nanisivik

The Mineral Resources International Ltd. cooperated with the Canadian government to develop this lead zinc deposit located on Baffin Island (see Figure K-1). The shipping season is limited to August and September, requiring extensive storage facilites and rapid ship loading facilities. Reserves are estimated to be 6.69 million tons of 14.7 percent combined lead zinc. The mining is by underground methods.

Because of the many benefits that development of this deposit would bring to the people of Canada, the government agreed to finance some of the infrastructure in exchange for an 18 percent interest in the property. The government participation included financing of the airport, roads, dock and town facilities. As part of the agreement, the company must work toward employment of Inuit natives for 60 percent of the crew.

During development of the deposit before the airfield was constructed, air support included twin otter, DC-3 and 737 aircraft landing on Strathcona Sound. The frozen ore is being drilled dry to eliminate the problems associated with using salt water for the drills. Power plant waste heat is used to dry concentrates and the mill process water is heated.

North Rankin

North Rankin Nickel Mines Ltd. is located 62°49' North latitude, 320 miles north of Churchill, Manitoba, on Hudson Bay near Rankin Inlet (see Figure K-1). The mine was closed in 1963, after ten years of production, when the reserves were depleted. The nickel content of the ore was 3.14 percent, and for copper was 0.92 percent. Drilling in the underground mine was with salt water obtained from a well drilled to below the permafrost level. This salt water was twice as saline as sea water. The drills using this water required frequent lubrication and periodic overhaul. Mined out areas were backfilled with ice which froze solid, allowing mining of the pillars. The ore was milled in a pebble mill, eliminating the need to ship steel balls to the mine.

Local native Eskimos were trained for many of the jobs and supplied with houses superior to the ones they were accustomed to in the village. This served as an incentive to work at the mine but unfortunately, when the mine closed, the trained native workers were unemployed again. Some found work canning fish or making art objects.

The Quebec Labrador Iron Mines

Three companies produce iron ore from the Quebec Labrador border area. Production began in the mid 1960's with the development of Iron Ore Company in Canada's Knob Lake deposit, described in Appendix F. Other mines south of Schefferville (Knob Lake) include Iron Ore Company of Canada's Carol Mine at Labrador City, Wabush Mine's Scully Mine at Wabush City, Quebec Cartier's Lac Jeanine and Fire Lake Mines at Gagnon, and its Mount Wright mine at Fremont (see Figures K-1 and F-1). The iron is shipped by rail from all three to ports on the St. Lawrence Seaway. These mines have no permafrost and experience few cold weather problems. They all order cold weather steel components on equipment, use heated cabs and utilize low viscosity lubricants in the winter months.

The mine at Lac Jeanine is now depleted and shut down, but when it was in operation it was the only mine in the world to utilize a trolly to assist the diesel electric trucks. This enables them to travel the eight percent grade at 14 to 16 m.p.h. as opposed to 4 to 6 m.p.h. unassisted.

The mine at Mount Wright is new, commencing operation in 1975. It utilizes a computer control system for scheduling trucks. Likewise the town of Fermont was designed with the lessons learned at Gagnon in mind. Wives of personnel at Gagnon were consulted and their suggestions were incorporated in the design of Fermont townsite. This area of Quebec has strong winds year round, and the designers of Fermont took this into account. On the up wind side of the town a 2,600 foot long five story building acts as a very effective wind screen.

Tantalus Butte Coal Mine

Cyprus Anvil Mining operated a small coal mine near Carmacks, Yukon Territory. This coal was used to dry the concentrate produced at the Anvil Mine. Coal is back-hauled to Anvil by the concentrate trucks returning from Whitehorse. Mining of the steeply dipping seam is by underground room and pillar methods. Most of the work is done by hand. The mineable underground deposit is now mined out. Coal was hauled to the bunker in wooden cars of one and one half ton capacity. These cars were pulled by a battery powered locomotive. Mine output was seventy tons per day. The mine utilized chiefly local Indian workers who were not required to work every day. They worked when they wished, the chief requirement being that they arrange to have a minimum number show up each day to insure production. The mine superintendent, the mine foremen and a few experienced miners provided continuity and formed the backbone of the work force.

The coal was dry and few problems were encountered handling it during the cold season. The excellent natural ventilation in the mine helped provide a safe working atmosphere.

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