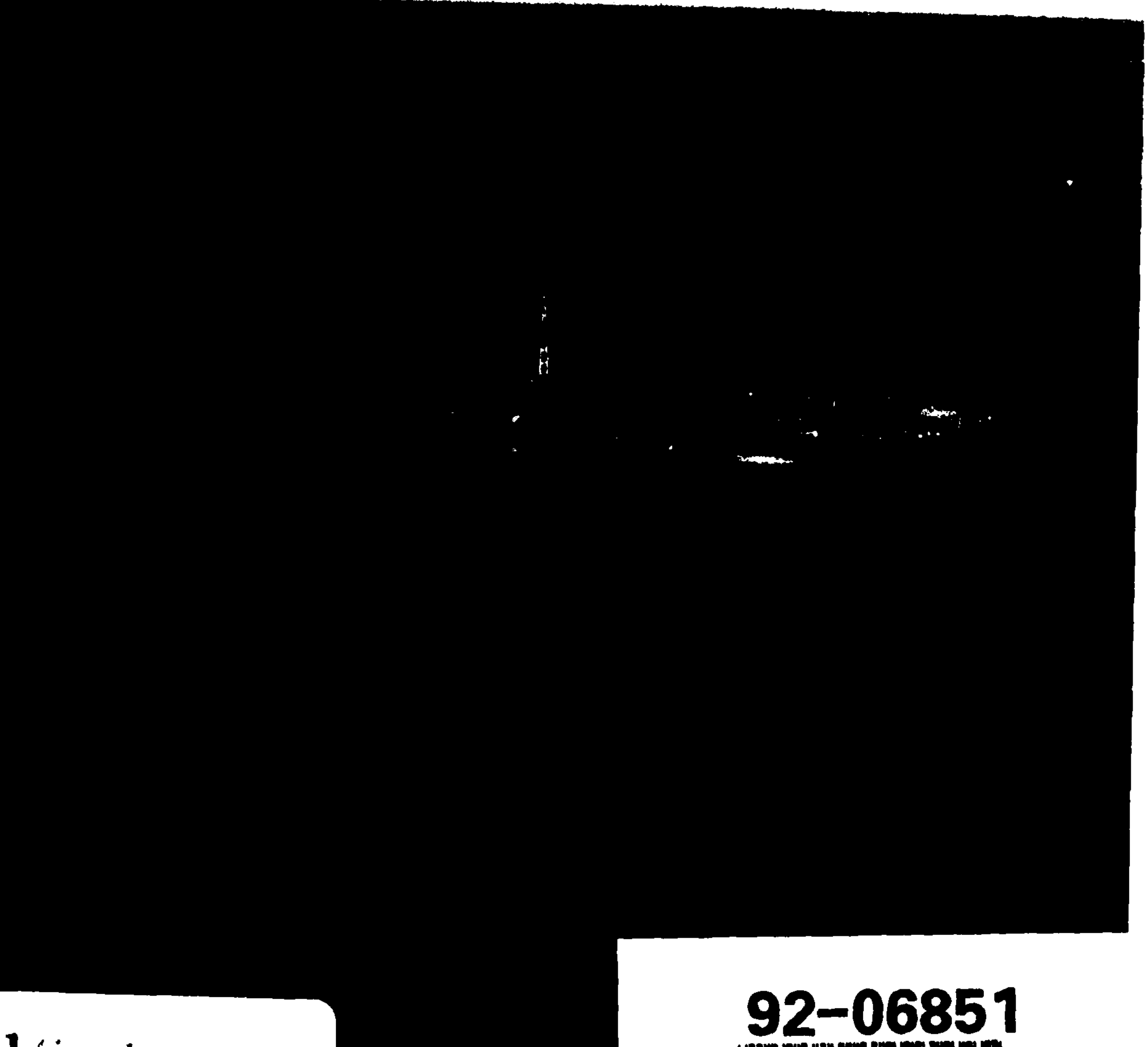
CRREL REPORT 91-21

Construction Guidelines for Oil and Gas Exploration in Northern Alaska

Frederick E. Crory

November 1991



For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

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The opinions, findings, conclusions, or recommendations expressed in this report are those of the author and do not necessarily reflect the views of the Bureau of Land Management, Minerals Management Service, U.S. Geological Survey, or the Corps of Engineers.

Cover: Aerial view of Inigok well site. This exploration well was drilled to a depth of 20,102 ft. (Photo by F. Crory.)

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Construction Guidelines for Oil and Gas Exploration in Northern Alaska

Frederick E. Crory

November 1991

Prepared for
BUREAU OF LAND MANAGEMENT
U.S. DEPARTMENT OF THE INTERIOR

PREFACE

This report was prepared by Frederick E. Crory, Research Civil Engineer, of the Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The report was prepared for the Bureau of Land Management, U.S. Department of the Interior. The project officer was D.S. (Skip) Braden, who conceived the idea for these guidelines and who contributed many helpful suggestions during their initial preparation. His contributions are gratefully acknowledged by the author.

This report presents construction guidelines for activities associated with petroleum exploration in northern Alaska. The guidelines attempt to orient the reader to the unique features of this area and to the design and construction techniques in this relatively new field of arctic engineering. Where appropriate, examples of both old and new ways of constructing and operating on snow, ice and frozen ground are presented. Such comparisons serve to explain why different techniques perform as they do, including their long-term impact on the environment. The text also reflects on how and when different construction activities can be accomplished, rather than resorting to simple, but sterile, specifications having little or no explanation.

The author wishes to acknowledge the contribution of the U.S. Geological Survey, in particular the Office of the National Petroleum Reserve Alaska (ONPRA). The author's participation in the NPRA exploration program, from 1977 to 1982, provided him with a unique opportunity to learn much about the design, construction and operational problems of exploration programs in northern Alaska. He also gives special thanks to Dr. George Gryc, Dr. Max Brewer and the late Dr. Reuben Kachadoorian, who shared their many years of experiences in such northern operations.

Finally the author acknowledges his many colleagues at CRREL who shared their expertise and provided many of the references cited.

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EXECUTIVE SUMMARY

Explorations for oil and gas in the remote areas of northern Alaska are difficult and expensive, but can be successfully accomplished by careful planning and scheduling with designs that do not disrupt the existing environmental conditions, including the permanently frozen ground. All construction and transport activities must respect and protect the environment, avoiding past practices that left enduring scars on the tundra.

A shallow exploration, to less than 10,000 ft, can be drilled in 45 to 90 days. Accordingly, it can be completed in a single winter, with sufficient time for the overland trips, construction of a snow/ice drill pad and a short runway on the adjacent tundra or nearby frozen lake. Winter trails can be effectively employed, with little tundra damage, by limiting such trail making and use to periods when the ground is frozen and snow covered. This same criterion for winter trails is taken one step further when constructing snow roads, drill pads or runways on the tundra. These require the addition of more snow, chipped ice and water to produce a frozen pavement, 12 to 18 in. thick, capable of supporting heavy loads. The ice pavements thaw and disappear in the springtime.

When the proposed target depth of the exploration is greater than 10,000 ft, the work cannot be accomplished in a single winter and other options must be considered. The first option, normally for wells between 10,000 and 15,000 ft, is to drill during two successive winters but suspend all activities during the intervening summer. Another option is to have the rig on site before the start of winter and/or leave the rig on site in the spring. Normally in these situations the drill pad is constructed with local frozen soils, rather than snow, and all equipment is kept stacked on timbers or plywood to prevent it from being frozen in place or to limit subsidence.

Explorations that exceed 15,000 ft are more difficult and require continuous drilling, which avoids the problems and associated work required in suspending the drilling. Accordingly, deep explorations require gravel drill pads, roads and runways that are operational in both summer and winter. Since these facilities are not permanent, they are normally designed and built to provide good service, with minimum maintenance, for only two years. However, the design of such facilities must consider the long-term thermal and erosional effects from such gravel embankments, which normally include the removal of all culverts and bridges, and at least some revegetation, to enhance restoration by native species.

These guidelines address, in separate chapters, how to construct winter trails, drill pads, roads and airfields, including information on how each is to be abandoned and the natural environment restored. Since the basic premise is to work with nature, the northern environment is introduced first, so that subsequent construction tasks can be related to specific periods and conditions in which the work can be accomplished most effectively. Examples of old methods of conducting such explorations are also discussed to explain why they are no longer permitted.

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CONSTRUCTION GUIDELINES FOR OIL AND GAS EXPLORATION IN NORTHERN ALASKA

FREDERICK E. CRORY

CHAPTER 1. INTRODUCTION

This report provides guidance for construction activities commonly associated with oil and gas exploration in northern Alaska. The guidelines are intended for use by both industry and those federal agencies responsible for leasing, permitting and administering petroleum explorations on federal lands in Alaska north of 68° latitude. Every effort has been made to present the information in simple terms, readily understandable by both technical and nontechnical personnel, including those with little or no prior arctic experience. Accordingly, additional emphasis has been given to explain the unique problems associated with planning, designing, constructing and operating such facilities as drill pads, roads and airstrips. To show why some conventional temperate-zone construction techniques are not applicable to the Arctic, examples are given of early (1940s and 1950s) exploration efforts in the Navy Petroleum Reserve no. 4 (PET 4), now the National Petroleum Reserve–Alaska (NPRA).

These guidelines are not meant to serve as stipulations, although they might be used as the basis for such. The approach taken in these guidelines, with respect to environmental problems associated with such northern operations, is perhaps somewhat different from that found in other reports. In this report particular attention is given to the influence of the changed environment, by provoked disturbances, on the stability of the facility. Accordingly, emphasis is placed on design, construction and operation activities that will minimize or reduce the influence of such surface and subsurface disturbances. Although perhaps appearing to some readers as an unorthodox approach, the end result of protecting the land and the environment, while still providing for construction activities, can be achieved—to the long-term mutual and economic benefit of all parties concerned.

Area of study

The area of consideration for these guidelines includes all of the lands north of 68° latitude in Alaska, irrespective of ownership. Figure 1 is a map of the area, with all major locations and remote sites mentioned in the text being identified. The area of immediate interest includes the NPRA, which has been partially opened to leasing for exploration by private firms. Since subsequent leases could include tracts anywhere in the NPRA, within the Arctic National Wildlife Refuge (ANWR), or other areas north of 68°, the subsequent discussions are accordingly not limited to specific areas. To provide the largest data base possible, we have (with permission) visited and inspected construction activities, both old

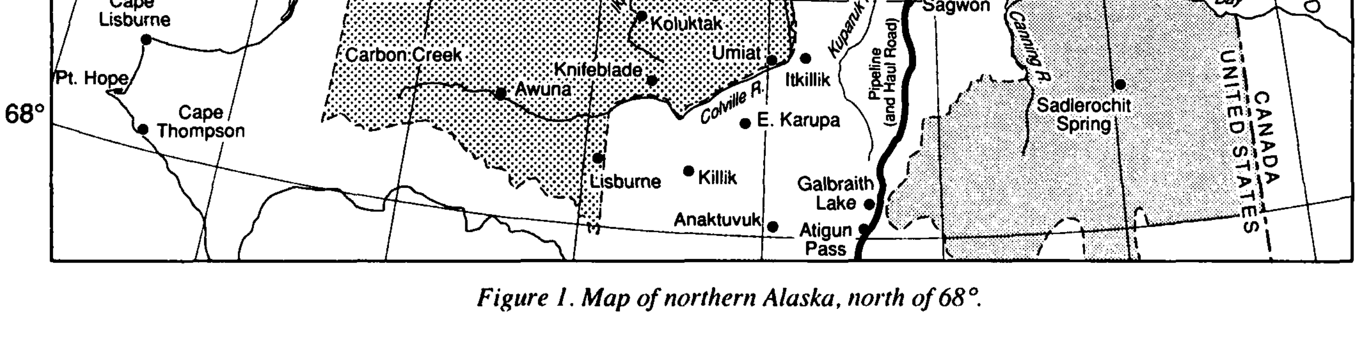


Figure 1. Map of northern Alaska, north of 68°.

and new, throughout the North Slope. These inspections included native villages, state and federal lands, the ANWR, the trans-Alaska pipeline corridor and the producing oil fields at, and near, Prudhoe Bay, and all exploration well sites within NPRA. While virtually all of these guidelines are applicable to land owned or controlled by these agencies, they are in no way intended to replace or otherwise supplant the guidelines or stipulations used by other agencies. We felt it essential to include all areas north of 68° to capitalize on the experience gained in specific areas.

These guidelines do not include offshore operations, with the exception of short discussions pertaining to nearshore ice for transportation routes and winter runways. These guidelines also avoid any discussion of construction and operations on barrier or artificial islands and causeways.

Subjects covered

The subjects of chapters and sections were selected because they presented either basic or essential information, or they dealt with specific construction activities commonly used in petroleum exploration programs. For instance, Chapter 2 discusses the basic terrain units, soils and bedrock, the climate and the unique environment of the area. Permafrost, or perennially frozen ground, is defined and explained in terms of the wide range of thermal regimes that may be encountered in northern Alaska. Photographs are presented that reflect the occurrence of ground ice as patterned ground, ice wedges or buried massive ice. Examples of natural and man-made surface disturbances that result in thermal erosion and thaw-settlement are also shown in a number of photographs and described in terms of both cause and effect.

Winter trails and snow/ice roads are discussed in Chapter 3. Winter trails are essential for the cross-country movement of drill rigs and construction equipment. Temporary snow/ice roads on the tundra are also used for hauling gravel and other construction material. Chapters 4–7 discuss the design and construction of roads, airfields and drill pads. Because shallow exploration wells can normally be drilled in only one winter, special attention is given in Chapters 6 and 7 to the use of expedient snow/ice drill pads and runways, including the use of frozen lakes. These chapters also contain information for the design and construction associated with deep wells, including insulated and uninsulated gravel roads, runways and drill pads.

Essential to any construction endeavor in the Far North is a full appreciation of operations in the snow and cold weather. Chapter 8 describes ways to plan, prepare and successfully carry out such work. Good logistics, thorough winterization and quality maintenance are emphasized as necessary to successfully accomplish both large and small tasks. Excavation of frozen ground and the use of explosives are described, with respect to constructing reserve pits, borrow pits and quarries. The persistent task of snow removal is specifically highlighted to remind the reader of the requirements to plan and provide for such in virtually every aspect of winter work. Safety is addressed, not only as a separate section, but interjected throughout other chapters to stress the importance of safety in such a remote and harsh environment.

The last chapter, understandably, covers the abandonment and restoration of drill sites, including the regrading and filling in of reserve pits and borrow areas. Short- and long-term obligations for revegetation and restoration of drill sites, including roads and airfields, are discussed in terms of wind, water and thermal erosion.

A summary is included at the end of each chapter to reinforce important points and to show how they are interrelated to the various construction tasks described in other chapters. These concluding sections also include discussions on successes and failures, exceptions to the general rules, and where specific construction techniques might be difficult or inappropriate in some areas. Redundancy, however, has been faithfully avoided on the premise that the reader will resist the temptation to use any chapter or section separately.

Basis for information

The data and information used in the preparation of these guidelines were derived from many sources. Reports on the initial exploration programs in PET-4 were particularly helpful. First, they describe how different activities were planned and carried out, based on the state of knowledge at that time. Secondly, the records and photographs of these early operations provide a valuable basis for understanding what caused the distresses that are still visible today.

Similarly, the examination of old drill sites was greatly facilitated by knowing the history of the initial exploration activity, which in many cases provided details on how the work was accomplished, such that one could understand the cause and effect of these activities with time, in some cases 45 years. Every drill site and hundreds of miles of trails in NPRA were inspected and photographed, expressly for these guidelines. Inspection trips to drill sites in the Umiat, Prudhoe Bay and Kuparuk areas were particularly helpful in providing information on both old and new construction techniques.

While data are still limited on this vast area, we have endeavored to use whatever is applicable to the areas of construction discussed here. Much of the information and many of the photographs contained in this report reflect design, construction and operational problems encountered in the 1977 to 1982 USGS exploration program in NPRA. Most of the techniques developed in that program were directly related to site-specific problems of accessibility, lack of suitable construction material and difficult subgrade conditions. Such constraints on exploration in such a vast area will probably change little in the next decade, although the techniques and equipment to accomplish the work will inevitably improve and change. People who work in the north country have traditionally been open and quick to share their experiences—both good and bad. This climate of mutual respect should be encouraged to continue the improvement of arctic engineering.

CHAPTER 2. BACKGROUND INFORMATION

An appreciation of the extent of the area addressed in these guidelines can be obtained by first viewing the region from space, as shown in Figure 2. This marked-up satellite photograph mosaic shows that the area is bounded on the east by the Canadian border, along the 141° meridian, for a distance of about 100 statute miles. The southern limit of the area, along 68° north latitude, extends some 600 miles from the Canadian border to the Chukchi Sea, near Cape Thompson. The land mass within this study area comprises almost 100,000 square miles—extensive by any scale, yet only about 17% of the total area of the state.

As shown in Figure 2, the 68° parallel passes through the very heart of the Brooks Range. The mountains on the east, however, extend farther northward. Some of these mountains, about 60 miles south of Kaktovik, reach elevations of 8000 and 9000 ft. In the extreme southeast corner of the area, one can also see that the mountains give way to hills and broad valleys, which drain southward to the Yukon River. In the central region, to the north of the Brooks Range, there is a rather abrupt change from mountains to hills, including a series of long east-west trending ridges. Farther northward, in this central region, the presence of the gently rolling hills can be appreciated by the limited or nonexistent drainage patterns. This otherwise featureless aspect on the satellite photo is in direct contrast to the thousands of lakes that occupy the Arctic Coastal Plain.

The basic terrain types or physiographic regions of arctic Alaska have been previously defined and mapped by Wahrhaftig (1965), as shown in Figure 3. The basic

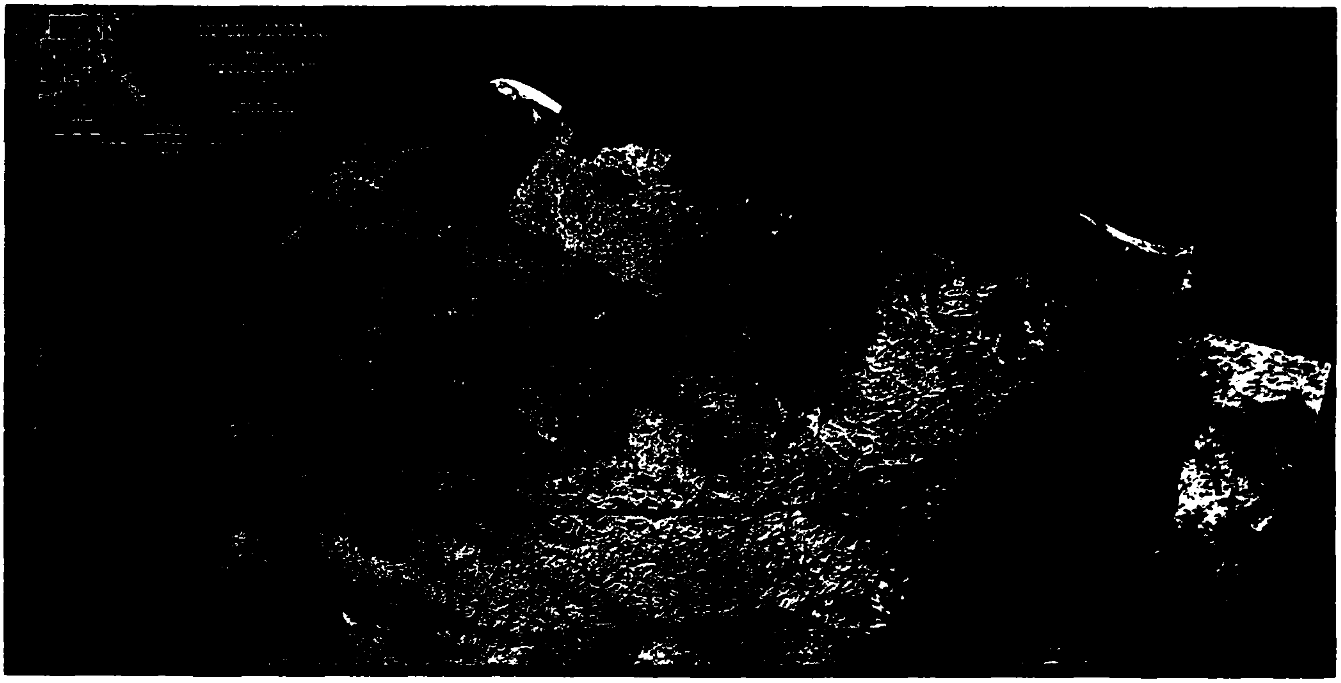


Figure 2. Landsat mosaic of northern Alaska, with 68° north latitude superimposed.

The 68° parallel is about 105 miles north of the Arctic Circle, which is 66°30'N. From Cape Thompson the coastline runs briefly northwesterly to Point Hope, and then northerly about 60 miles to Cape Lisburne. The coastline then runs relatively straight, to the northeast, from Cape Lisburne to Point Barrow, a distance of about 285 miles. From Point Barrow, the coastline with numerous bays runs essentially east-southeast, about 380 miles, to the Canadian border.

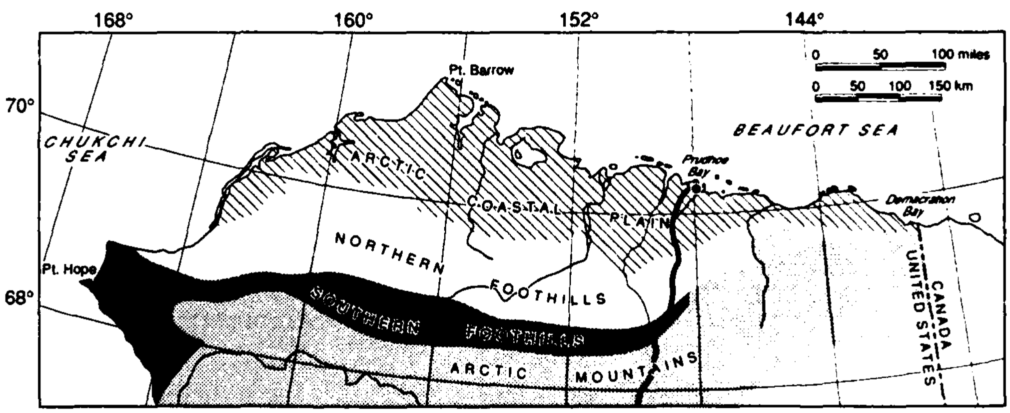


Figure 3. Physiographic regions of the Arctic (from Selkregg et al. 1975).

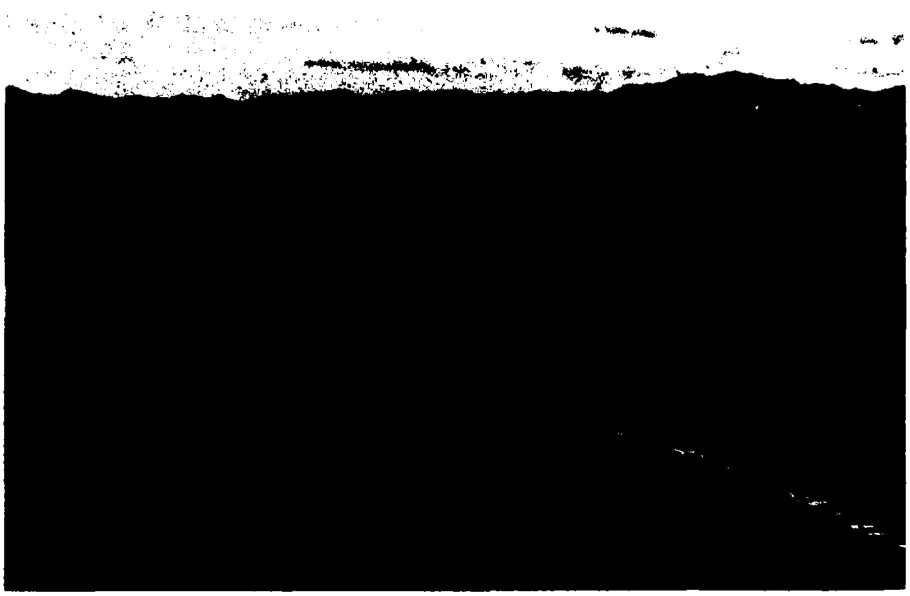


Figure 4. Looking south along eastern shore of Demarcation Bay. Derelict ship (LST) at left, British Mountains in background. About 5 miles from Canadian border.

Figure 5. Gently rolling hills of Northern Foothills, with caribou antlers in foreground.

terrain types, as described above, are the Arctic Mountains, Southern Foothills, Northern Foothills and the Arctic Coastal Plain.

In ANWR, in the northeast, there are no foothills; the mountains rise abruptly from the Arctic Coastal Plain as shown in Figure 4. In the central part of the region there are two distinctly different types of foothills as shown in Figures 5 and 6. The Southern Foothills are distinct hills or ridges with steep side slopes, whereas the Northern Foothills can be best described as gentle and rolling.

The Arctic Coastal Plain in the extreme eastern portion is characterized by a series of northward flowing streams, with relatively few lakes, whereas the remaining portions of the northern coastal plain have a series of ponds and lakes, which are unique in that they have their long axis oriented in a north-northwest direction (Fig. 7). The largest lake in the Arctic Coastal Plain is Teshekpuk Lake, nearly 25 miles long.

While technically outside the purview of this study, conditions along and off the coast, in the area called the littoral zone, also deserve attention. The continental shelf off northern Alaska is very shallow and extends many miles offshore. The larger bays, especially those associated with large rivers, are also very shallow and have heavy concentrations of fine sediments. Along the coast there are often barrier islands that are continuously, but slowly, shifting and changing.

Soils and bedrock

An understanding of the geology of an area is always important. Unfortunately this report cannot describe in detail the soils and bedrock conditions over such a large area. Some important geological aspects of the area should be understood, however, since they apply to the area in general and have direct relevance to virtually all construction efforts.

The mountains of the Brooks Range at one time were covered by extensive glaciers, which flowed northward and covered many areas in the Southern Foothills. These glaciers not only shaped the mountains but carried considerable volumes of material northward. The valleys and stream beds attest to the large amount of sands and gravels carried northward (Fig. 8), with the finer sediments being carried even farther, to areas including the Arctic Coastal Plain and Littoral Zone.

Northern Alaska in ancient times was also submerged, providing conditions conducive to the development of limestone, sandstone and other sedimentary rocks. In more recent times there were a series of ocean transgressions, and evidence of ancient beaches can be found at several inland locations (Tunalik, Inigok).

The tops of many hills and ridges in the Southern Foothills have exposures of bedrock. Normally such exposures reflect severe weathering, as caused by frost action. The gentle hills of the Northern Foothills normally have few bedrock exposures, except along rivers. The hilltop and side slopes, normally covered with grasses and sedges, have a mantle of silts and fine sands. While solifluction on such slopes can and does occur, most of these slopes appear quite stable despite the severe frost action. Significant solifluction, as evidenced by slides and stripes, can be found in certain areas, such as in the hills just north of Umiat (Fig. 9). Here there are clays, including potentially commercial deposits of bentonite.

There are now a series of USGS open-file reports that show both bedrock and unconsolidated (soil) deposits of northern Alaska. These reports have the normal quadrangle maps (1:250,000) subdued, with the different soil and bedrock units superimposed. Scarps and erosional features are also identified, as are other features such as anticlines, synclines and faults. Included on these maps, or on a separate sheet, are engineering-geological interpretations of each soil and rock unit identified. These interpretations describe each type of material, its normal distribution and thickness, including permafrost, and the thickness of the active layer, amount of associated ground ice and susceptibility to frost action. Of particular interest is a brief evaluation of the suitability of the material for construction and any special problems, including potential settlement, slope stability, and erodibility. Thus this new series of maps should, in combination with conventional topographic maps, be the basis for virtually all work undertaken in northern Alaska. These special maps also provide an opportunity to study and plan field work, long before the short summer season.

Figure 6. Southern Foothills with long exposed limestone ridges.

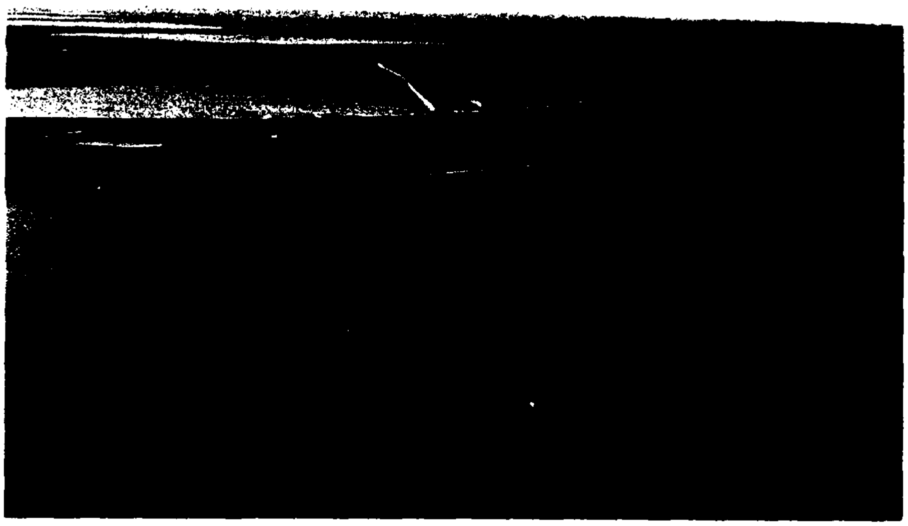


Figure 7. Coastal Plain of northern Alaska, showing oriented thaw lakes.

Climate and hydrology

Alaska is for all purposes a large peninsula, surrounded on the north by the Arctic Ocean, on the west by the Bering Sea and to the south by the Gulf of Alaska. Southern Alaska has a distinctly maritime climate, whereas Interior Alaska has a continental climate. Northern Alaska has its own unique maritime climate. With the protecting wall of the Brooks Range to the south, it is fully exposed to the maritime influence of the Arctic Ocean to the north. The maritime influence on northern Alaska (from the Arctic Ocean) is quite different from that of southern Alaska, which is influenced by the Japanese current. The Arctic Ocean environment is primarily influenced by pack ice. The Beaufort Sea, from Barrow to the Canadian border, is normally covered with pack ice. Only for several months in the later summer does it recede northward enough to allow coastal shipping, provided of course a storm does not drive the pack ice southward to the coast. The pack ice off the west coast of this area, in

Figure 8. Gravel deposits on east bank of Clarence River, 3 miles from Canadian border.

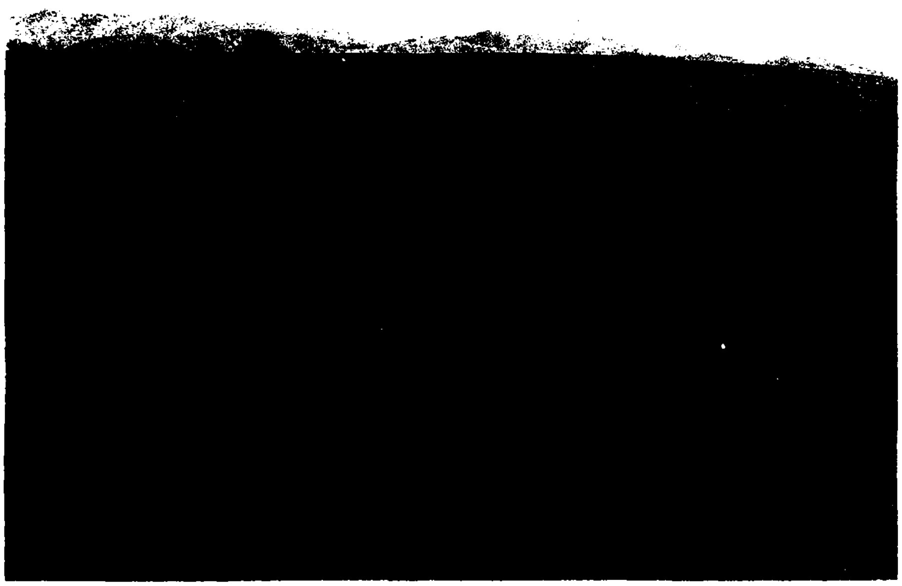


Figure 9. Solifluction lobes.

the Chukchi Sea, does open up each summer. However, the winter pack ice and cold summer waters have a strong influence on the climate of northern Alaska. Air temperatures in northern Alaska approach, but do not exceed, the extremely low temperatures of interior Alaska; however, the more persistent winds in the north can make it feel much colder.

Weather records from nine stations in northern Alaska have been summarized in Figure 10, reflecting average daily maximum and minimum temperatures for each month and the extreme or record highs and low temperatures for each month. Monthly and annual climatological summaries for these and other stations with long-term records are available from NOAA. These summaries contain important information on not only temperatures but winds and precipitation. The annual summaries also compare the weather for each year against long-term average conditions and previous extremes, and include pertinent information on unusual or severe events, such as coastal storm surges.

Barrow has been used as a staging area for many field operations and it is important to appreciate the weather conditions that have been recorded there over the years. The mean annual air temperature is 9.6°F and the maximum daily temperature exceeds the freezing point for an average of 109 days/year. Conversely, minimum daily temperatures are below the freezing point for an average of 324 days each year. Freezing temperatures and snow have been observed in every month of the year. February is normally the coldest month, with an average temperature of −19.6°F, the recorded lowest daily temperature being −56°F. July is the warmest month, with an average temperature of 38.9°F, the highest recorded daily temperature being 78°F.

Precipitation at Barrow is very low, the rainfall and water equivalent for snow combined averaging only 4.75 in. Such a low value is indicative of a desert environment, although one would hardly believe such could be true when one views the many lakes of the Coastal Plain, which includes the Barrow area.

Winds at Barrow are primarily from the east or ENE and the average wind speed is just under 12 mph, which remains relatively constant throughout the year. Stronger winds, especially those associated with storms are from the west and can occur in every month. Snowstorms, including blizzards, can therefore produce large drifts with these westerly winds, whereas the more prevalent easterly winds will obviously carry the surface snow in the reverse direction. The amount of snow falling from each storm and the depth of snowfall on the ground at any given time is difficult to accurately measure because of these winds and associated drifting.

The sky cover, or degree of cloudiness,

Average maximums, minimums, and extremes have been combined on a single chart for the nine available observation locations. This allows comparisons between stations and shows the rapid temperature changes that occur during spring and fall months. Because only one to five years of record are available for Oliktok, the information presented for this station does not allow long-term averaging.

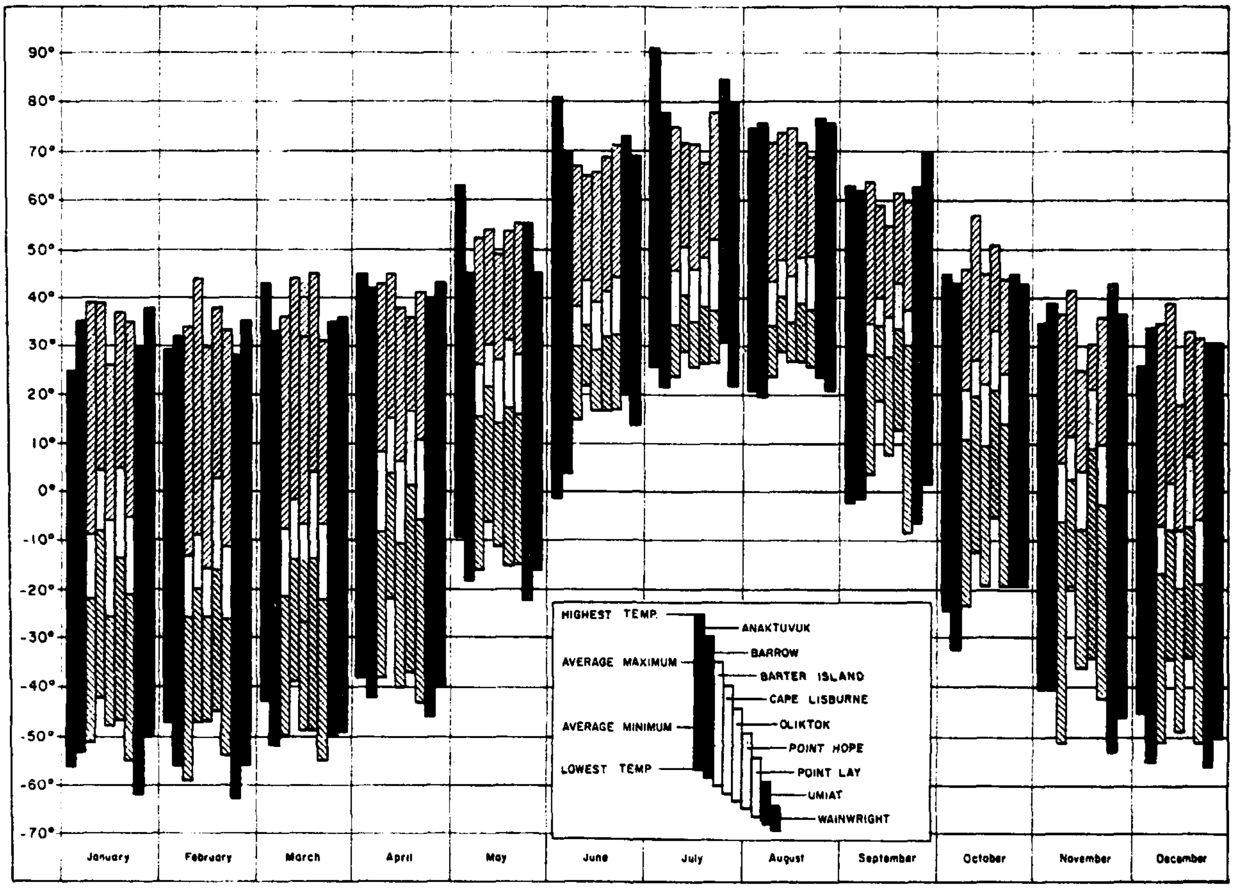


Figure 10. Temperature averages and extremes for selected stations (from Selkregg 1975).

precipitation and fog, is apparently directly related to the amount of available sunlight. All three build up to a maximum along with the hours of sunlight and sustain this maximum through the fall months. With the advent of cold weather the sky conditions improve. Data on the frequency of clear vs cloudy days, days of thick overcast and rain, and the presence of fog are important to flying and outside work and are also an important influence on the extent of solar warming of the ground surface and the actual air temperatures. Accordingly, one must have an appreciation of this information and the hours of daylight and darkness to plan for air travel and outside work in this region.

Theoretically, at sea level along the Arctic Circle (66°30'N) the sun will be down to the horizon, but not set, and then begin to rise again on only the longest day of the year (22 June). Conversely on the shortest day of the year (22 Dec) the sun in late morning will appear only as a twilight and then, after several hours of diminishing light, drop back below the horizon. At Barrow (at 71°18'N) the sun is above the horizon all day from 10 May until 2 August, and conversely never rises above the horizon from 18 November until 24 January. One is always impressed by the rapidity with which the amount of daylight increases each day, particularly during the month of March. Conversely, one is equally impressed, or depressed, by the daily rate of change in the fall, as the amount of daylight decreases each day. Charts reflecting the amount of daylight, twilight and darkness are available for Barrow and elsewhere in Alaska (Fig. 11).

Unfortunately, an insufficient number of weather stations are located within this area of northern Alaska. The majority of stations are along the coast, either at large villages or at DEW line stations. The exceptions are two stations with long-term records at Umiat and Anaktuvuk. Umiat is in the valley of the Colville River while Anaktuvuk is in a pass through the Brooks Range (Fig. 1). More recently, stations have been established along the trans-Alaska pipeline corridor and pro-

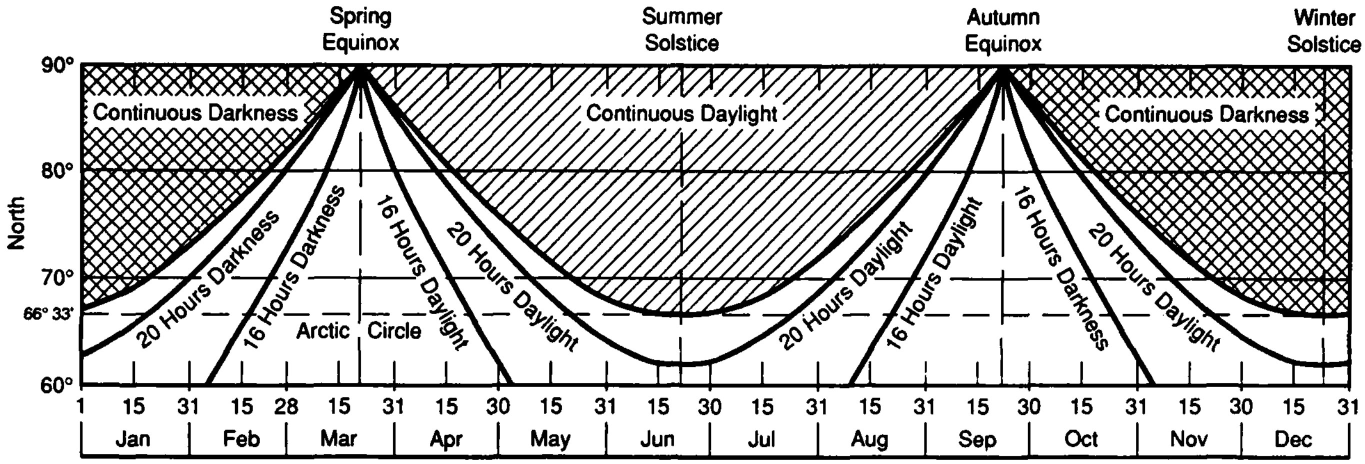


Figure 11. Duration of darkness and daylight for the North Slope and other areas of Alaska.

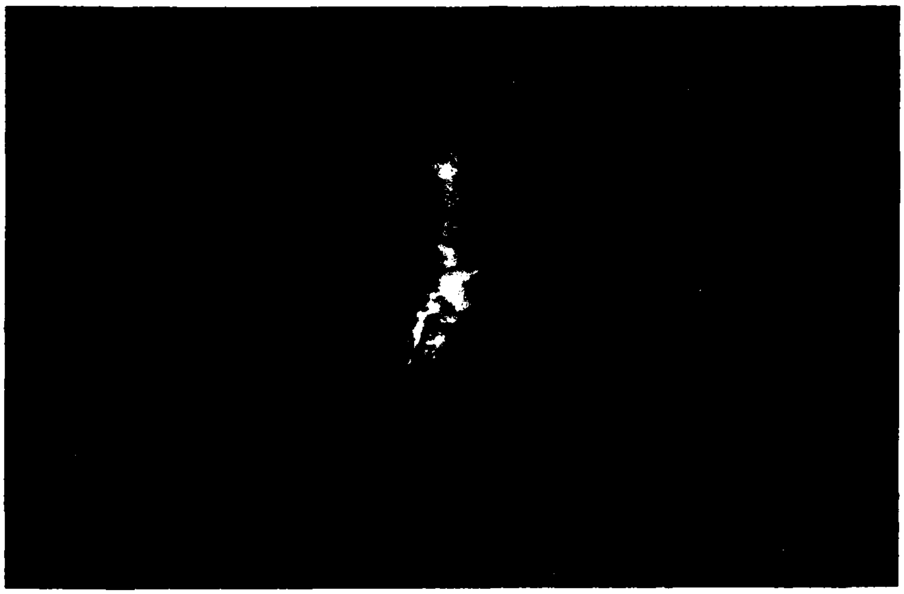


Figure 12. Tundra fire only minutes after lightning strike in Carbon Creek area.

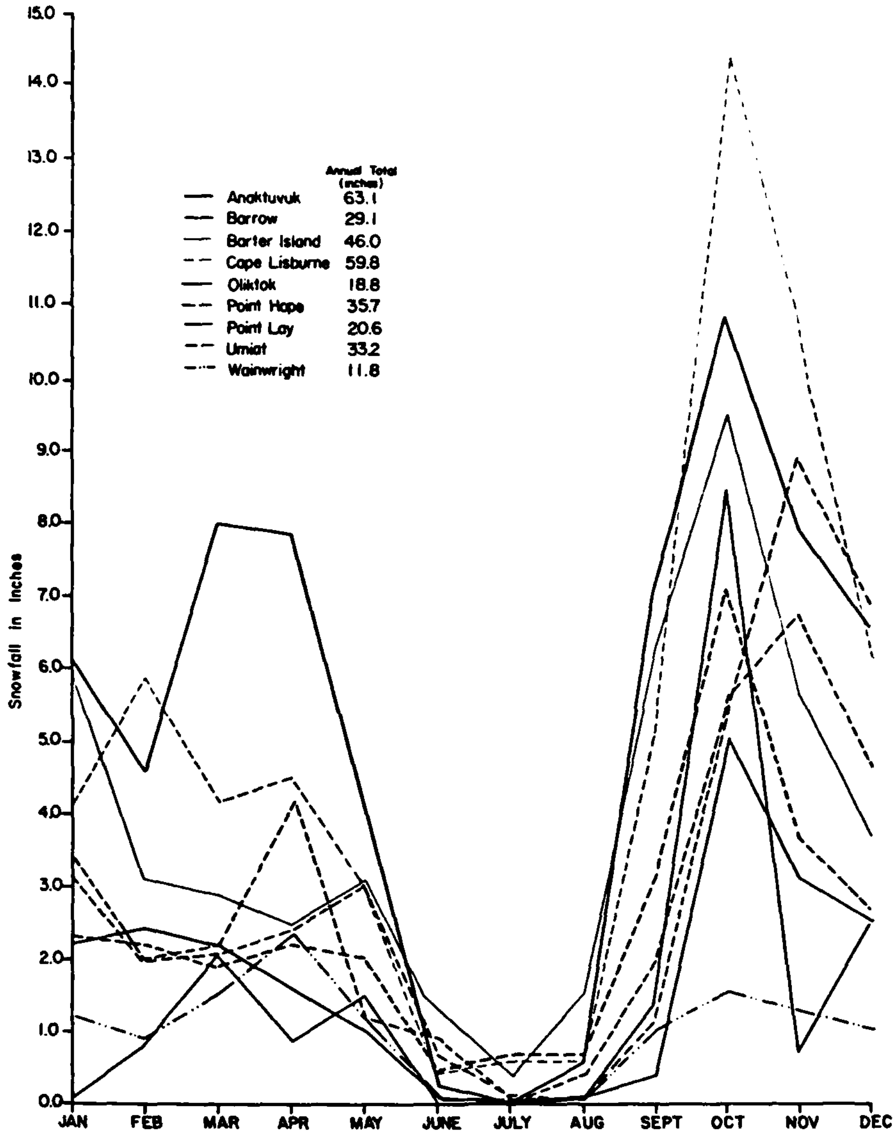
vide interesting data on the different climates along this north–south transect from Prudhoe Bay to Atigun Pass (Haugen et al. 1983).

Weather conditions can be quite different away from the arctic coast. Air temperatures during the summer months at sites 50 miles south of the coast are consistently higher than along the coastline. Fog is also more persistent along the coast. Barrow has an annual average of 65 days with heavy fog, 37 of which occur in June, July and August. Barter Island, notorious for its bad weather, has 75 days each year of heavy fog (Selkregg 1975). Such fogs can be very dense in the morning, burn off during the day and return again by late afternoon.

In the Southern Foothills area one will also note the midday buildup of clouds associated with the nearby mountains. Very heavy rain can accompany afternoon thunderstorms in this area. Lightning associated with such thunderstorms can start tundra fires (Fig. 12). Such fires can burn many acres and cause severe thermal disturbance to the tundra (Johnson and Viereck 1983, Hall et al. 1978).

The snowfall and precipitation plots for this region (Fig. 13 and 14) are very important, particularly with respect to overland operations. The data show that snowfall and overall precipitation increase as one goes south from the coast, and as one goes eastward, the greatest amount of snow and precipitation falls in the Philip Smith Mountains, to the south of Kaktovik (Sloan 1980). Precipitation is normally heaviest in late summer and early fall. Snowfall is also heaviest from August to December, peaking in October. A secondary peak in snowfall can occur in the spring. Snow on the ground surface acts much like a blanket, being a very good insulator.

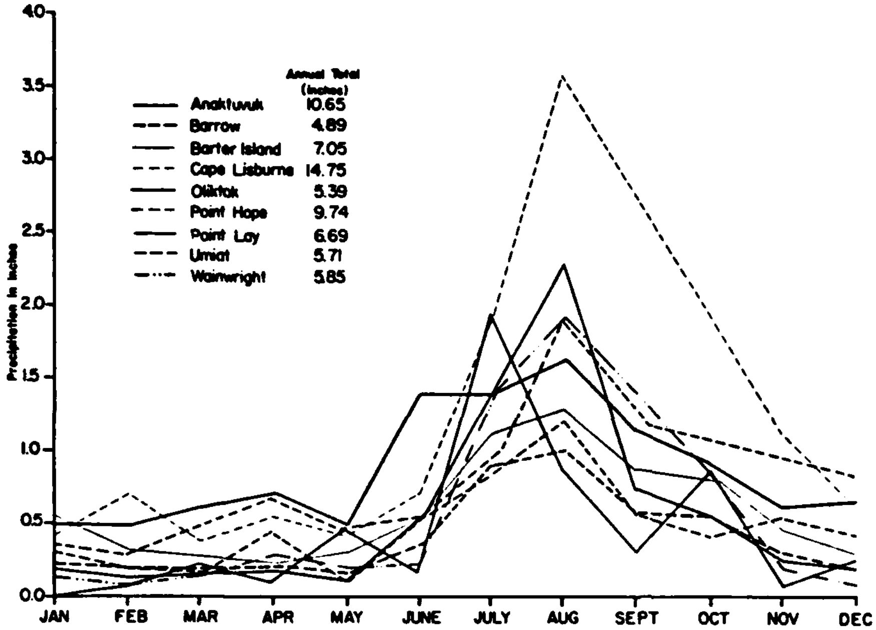
For many design calculations, such as for buildings, foundations, roads and airfields, the most frequently used climatic factors are the freezing and thawing indices, which consider temperatures over an entire winter or summer. Freezing (FI) and thawing (TI) indices are based upon degree-days relative to the freezing point (32°F or 0°C). For instance, if T°F is the average air temperature recorded on a certain day, the number of Fahrenheit degree-days for that day is (T–32). If the result is positive, it indicates degree-days of thawing; if negative, degree days of freezing. After similar calculations have been made for each day of the year, and compiled as a cumulative algebraic sum,



In contrast to the single period in August when most precipitation occurs, the snowfall pattern shows a primary peak in October and a secondary peak in spring which varies from February to May. Period of record is 8 to 20 years.

Adapted from the National Oceanic and Atmospheric Administration Environmental Data Service.

Figure 13. Average monthly and annual snowfall for selected stations (from Selkregg 1975).



The line graph plot of the nine data stations shows the distribution of precipitation through the year, showing clearly the comparatively heavy precipitation that occurs in late summer and early fall. Period of record is 8 to 20 years.

Adapted from the National Oceanic and Atmospheric Administration Environmental Data Service.

Figure 14. Average monthly and annual precipitation for selected stations (from Selkregg 1975).

they can be plotted against time to reflect the freezing index and the thawing index. When such data are compiled for many years, one can establish mean and extreme freezing and thawing indices for a given weather station.

When such indices are compiled with similar data from other stations, maps can be prepared showing the distribution of freezing or thawing degree days across the region, as shown in Figure 15. This figure shows the mean FI along the coast, from Barrow to Kaktovik, as 8500°F degree-days. The FI decreases as one goes southward, being 6500 or less in the southwest near Cape Thompson and about 7750 in the southeast corner of the study area. Figure 15 shows the mean TI along the north coast between Barrow and Prudhoe Bay as being only 500°F degree-days, with the index increasing to 1500°F degree-days along the 68° parallel. This threefold difference in TI, in combination with the decrease in FI across the region, is important, as will be discussed in subsequent chapters.

It is important to remember that maps like those shown in Figure 15 represent isopleths of mean values, not extremes or design values. Statistical studies have demonstrated, for instance, that the extreme values are about 1.18 and 0.88 times greater, or smaller, than the mean FI. Design indices are, of course, between the extremes and mean values, usually being defined as the average of the three coldest or warmest values over a period of 30 years.

In the contiguous 48 states emphasis is placed on the date of the last frost in the spring and the first frost in the fall, because these dates are important to agriculture. In northern Alaska such dates are irrelevant because frost is to be expected in all of the summer months. Accordingly, greater emphasis is placed on what is termed the spring breakup and the fall freezeup. Breakup and freezeup are not specific dates but rather general periods which, from historical observations, have usually occurred about that time each year.

Breakup is generally described as the period of active snow melting, and at least initial edge melting of ponds, which results in the rapid rise and flowing of streams and rivers. In some situations the breakups may be specifically related to inland tundra, rivers, lakes or the overshore ice. The breakup can be gradual if the weather is clear and overnight lows dip below freezing, with the major melting being caused by solar radiation. On the other hand, sudden and severe breakups can be precipitated by rainy and consecutive cloudy and warm days. Since the ground is solidly frozen in the spring, all the melting snow and ice must run off, as opposed to percolating into the ground, as is the normal case in the temperate zone. Fortunately, the spring breakup rarely occurs in all areas of this region at the same time; unfortunately, the greatest

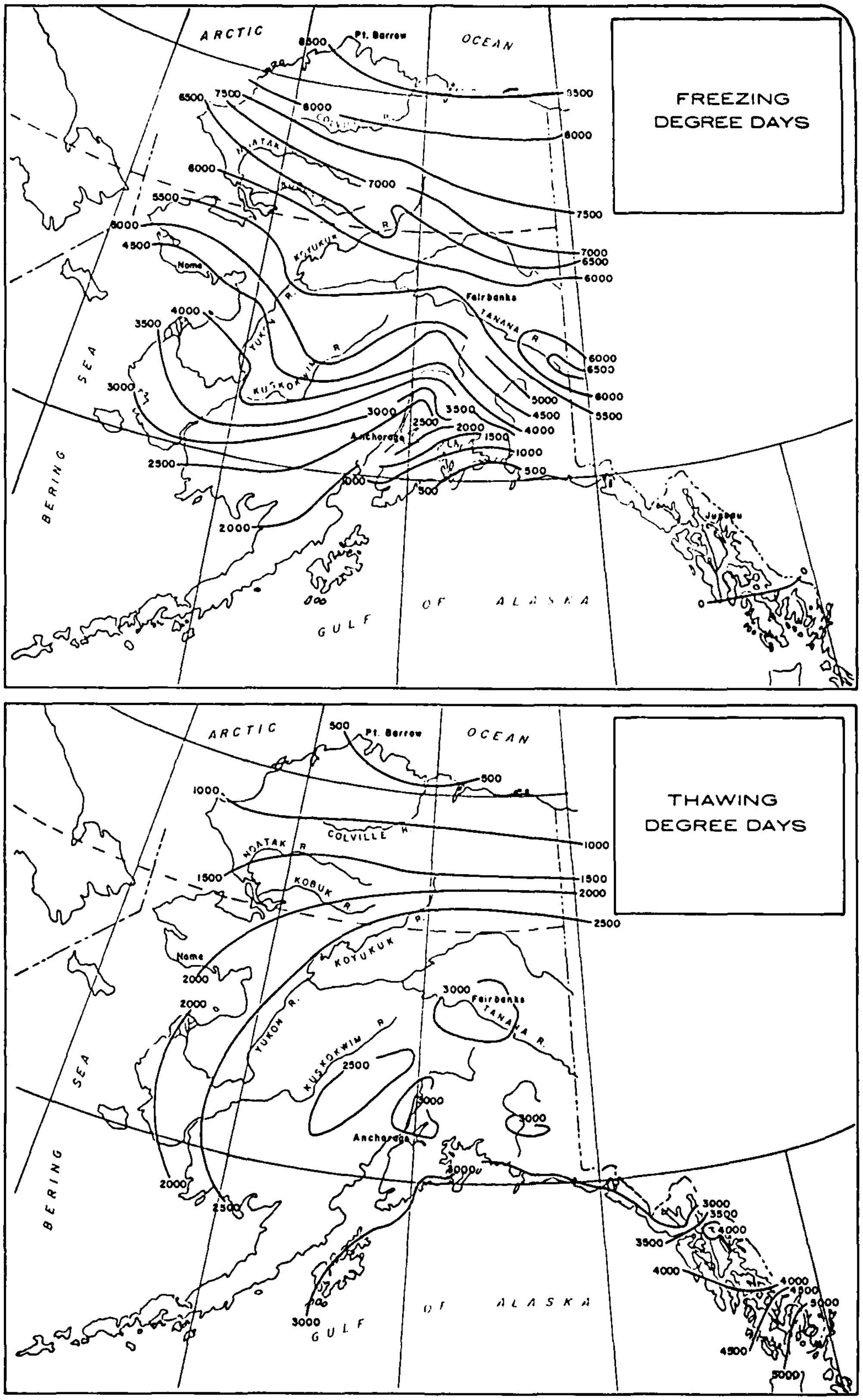


Figure 15. Freezing and thawing degree days for Alaska (from Selkregg 1975).

snowpack is in the mountains and usually drains northward. The snow and ice just inland of the coast are usually the last to melt, and meltwater from the inland rivers overspreads the coastal bay ice. Valuable information on the depth of snow on the ground and the unique hydrological conditions of this region is available for this area (Sloan et al. 1977, Sloan 1980, Drage et al. 1983).

Freezeup is a descriptive term applied to that period in the fall when the ground and lakes begin to freeze. This period is usually accompanied by snow that will remain on the ground for the rest of the winter, although several previous snowstorms will have melted away. Accordingly, freezeup is usually described as being the earliest period when the ground surface remains frozen and the snow cover persists.

Tundra, permafrost and other features

Unlike the rest of Alaska there are no trees in northern regions, only occasional dwarf willows, birch and other shrubs (Fig. 5), with isolated patches of alders along some of the larger rivers. The treeless tundra in the summer may appear to be an endless carpet of grass, much like a prairie. Upon close examination, however, one finds it to be a complex community of grasses, mosses, sedges, flowers and shrubs. Some species prefer the more aquatic environment of the valleys and lowlands, others prefer the better-drained side slopes or gentle hilltops, while still others prefer (or struggle to survive on) the dry, wind-swept and weathered bedrock of the ridges and mountain slopes. Wildflowers are to be found in each of these environments, although they are never as profuse as the mosquitoes that abide throughout the tundra during the summer.

The adaptability of the different vegetative communities within this region is directly related to the presence of frozen ground at shallow depths (McGown 1973). Under normal conditions the depth of ground thawing at the end of the short summer is only a foot or two, thus limiting species to those that have only shallow roots and can tolerate low ground temperatures. Inhospitable as these ground conditions may appear, it is the frozen ground at shallow depths that acts as an impermeable barrier to retain the limited soil moisture available in this desert environment. Hence, the growth of these low-temperature-tolerant plants is made possible by the presence of the frozen ground.

Figure 16. Ice mound on the south side of the runway at Umiat.

The frozen ground at depth is called permafrost, or permanently frozen ground. Permafrost is defined as a ground condition wherein the temperature of the material has remained below 32°F (0°C) continuously for more than two years. The material may be soil, ice or bedrock. The material may be fully or partially saturated or may even be quite dry. It is the continuously frozen aspect that distinguishes permafrost from frost, which is a seasonal near-surface condition in which the ground thaws out progressively during the spring and summer and refreezes again each winter. Ground that thaws and refreezes each year, above the permafrost, is called the active layer. The thickness of the active layer varies slightly, from year to year, depending on weather and other factors. However, the depth of the active layer can be substantially increased if the ground surface conditions are changed by natural or man-made disturbances.

An understanding and appreciation of permafrost is fundamental to virtually all construction in this region. Permafrost conditions are not unique to northern Alaska, for they occur in 26% of the land areas of the world. The permafrost in northern Alaska is classified as being continuous (Ferrians 1965). It is found everywhere except beneath large lakes and rivers, or geothermally warm areas in the mountains. Permafrost in northern Alaska can extend to depths of 2000 ft or more, much deeper than found elsewhere in Alaska (Gold and Lachenbruch 1973).

The deep permafrost, the result of very low aboveground temperatures, has developed and persisted for tens of thousands of years. Geothermal studies by Lachenbruch and others suggest that centuries ago the climate in this region was colder than at present and hence more conducive to deep freezing. Recent studies also suggest that there may be a gradual warming of the permafrost, potentially related to global warming (Lachenbruch et al. 1983, Osterkamp and Payne 1981). Permafrost temperatures are sensitive not only to long-term climatic changes but to changes in ground surface conditions, either natural or man-made.

While perhaps more prevalent in central and southern Alaska, there are ground conditions in northern Alaska where the winter frost does not penetrate to and into the permafrost, leaving a zone of thawed soils between the bottom of the frost layer and the top of permafrost. Such thawed layers are called residual thaw zones, or taliks. Such conditions are to be found in the late winter or springtime beneath shallow or recently drained lakes. The occurrences of a residual thaw layer can also be associated with the lateral shifting of rivers and streams, wherein the permafrost is reforming in areas previously occupied by the stream. Taliks are also to be found at sites along the northern flank of the Brooks Range, where the bottom of the permafrost is quite shallow and groundwater may be draining through such residual thawed layers, especially where deep frost penetration is inhibited by deep snow. Along the coast, in fine-grained sediments, such taliks are sometimes associated with the concentration of brines. These isolated brine pockets are believed to have been formed during the ground freezing process, and the brine within the pockets sometimes has 6 to 8 times the normal concentration of salt found in seawater.

Taliks, while not widespread, are the root of many interesting formations, including ice mounds, or blisters, and the much larger pingos. Ice mounds sometimes appear in the strangest places. One is shown in Figure 16, which grew to a high of 8–10 ft, less than 100 ft from the runway at Umiat. Groundwater rises within the core of these mounds and builds up successive layers of ice. A much larger icing mound appeared during construction of the trans-Alaska pipeline, between Galbraith Lake and the construction camp, as shown in Figure 17. Normally such mounds do not include soil or vegetation and melt away the following summer; they do not necessarily form in the same location each year. Ice mounds may occur in undisturbed areas or in areas disturbed by natural events or construction (Brown et al. 1983).

Pingos are similar to ice mounds but form by distorting and forcing up the frozen active layer, such that these mounds have soil and vegetation on them as shown in Figure 18. They often, but not always, develop near the center of old drained lakes and grow larger each year, sometimes achieving heights of 100 ft or more. While the interiors of the pingos are filled with water and ice, pingos do not thaw and disappear like ice mounds, being thermally protected by the soil and vegetative cover. Normally they split longitudinally across the top and eventually collapse into the center. Pingos can, however, persist for many decades and per-

Figure 17. Ice mound near Galbraith Lake.

Figure 18. Pingo that developed in old lake bed. Note polygonal features on pingo slopes.

Figure 19. Sadlerochit Spring in ANWR.

Figure 20. Icing along river in coastal plain of ANWR, during late summer.

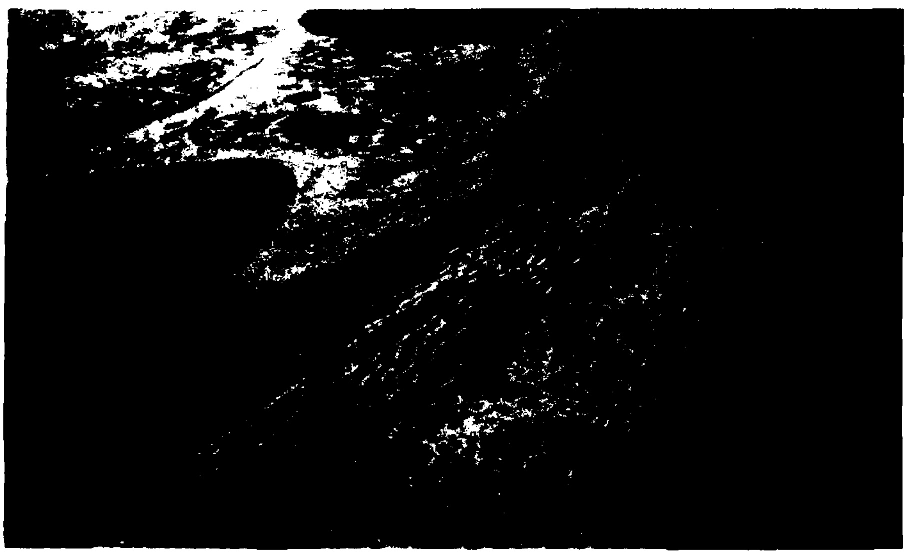


Figure 21. Patterned ground, reflecting ice wedges.

haps centuries. They are often very distinct topographic anomalies, often appearing as an isolated hill in an otherwise virtually level area, and are scattered throughout the Arctic Coastal Plain and even into the Northern Foothills (Ferrians 1988). McKay (1983) has studied and written extensively on the pingos in the Tuktoyaktuk area of Canada.

During the wintertime the only precipitation is snow, and the active layer in most areas is completely frozen. Accordingly, watersheds contribute little or nothing to the flow of most streams and rivers. Many of the larger rivers, such as the Colville, reflect a distinct lowering of the water level during the winter. In places, the early winter ice is left high and dry along the shores, and longitudinal cracks appear along the edges of the deeper portions of the rivers. However, on some streams, such as those draining northward from the mountains in the Arctic National Wildlife Refuge, the groundwater recharge may be relatively constant all winter, especially when the headwaters are warm springs, such as shown in Figure 19. Ice formations on these spring-fed rivers can be extensive. The upwelling and overflowing of water builds up layers of ice atop the original river ice and spreads laterally away from the stream. The thickness of such icings can be 20 ft or more, since the water freezes very rapidly atop the ice. Such river icings, called naleds, are very prevalent along the Canning, Saddlerochit, Hulahula and other rivers in the northeast and extend for miles. These icings are so extensive and thick that they do not melt away each summer; the rivers flow in channels and tunnels within the ice (Fig. 20).

Ground ice and patterned ground

Ice in northern Alaska is not limited to ponds, lakes and rivers. There is perhaps more water in the form of ice below the ground, in the permafrost, than in all the ponds, lakes and rivers of the area (Brown 1967). The volume of ground ice decreases with depth, ice near the surface being normally associated with ice wedges. At depths of 50 ft or more, ice is almost entirely in the form of ice lenses

Figure 22. Patterned ground along river.

and interstitial ice crystals within the pores of the host soil. The multitude of thaw lakes within the Coastal Plain is apparently directly related to this large volume of near-surface ground ice.

There are several major types of ground ice. The easiest form to recognize from the air, or even on the ground, is polygonal ground ice (Fig. 21). The patterns may be more or less square in shape, as shown in Figure 22, reflecting the evolution of the ground ice along the bends in a river, or they may be 5- or 6-sided. Polygonal ground is not classified by the number of straight sides enclosing a given unit area but rather by the difference in elevation of the center with respect to the perimeter. Hence the terms high- or low-centered polygons are used. The high-centered polygons shown in Figures 21 and 22 sometimes have what is called a medallion in the center. These medallions consist of fine-grained soils that literally erupt, in a small way, and spread laterally. They are often round, from 2 to 4 ft in diameter, and less than a few inches thick. From the air these medallions appear as dots, accentuating the center of the polygonal pattern. The polygonal pattern surrounding such high-centered areas is a distinct depression that changes direction upon intersecting the leg of an adjacent polygon. Normally the depressions are only several feet wide and are completely vegetated.

A visible crack may be seen in the bottom of these depressions, especially in the springtime, as shown in Figure 23. These polygonal cracks do not reflect a gradual tearing or pulling apart of the vegetation roots, for the crack is cleaner than one could make with a knife. The crack is formed virtually instantaneously, sometimes with an audible "bang," as the ground shrinks in the wintertime. The ice in the wedge fails in tension at or near the same place each year because of the weaker plane created by the vertical ice wedge. Water, of course, enters this crack each summer and freezes, contributing to the growth of these V-shaped ice wedges. The theory of ice wedge formation in polygonal ground is to be found in an outstanding paper by Lachenbruch (1962).

The second type of polygonal ground is the low-centered polygon. Here the ice wedge, which is continuous around the polygon, is so aggressive that it shoves the soil and vegetation laterally, forming a ridge or pair of closely spaced ridges. This ridge around the perimeter acts as a dike containing the melted snow and any rain, blocking all lateral drainage during the summer. A good example of the low-centered polygonal ground is shown in

Figure 23. Crack exposed in the spring-time above ice wedges.

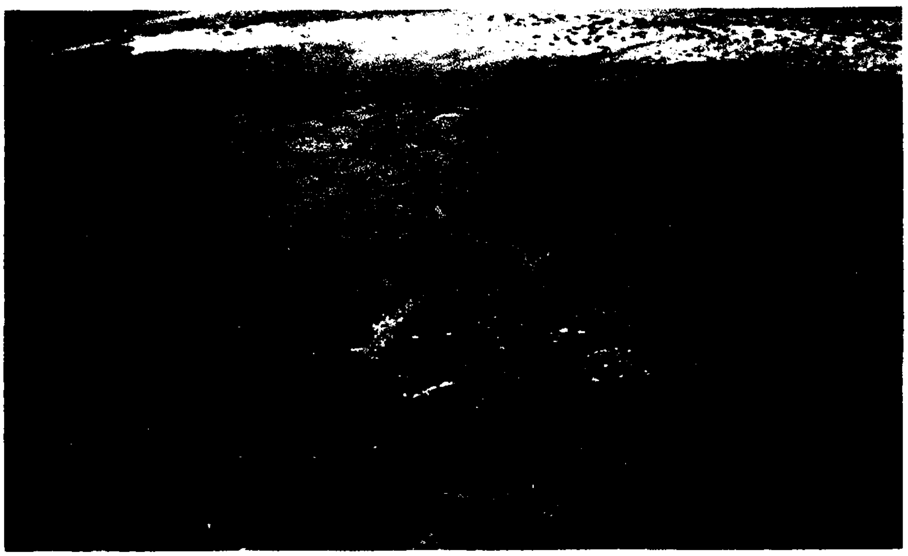


Figure 24. Low-centered polygonal ground.

Figure 25. Erosion of shoreline along Smith Bay, showing ground ice. Note thin layer of organics over ice

Figure 24, the pattern resembling a rice paddy. This photo also clearly illustrates why the vegetation must include varieties that can survive in an aquatic environment and why from an erosional standpoint, it is important to avoid damaging the dike around each polygon.

While it takes very little effort to dig away the vegetation lying above the ice wedges that mark the boundaries of each polygon, one will not gain a full appreciation of the size and extent of the wedge until the wedge is examined in a vertical cross section. Fortunately, one can find such cross-sectional exposures along the shores of lakes or along the coast, where active erosion exposes the ice (Fig. 25). These vertical ice wedges are typically 4 to 6 ft wide at the top, tapering to a point some 10 to 15 ft or more below the surface. Since the wedges intersect to form a polygonal network, the greatest concentration of ice is at the intersections.

Sometimes ice wedges have no polygonal ground surface features. Such deep ice wedges are considered inactive, no longer growing wider and deeper, but persisting as relict ice. Normally the original ground in such cases has been covered by a mantle of other soils, which occasionally does not contain shallow ice wedges. In some locations, particularly in sandy areas, there may be no visible surface indication of a polygonal pattern, yet ice wedges are to be found at very shallow depths. There are also other clues to the existence of ground ice, such as the small pools that appear at discrete intervals along small streams that drain the valleys in the Foothills area. This is called button drainage and one example is shown in Figure 26. The pools or buttons form at ice wedges that thaw and create small pools.

Ground ice is also to be found only 1.5 to 3.0 ft below the ground surface in what can only be described as massive ice. While the mechanics of massive ice development is still not completely understood, it is believed that such ice, ranging from several feet to more than 20 ft thick, is formed by the progressive annual growth at the bottom of the active layer.

Figure 26. Button drainage along small stream. Pools at buttons reflect ice wedge locations.

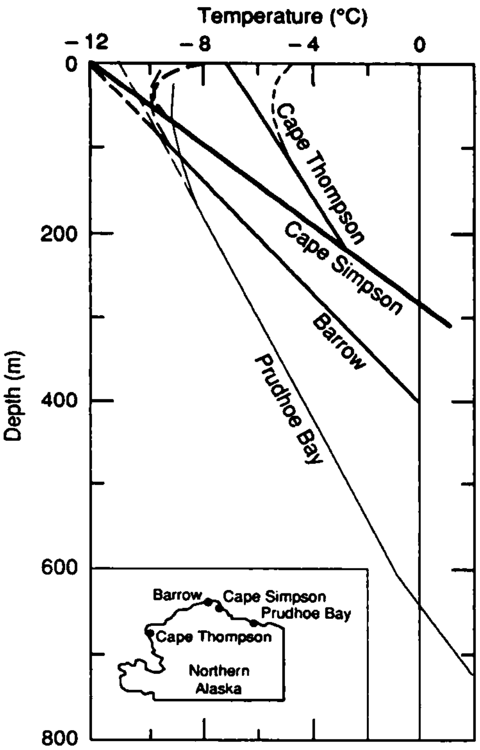
In the fall the bottom of the active layer refreezes from the top of the cold permafrost upwards, while the low temperatures are freezing the active layer downward from the ground surface. The thin soil and vegetation layer is thus annually displaced upward, as a new layer of ice is formed on the already existing horizontal ground ice. While the extent of such buried ice sheets has not been extensively investigated, they are believed to be quite large. However, there may be very little topographic relief, such as hills, knobs or pingo-like formations, or even polygonal features, to suggest that the ice is even there. Massive ground ice such as this was revealed when excavating the reserve pit (where cuttings from the drill operation are deposited) for the exploration well at Tunalik in the National Petroleum Reserve–Alaska. Similarly two drill holes at the nearby runway revealed about 10.5 ft of ice under a 2-ft thick organic mat. Clean beach sand was found under the ice at both locations.

Ground ice occurs not only as vertical wedges or horizontal layers but also in the form of crystals, lenses or discrete layers within the frozen ground, particularly in fine-grained soils. Silts and organic silts, which are commonly found throughout the area, have a notoriously high ice content. While difficult to quantify, ice is also found in bedrock. All bedrock exposed to annual thawing and refreezing is also subjected to ice forming and reforming each year within fissures and joints. Ice within these jointing systems is responsible for the lateral and vertical displacement of large blocks and is an important factor in the natural weathering process of rocks in cold climates.

Frost action within the active zone is also responsible for other types of ground patterns, which can be readily identified. These include boulder fields that may have little or no appreciable vegetative cover or soil matrix, or sorted stone circles in which the larger stones are moved laterally, with smaller stones or soils within the center of the circles.

Thermal regimes

Permafrost has often been described as being like concrete. Anyone who has attempted to use a pick and shovel to excavate frozen ground, especially in the winter, would agree in many respects with this comparison. Permafrost, however, may thaw if thermally disturbed. When fine-grained soils are thawed, they can be readily dug by hand, have very



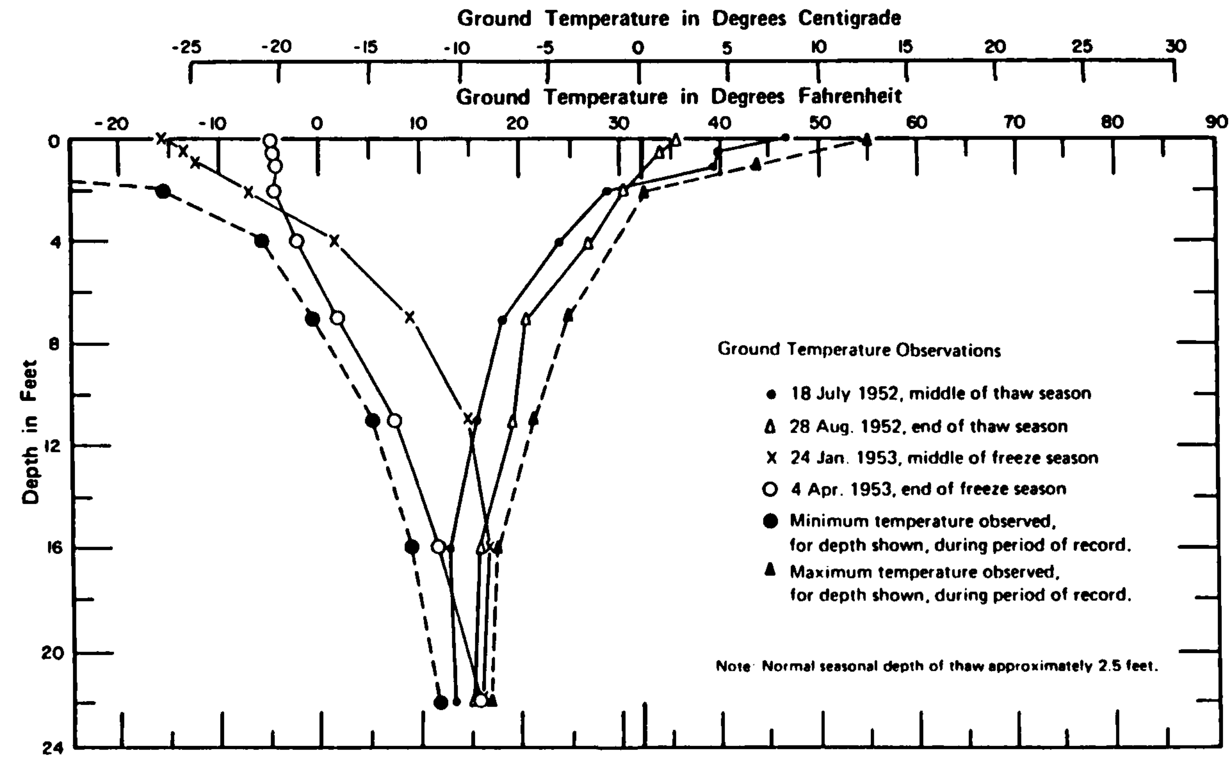
little strength and may even flow like mud. Accordingly, there can be a drastic change in strength and other properties upon thawing.

Temperature is therefore very important. To simplify the following discussions regarding ground temperatures, we will first examine the thermal regime of permafrost as it applies to great depths, i.e., > 2000 ft, and then examine in more detail the regime near the ground surface.

Ground temperatures with depth in northern Alaska have been very carefully measured in abandoned exploration wells. The wells were cased and left filled with diesel fuel. The temperature observations were carried out over many years to avoid the thermal disturbance created by the drilling. These observations, taken by the USGS, now span more than 30 years and have proven extremely useful in the analysis of permafrost, past climatic changes, and more recently with respect to global warming.

Figure 27. Generalized profiles of measured temperatures (from Lachenbruch et al. 1983) on the Alaskan Arctic Coast (solid lines). Dashed lines represent extrapolations.

Ground temperatures with depth at several locations in this area are shown in Figure 27. While Barrow, Cape Simpson and Prudhoe Bay are all along the north coast, there is an obvious difference in the depth to the bottom of the permafrost, assumed to be at 0°C. This figure also shows the wide range in geothermal gradients (°C/m) between the wells. The geothermal gradients are remarkably straight, reflecting quasi-equilibrium conditions, as the heat from greater depths is conducted upward. Frozen soils and frozen bedrock have a higher conductivity



The 1952-53 season was chosen as typical. Plots of maximum and minimum temperatures for the middle and end of both the freeze and thaw periods are presented, along with maximum and minimum soil temperatures recorded at each depth during the period of record. Period of record is 10 years.

Source: U.S. Army Cold Regions Research and Engineering Laboratory.

Figure 28. Ground temperature profiles for Barrow (from Selkregg 1975).

than their thawed counterparts and thus are capable of conveying the heat from below the bottom of the permafrost. Ground temperatures at much greater depths are quite high. One can perhaps appreciate how high when considering that the crude oil being produced at Prudhoe Bay is about 82°C (180°F). In very deep exploration wells the temperatures at depth are even higher. At the 6100-m (20,000-ft) depth, at Inigok No. 1, the temperature was 201°C (394°F) and, at about the same depth in the Tunalik well, about 210°C (410°F).

With the virtually constant slope of the lines depicting temperatures with depth in Figure 27, it would appear logical to project these lines to the ground surface to define a mean annual surface temperature. However, temperatures with depth are not linear or constant with time from the ground surface to depths of 20 m or so. Accordingly, we need to enlarge the scale to examine more closely how these shallow temperatures change with time and depth and what influences these changes. Ground temperatures with depth for Barrow are shown in Figure 28, at different times of the year (Aitken 1965). These observations reflect the very shallow depth of summer thawing and the very small annular variation in temperature below 20 ft. The depth at which the annual temperature variations do not change is called the depth of zero amplitude. Ground temperatures above this depth vary cyclically over the year and can be approximated by a sine wave. Shallow ground temperatures are very sensitive to the amount of snow cover, the vegetation and the depth of surface organics, soil and moisture content, wind, solar exposure and, of course, air temperatures. Short- or long-term changes in one or more of these factors and the latent heat associated with freezing and thawing within the active layer make all thermal analyses near the ground surface very complex (Aitken and Berg 1968).

For design and construction purposes, one is interested in the mean annual ground temperature (at or near the depth of zero amplitude), the surface temperatures, and air temperatures. Ground temperatures

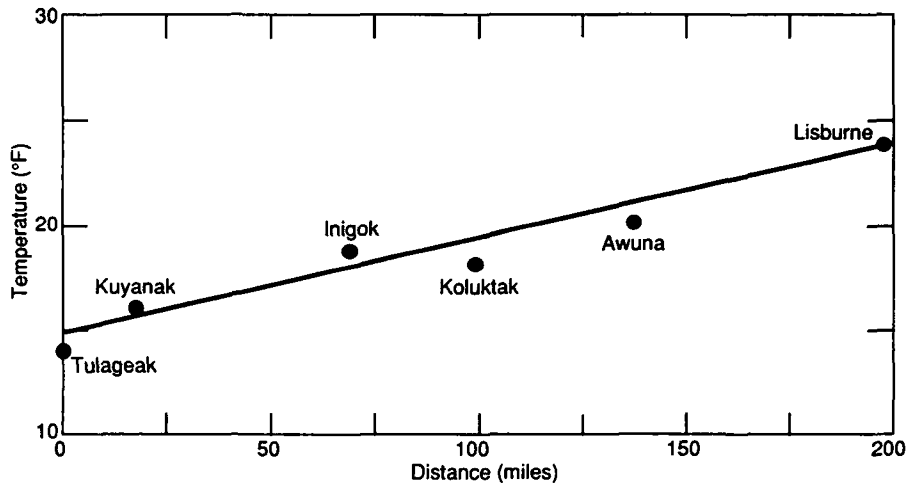


Figure 29. Ground temperatures at the depth of zero amplitude along a north-south transect across the NPRA.

can be determined quite simply by installing a temperature assembly in a small diameter drill hole, about 50 ft deep. The other means and extremes of air and ground surface temperatures can be determined only from long-term records, which are very limited in this area, as previously discussed. Thus one places more emphasis, at remote sites, on onsite air temperature observations in combination with ground temperatures with depth. Ideally these observations are carried out for a year or more before actual construction begins. Air and ground temperature observations can be recorded on very small battery-operated recorders that can operate, without service, for a year or more. The recorded observations can be compared to other locations, with longer records, to assess whether the data are typical or biased toward a warmer or colder summer, or winter, or both. One should also remember that thermal conditions at depth can vary from place to place, from one side of the hill to the other, or under different surface vegetation and organic layers.

Ground temperatures at depths of 30 to 50 ft remain virtually constant throughout the year and are important nodal points in thermal modeling. If one plots the ground temperatures at the depth of zero amplitude from different well sites along a north-south transect across the NPRA, as shown in Figure 29, it is readily apparent that such temperatures get higher as one goes south and approaches the Brooks Range. All of the temperatures shown in this figure were taken at ground temperature assemblies located in undisturbed ground, away from drill pads or runways.

Surface changes and erosion

To fully appreciate the impact of any proposed activity on the North Slope, one should first understand the dynamic changes that occur naturally. While some of these, such as tundra fires, pingos and icings have already been described, there are other changes that should be recognized by even the casual observer. Along low-lying sections of the coast one can see driftwood, often consisting of large diameter trees from the Mackenzie River, which have been washed up onto the tundra, 100 ft or more from the shore. While some of this wood and even occasional erratic boulders may be the result of ice that has been driven ashore (Fig. 30), the majority of the more inland wood is assumed to result from storm surges. Several storm surges have been experienced at Barrow in the last 30 years, and the effects of these are clearly in evidence long after the water has receded. The

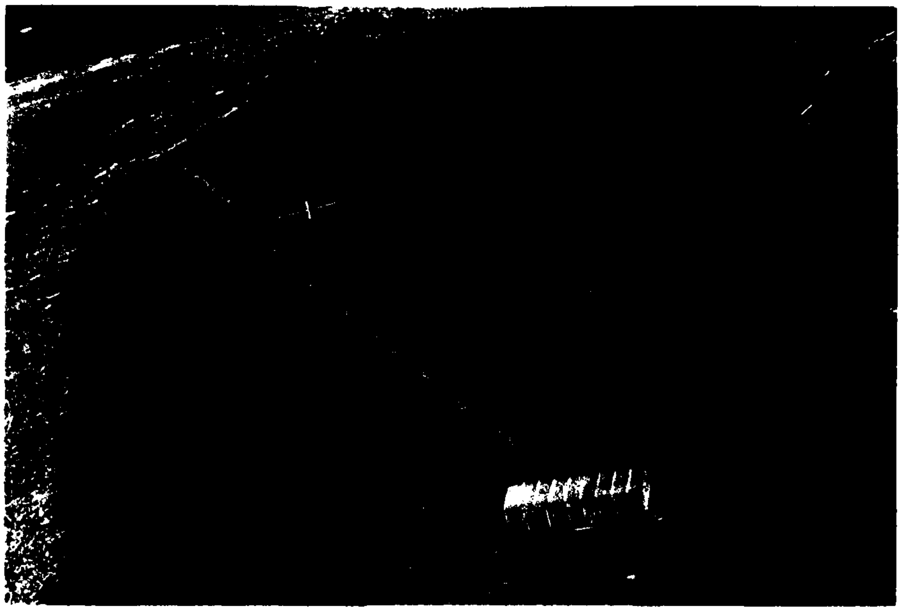


Figure 30. Abandoned DEW line site near Demarcation Bay showing effects of seawater flooding on tundra at upper left and accumulation of driftwood at left.

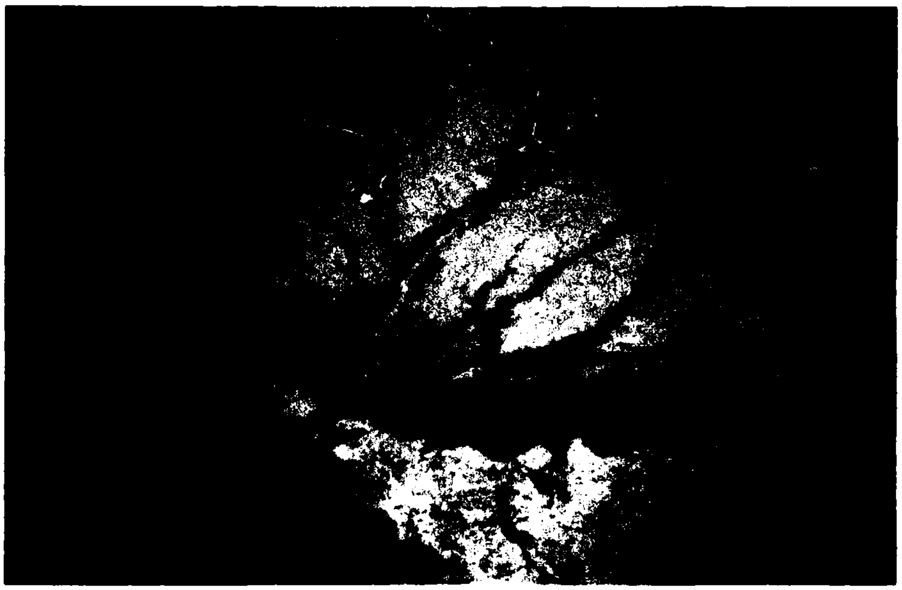


Figure 31. Recently drained lake, south of Barrow, showing little or no vegetation. Note drainage pattern.

tundra vegetation is usually killed by the seawater and the polygonal ice wedges thaw and subside, as shown in Figure 30. In some areas, such as Smith Bay, the destruction of the vegetation is so complete that it has all the appearances of an area devastated by an oil spill. Lakes and ponds near the coast may also retain a high salinity from such storm surges.

When viewing from the air, one can see the distinct outline of the shoreline of old, former lakes, many of which were apparently larger than the present lakes. The regrowth of vegetation within these old lake beds gives mute testimony to the length of time since the lakes were drained, with the exposed sediments and absence of vegetation in others reflecting more recent drainage (Fig. 31). In some lake areas there is very little drainage in the way of streams or rivers, and one lake seemingly drains into its neighbor, often by way of an interconnecting swale. In other areas a series of streams and rivers penetrate through a series of lakes. Because of the low gradient of these streams they often meander over a considerable distance. When such streams cut into the bank that contains a lake, a gigantic flood of water escapes, causing widespread downstream flooding. One such lake, which eventually will be broached by a stream, is shown in Figure 32.

The lakes within the Arctic Coastal Plain typically have deep and dark interior sections, which are surrounded by tan or brown tapering shallows (Fig. 33). The shallows usually freeze to the bottom each year, whereas the central pool does not, often providing a wintering-over spot for lake trout and other fish. These deeper lakes turn over twice a year, in the early summer after the ice cover has disappeared, and again in the fall. A photograph of one such lake turning over is shown in Figure 34. The lake was light brown and appeared to be uniformly mixed, in sharp contrast to its neighbors. The turning over is caused by the change in density of the near-surface water, which is heaviest at +4°C. The denser water sinks in convection cells and the soft bottom sediments are stirred up. The lake waters are very turbid during these periods and completely unusable as a source of drinking water. This turbidity may last hours or days, depending on the cloud cover and other weather conditions.

In the late summer, one can often see ice below the water in small and shallow lakes or ponds. This ice is kept submerged because it is connected to the frozen sediments at the bottom of the lake. Such anchored ice may persist throughout the summer, and is commonly seen in colder-than-normal summers. Knowledge of the lakes throughout the Coastal Plain and even within the Foot-

Figure 32. Lake that will soon be broached by cut bank of meandering river.

Figure 33. View of lake showing deep interior and shallow perimeter on calm day.

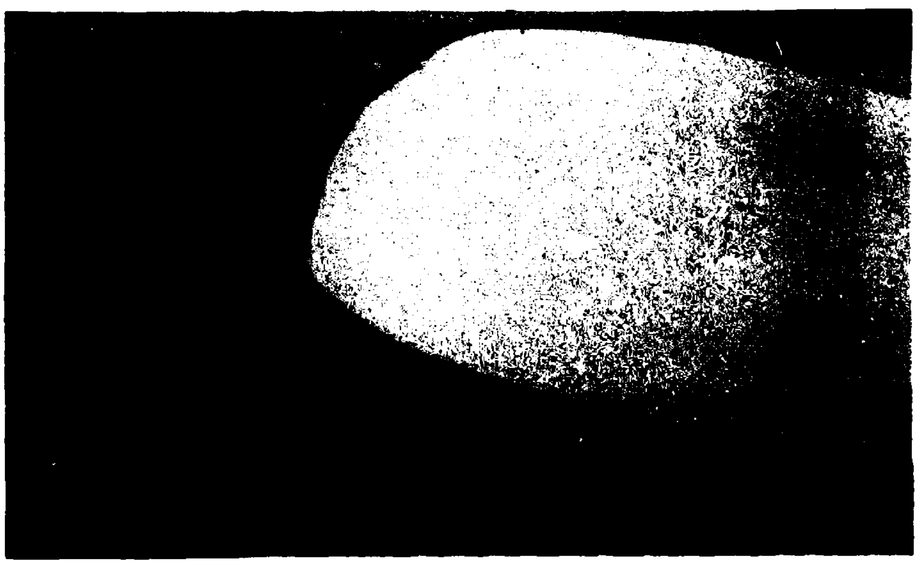


Figure 34. Lake turning over in spring. Note muddy water compared to lake at lower left. Note polygonal ground patterns and former shoreline of ancient lake at upper left.

Figure 35. Old trail in Kaolak well site area, showing development of ravine.

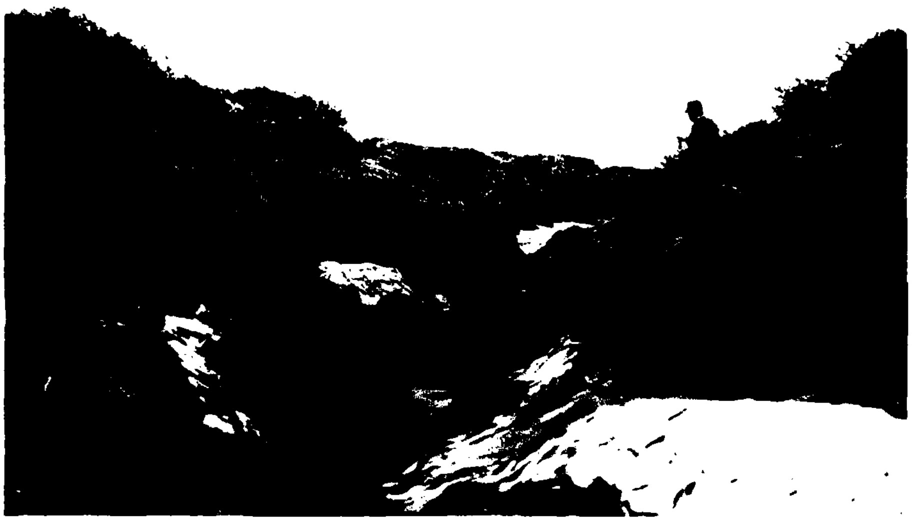


Figure 36. Ravine of Figure 35, as seen from ground.

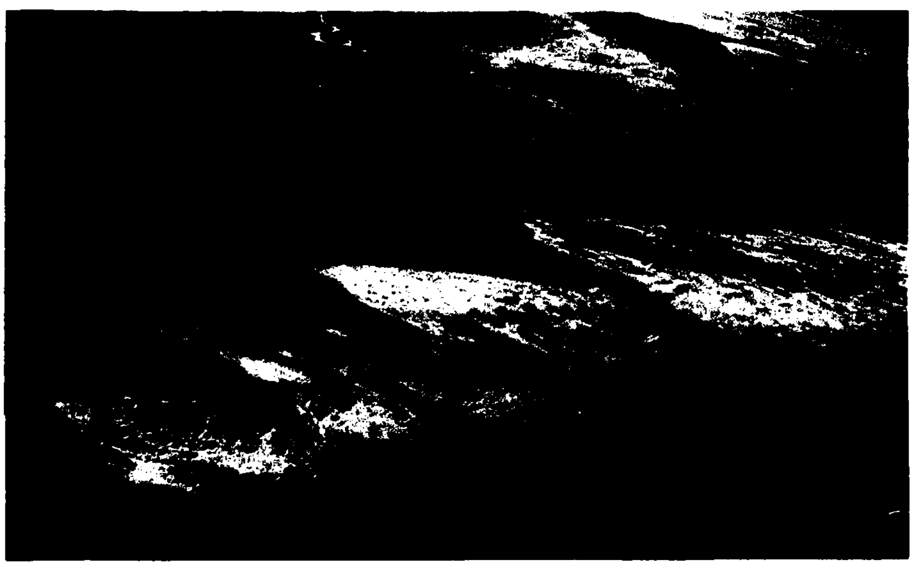


Figure 37. Ventifacts along Ikpikpuk River.

hills can be important in the selection of one or more for ice airstrips, as sources for ice aggregates for snow/ice roads, or as a source of water.

Erosional features caused by natural events can provide insight into what might happen if the same terrain were disturbed by construction activities (Haugen and Brown 1971, Onesti and Kirsch 1982). Prime examples of man-made and natural erosion are to be found in the Fish Creek area (Lawson 1978, Lawson et al. 1978). In other areas, erosion and thermokarst features caused by vehicles in earlier exploration programs can also be seen (Fig. 35 and 36). Erosional features caused by winds, called ventifacts, are also helpful in gaining an appreciation of what might happen if the same sandy materials were incorporated in high fill sections, such as drill pads (Fig. 37).

Summary

The 100,000-mile^2 area of Alaska to the north of the Brooks Range includes mountains 8000 to 9000 ft high, the Southern Foothills with east-west trending ridges, the Northern Foothills with gently rolling hills covered with grasses, mosses and sedges and the Arctic Coastal Plain with a multitude of oriented thaw lakes. The new series of USGS open file reports shows the bedrock, soils and permafrost features within each quadrangle of the North Slope, providing an opportunity to plan and prepare preliminary designs prior to the short summer season.

The cold maritime climate of northern Alaska must be fully understood and appreciated because virtually all activities involved in petroleum explorations are related to the environmental conditions. The area is an arctic desert, with an annual precipitation of less than 5 in. Snow and below-freezing temperatures occur in every month. Low winter temperatures, combined with persistent winds, produce a severe wind-chilling effect. Outdoor activities are also influenced by the long arctic winters without sunlight. Nevertheless, these winter conditions make exploration work possible by providing a persistent snow cover, frozen ground and thick ice covers for 6 to 7 months each year.

Permafrost and ground ice are important considerations in all construction activities. Polygonal ground, pingos, taliks and naleds are examples of the distinctive features of the area that one must recognize and appreciate; one must plan for these features to successfully carry out exploration activities without causing irreparable damage to the environment.

CHAPTER 3. TRAILS AND WINTER ROADS

Since roads are lacking in northern Alaska, supplies and equipment must be moved overland to new exploration sites. Before discussion of how such moves are currently made, some background information might be helpful to appreciate why some former overland operations are no longer permitted.

To understand the modes of cross-country operations employed in northern Alaska in the mid-1940s, and throughout the 1950s, one must appreciate the vehicles and equipment used at that time. The knowledge that huge loads could be (and are still) hauled by sleds on snow-covered trails was well known. Similarly, the large bulldozers available during and after World War II provided the necessary horsepower to pull the large sleds, wannigans and wagons to support the petroleum exploration efforts on the North Slope. Other war-surplus tracked vehicles, such as the weasel and amphibious tractors, were also pressed into this northern operation.

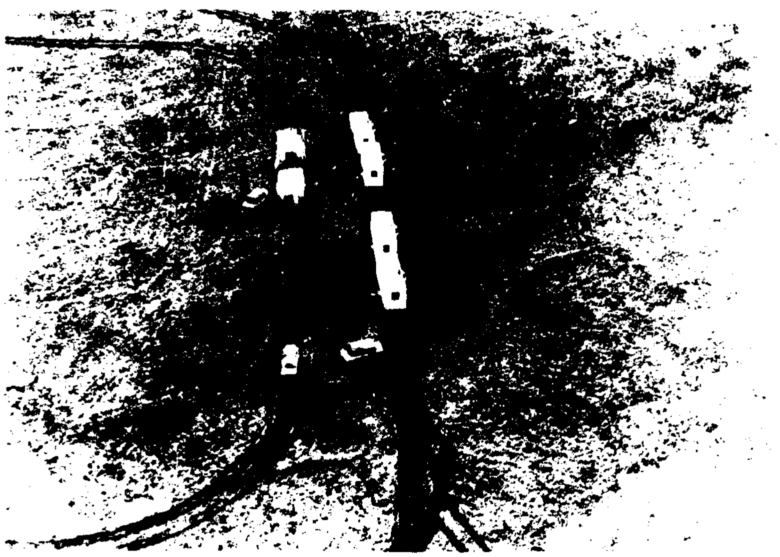


Figure 38. Geological field party operating in PET-4, about 1947, using tractors, sleds and weasels.

Figure 39. Tractors operating on tundra in PET-4 during the summer (1947?). Note scars left by single and multiple passes of tractors.

After establishing a base of operations at Pt. Barrow, initial petroleum exploration efforts ranged farther and farther inland. Geological field parties covered sector after sector, during the summer, using tractor-drawn wannigans and weasels (Fig. 38). Fuel caches were carefully planned and stocked in the early spring by ski-equipped bush planes, allowing the party to operate for months during the summer.

Overland movements from Barrow to Umiat were initiated during the winter of 1944-45 across the frozen and snow-covered tundra and lakes to the southeast of Barrow, then southward up the Ikpikpuk River and finally eastward along the ridges to Umiat (Reed 1958). The necessity to cross deep snowbanks and rivers caused many delays and hardships. The following year greater use was made of ice, with the "cat" trains running along the frozen coastal ice to the Colville Delta. There they turned southward, using the frozen Colville River to reach Umiat. This route, while longer, proved to be much easier and quicker than the previous overland route. While this sea ice and river ice route was used for many years in support of the activities at Umiat, there were other inland sites that had to be drilled, requiring cross-country rig movements.

These early cross-country movements also included summer operations, since the tracked vehicles could operate on the shallow active layer. However, the tracks of the vehicles sank in and caused ruts, even with a single pass (Fig. 38 and 39). Route selection to avoid marshy areas, streams and rivers became increasingly important for these summer operations. Large fuel drum caches were also established and several trails usually converged at these fuel caches. This often encouraged repeated use of the trails, in both winter and summer. Large drilling rigs were also moved in the summer and fall. Rather than drag the heavy sleds on the grassy surface, blading away the vegetation and surface organics was found to allow the sleds to bear directly on the top of the permafrost, with the sled runners sliding easily on the thin layer of mud. These bulldozed trails are still in evidence, some four decades later (Fig. 40). The organic berms on each side of these trails have subsided and weathered to some extent, but they are still in place. The berms act as dikes, causing snow to drift and collect within the trail and to each side.

Such disturbed trails also produced an aquatic environment, conducive to different varieties of natural grasses, predominantly the cotton grass. Several stretches of these old bulldozed trails can now be best described as a series of linear ponds or canals (Fig. 41). Conversely, in the Foothills, some of these trails traversed slopes and intercepted surface runoff, which was then channeled along the trail. It is perhaps fortuitous that the area has short summers and little precipitation, for deep gullies, like those shown in Figures 35 and 36, would be more prevalent.

Tractor-drawn sleds have been employed on many projects over the years, including the construction of the Distant Early Warning sites along the northern coast. Before the widespread use of natural gas at Barrow there were annual "swings" to obtain coal for the winter. Following the discovery of oil at Prudhoe Bay, and the ensuing delays in completing the Haul Road, a winter road was built from Livengood to Anaktuvuk Pass, then north and east to Prudhoe Bay. This winter road, called the "Hickel Highway," was used during the winters of 1969–70 and 1970–71 by trailer trucks and other wheeled vehicles, rather than sleds. Many of these old trails and winter roads are shown on current topographic maps, not because they are established routes to follow, but because they were clearly seen by the map makers as trails on the airphotos. One should study these topographic maps to appreciate the extent to which some form of overland transport has been utilized in the past.

To simplify the following discussions, a few definitions might be helpful. *Trails*, as used here, refer to winter trails that require virtually no construction or maintenance effort, except perhaps to remove or level off obstructing, isolated snowdrifts. The trails are unimproved except by the compactive effort of the leading vehicle using the trail that winter. Normally the vehicles employed on such trails are Caterpillar tractors and sleds, or large rubber-tired vehicles (Rolligon, Delta, Foremost, etc.). Normally, conventional vehicles, with small highway tires, are not used on trails.

Winter roads are prepared or constructed roadways that use the existing snow cover, additional snow or crushed ice, which is compacted and watered to produce a hard surface capable of supporting conventional highway vehicles

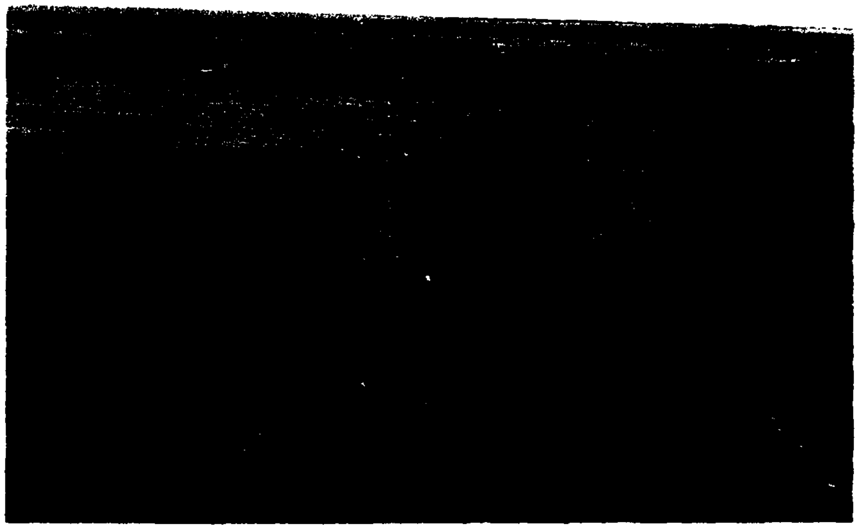


Figure 40. Old bulldozed trails near South Meade well site. Note man in center of 1981 photo.

Figure 41. Canal formed by passage of vehicles after more than 40 years.

Figure 42. Foremost off-road vehicle, with trailer. This type of vehicle is now used instead of tractors and sleds.

with regular tires, with or without chains. Winter roads constructed with ice are sometimes called ice roads; however, the term ice road is normally applied to roads over frozen rivers, lakes or offshore areas.

Off-road operations involve any trafficking of the tundra or frozen water bodies, including the transporting of snow or ice for the construction of winter roads, which is not done on trails or winter roads. Off-road operations also include the trafficking of the tundra during the winter for snow removal operations at drill sites. No trafficking of the tundra by heavy vehicles during the summer has been allowed for more than a decade.

Time of year and degree of impact

Unlike a generation ago, all cross-country movements today are limited and controlled by the groups or agencies having jurisdiction, be they Federal, State or Native Corporation. Typically such operations are limited to the winter months, and specifics must be supplied with the application as to the route, types of vehicles, proposed time schedules for construction and use, etc. In short, overland operations involve a lot of preparation and planning.

While stipulations may vary somewhat between agencies, all cross-country moves are generally restricted to the wintertime, when the ground is frozen and there is a snow cover. Since the managers of some operations would like to begin as soon as possible in the early winter, and extend as late as possible into the spring, there must necessarily be certain conditions that must be met. For instance, the U.S. Navy and the USGS established in 1975 and 1977, respectively, that seismic survey operations and winter road or trail construction could not commence until there was along the route at least 12 in. of seasonal frost in the tundra and underlying mineral soil, and an average depth of 6 in. of snow (Schindler 1988). These stipulations also provided additional information for planning purposes, indicating that such combined frost and snow conditions would not normally prevail until about 15 October, occasionally not until 1 November. As previously discussed under the climate section above, there is a primary snowfall peak in October. Thus, under normal conditions there will be an ample snow cover by 15 October.

Because of the availability and demonstrated ability of some special vehicles that have recently been introduced into arctic service, some stipulations may be waived with respect to starting dates, frost depth and snow cover. Such exceptions allow the use of lightweight all-terrain vehicles (ATVs), low ground pressure vehicles (Rolligons), and air cushion vehicles (ACVs), which require little or no frost or snow cover. Some of these special vehicles can operate throughout the summer months as well, based on single and multiple pass tests of these vehicles, to determine both short- and long-term disturbance of the tundra (Abele et al. 1978, 1984).

Bulldozing of winter trails, for the preparation of winter roads, is not allowed. This reduces the possibility of cutting off the tops of the grass tussocks or cutting through the organic ridges that exist in the low-center polygonal ground areas discussed previously. The use of shoes at the bottom corners of the bulldozer blade is normally not allowed. In theory the shoes should keep the blade from cutting into the vegetation; in practice the shoes cause the most damage. Thus, the normal sequence of today's trail and initial winter road construction is to first employ a dedicated vehicle (Rolligon type or low ground pressure tractor) to compact the snow. After several passes of these vehicles the trail is ready for normal usage by conventional tractor-sleds or other overland vehicles (Fig. 42). For some snow conditions, particularly for densely packed wind-driven snow, little or no preparation of the trail is required.

In the springtime, increasing amounts of solar radiation and higher daytime temperatures can begin melting the snow cover on the lakes and tundra. Stipulations by the USGS, based on previous operations within NPRA, require that all winter road or trail use cease when melting occurs, usually by about 5 May in the Foothills area (at elevations exceeding 300 ft) and about 15 May in the coastal areas (Schindler 1988).

Limiting trail use to only the wintertime, when the ground is frozen and snow covered, is a significant change from the year-round operations of a generation ago. The impact of winter-only operations varies widely and is a complex function of many factors, acting independently and in combination. First there is the compaction of the vegetation, even under the stress-reducing blanket of snow. This compaction appears to vary with the vehicles, snow conditions, and the vegetation types, ranging from only bending the grass to physically crushing or breaking taller vegetation, including dwarf willows and other shrubs. The worst visible damage is usually noticed where vehicles have turned around, the worst offenders being bulldozers, which must pivot. Compacting the snow along the trail also changes the thermal environment that the vegetation normally experiences. This is not unique to the Arctic for the "winter kill" from tire tracks on snow-covered lawns in the temperate zone (Fig. 43) is the same process at work. The compacted snow, augmented by additional snow that drifts into the trail, may also persist longer into the springtime. This can reduce the length of the subsequent growing season, and further stress the plants. Normally there is little permafrost degradation beneath modern arctic winter trails and the plants appear to have every chance of reestablishing their original condition (provided the same trail is not used repeatedly), although such healing may take years or even decades.

Usually the most visible signs of distress on modern winter trails are those short stretches across low spots or drainage swales between lakes, particularly on heavily used trails. In addition to the obvious distress to the vegetation caused by multiple vehicle passes, some segments of the trail may be rutted or even covered with an organic mud. Such distress is normally attributed to late season operations, when these low areas are partially or wholly covered with slush or meltwater.

Figure 43. Winter kill of front lawn by wheeled vehicle, in Hanover, New Hampshire.

Route selection and trail marking

Route selection for cross-country moves is usually done in the office, with maps at both the 1:250,000 and 1:63,360 scale, if available. Other maps that should be used include those for soils and geology, special wildlife habitat, nesting and denning areas, and when available, vegetation. If the proposed route includes near- or offshore routes, bathymetric and ice maps should also be assembled and consulted. The date of all maps should be carefully noted, because some features may have changed over the years, particularly lakes and coastal shorelines.

Old trails on these maps should not be considered as representing trails to be reused. In many cases they should not be reused, for they may be badly scarred and reflect the 1940s and 1950s style of summer operation. The route, as opposed to the specific trail, may be helpful, when considering how to get from point A to point B.

Various considerations go into the initial selection of the route, including the proposed time or times of the year when the trail will be used, thickness of ice to be expected, types of vehicles and their ability to negotiate steep grades, etc. Vegetation maps and airphotos are also helpful in the selection of preferred routes or identifying problem areas that should be avoided.

Frozen lakes, rivers and coastal areas are valuable options for winter cross-country moves, since they usually provide for faster travel, require little or no preparation, and create the least disturbance. Strict attention, however, should be given to sensitive shorelines. Many lakes have relatively steep banks along certain portions or the shoreline. Steep bank areas often have notoriously deep snowbanks. Conversely one should also carefully consider and examine low-lying or swampy areas around lakes, where streams may enter or leave the lake. Normally one would want to be close to but not directly in these drainageways.

The steepness of river banks should also be carefully studied, avoiding areas with meandering channels with high cut banks on alternating sides. Changes in stream widths and velocities should also be kept in mind, particularly at bends, for increased water velocities can contribute to thinner ice. Hydrologic records, if available, can be helpful in establishing how much the river might drop in the winter. One should carefully note where old trails crossed the same or similar rivers or streams in the area.

Before taking to the field for a summer reconnaissance it is important to have preselected a route. However, one should have an open mind, and various alternative routes should also be plotted for field examination. Normally the field inspection of the primary and alternative routes is done with a helicopter, preferably during the summer. The initial reconnais-

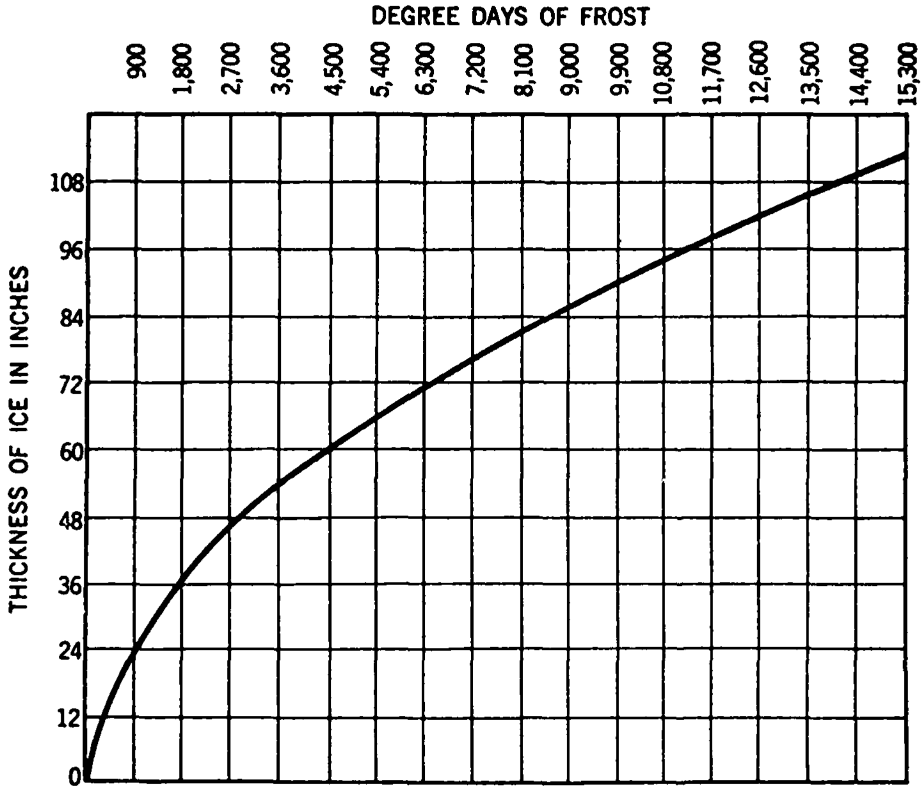


Figure 44. Rate of growth of freshwater ice per degree-days of frost (U.S. Army 1962).

sance begins with a general inspection, including any old trails, the more difficult stream crossings, etc., just to get the lay of the land.

Immediately following the initial reconnaissance a specific corridor will normally be investigated. During the detailed inspection of this corridor, various alternative routes are investigated for different segments. These routes are carefully mapped, for they may in fact be used, if the primary route is later rejected, e.g., because of thin ice, etc. Critical elements are mapped and photographed during this reconnaissance and field notes are carefully kept for preparation of a detailed report. This report is not only used for permit applications, but also for planning and actual operations. Information in these reports can often dictate the type of equipment that might be required to initially break trail, or be used on the trail during different periods of the winter.

The primary trail, after being carefully selected, is then staked out with appropriate poles, flags and barrels. The trail markers are placed with the equipment operators in mind, not for the convenience of the surveyors. The trail markers are consistently set at a constant distance (10 ft) to one side of the trail (i.e., to the left going north or west). Various trail markers have been used over the years, ranging from bamboo poles with flags, to aluminum poles with light reflectors. Common to all poles is the problem of driving them into the permafrost, since the thawed organics of the active layer normally will not provide sufficient lateral restraint to keep the poles upright very long. One solution is to carry a small portable gasoline drill to prebore a hole into the permafrost for the stake or pole. Aluminum poles have also been installed by first driving a short length of rebar into the permafrost, with the aluminum pole being slipped over the top of the rebar. Typically the rebars are 1/2- to 1-in. in diameter and about 4 ft long, while the aluminum poles are 3/4- to 1.5-in. in diameter and 8 to 10 ft long. Bamboo poles are typically about the same size. Low-ground-pressure vehicle operators, however, do not like these rebars, for they reportedly can puncture tires. Accordingly, if used, all rebars should be removed when the aluminum poles are picked up.

Painted oil drums are conspicuous markers that are especially useful on prominent hills and to mark specific landmarks or mileposts, lake crossing points or other significant points along the trails. The drums are typically set upright and filled with sand or water to a depth of 12 to 18 in., so that they remain upright in high winds. All such drums should be numbered, dated and have the owner's name, and be removed when no longer required.

Plastic surveyor's tape and flagging can be of value to the original surveying of the trail. However, most plastics cannot endure the wind and embrittlement from the low winter temperatures. Colored cloth, properly secured to the stake or pole, is more enduring. Reflectors on the poles are particularly useful in reflecting headlights, since most of the operations along the trail are done in darkness. Reflectors are attached with double "U" clamps to the poles and aligned with the route. Depending on the terrain, the trail markers may be set at close intervals (0.1 mile) or less when changes in direction are required. On long trails it is important to have mileposts with which vehicle operators can check their progress and position on the map. Knowing one's location on the trail is critical in the case of breakdowns or accidents, when one must radio for assistance.

Trail markers are particularly useful when originally breaking trail, for the trail itself is normally followed by subsequent vehicles. Snow drifting can obliterate portions of the trail, however, especially after heavy snowfalls. Thus, the trail markers can serve an important function well into the spring. Trail markers are sometimes left in place for a year or more, so that the trail can be aerially fertilized or in some cases reused in a subsequent winter.

Ice thickness

Ice on lakes is important for cross-country operations of tracked and wheeled vehicles and for temporary airfields. Although this section deals with the use of ice for trails and ice-road operations, much of this basic information on ice will be later referred to when considering ice runways in Chapter 6.

The freezing of ponds, lakes and rivers in northern Alaska is not unlike that in the subarctic and temperate zone. One should realize that the rate of freezing and depth of ice, at any given time, is a function of the severity and duration of the cold weather and is highly influenced by a snow cover. One should also accept the fact that each winter is different (Michel 1971), although the lack of sunshine and the greater severity of the freezing index will consistently produce much thicker ice, typically 3 to 6 ft thick, than in more temperate regions.

Figure 44 shows the relationship between the thickness of freshwater ice and the degree-days of frost, FI, as previously discussed in Chapter 2. Normally, for planning purposes one is interested in the thickness of ice at a given time, not the average or maximum values at the end of winter. The limited data available on several lakes across the North Slope are presented in Figure 45, which demonstrates the variation in ice thickness with time (Bilello 1980, Walker et al. 1986). There are also limited data on the thickness of sea ice, as a function of time, near some DEW line stations. Ice thickness data are also available on lakes that were used for ice airstrips in conjunction with previous explorations. While normally such data are limited to only one or two winters, such site-specific data can be valuable. Unfortunately, much of this information is seldom published and is quickly lost. An exception is the research by Mellor (1982), who observed ice thicknesses on inland lakes in the Inigok-Awuna area and other areas of the North Slope.

The thickness of the ice is one of the principal parameters that can be related to the bearing capacity of floating ice sheets. The other important parameters

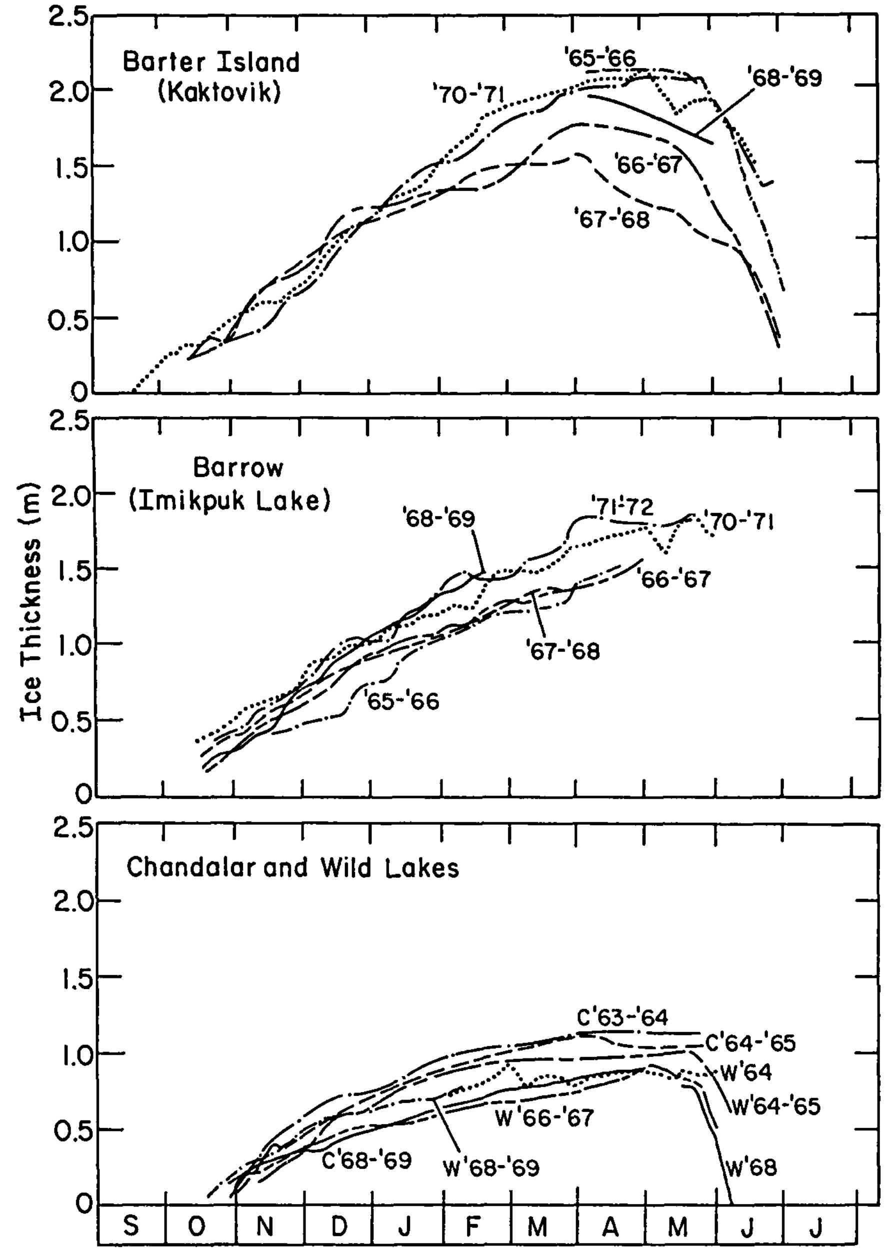


Figure 45. Thickness of ice during different winters at selected lakes in northern Alaska.

are the air temperature, ice surface temperature, and the quality of the ice. Ice is not a solid with consistent strength properties. It is viscoelastic at very low stresses applied for short durations, and plastic under long duration loads. The strength of ice is also temperature dependent, the strength increasing with decreasing temperatures. While temperature effects apply to the critical upper surface of the ice in direct contact with the applied load, the bottom of the ice is in contact with water, at only the freezing point.

Ice that forms on northern lakes is seldom found to be clear, bubble-free, black ice, for invariably it has had a succession of snow accumulations that may have undergone several warming or thawing periods, or even rain. Heavy snowfalls on thin ice can submerge the

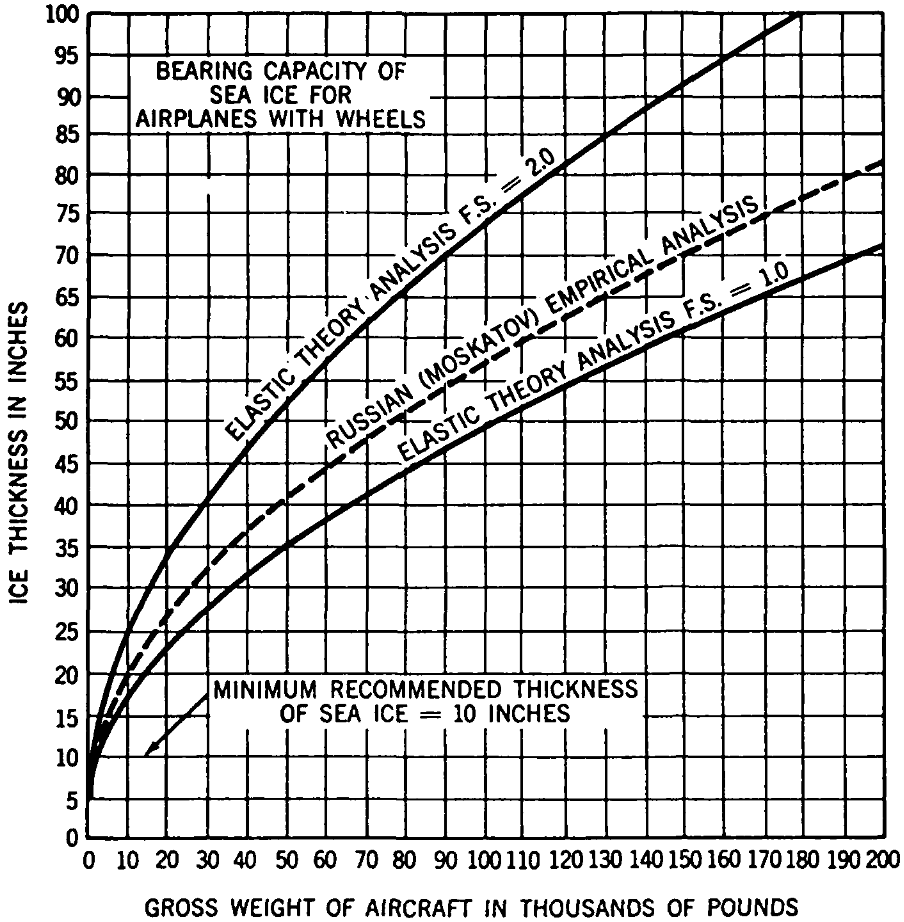


Figure 46. Bearing capacity of sea ice for wheeled airplanes (from U.S. Army 1962).

ice, causing water from beneath the ice to rise up through cracks or holes to flood the snow on top. Eventually this slush freezes and becomes part of the total ice thickness observed. It contains many air bubbles and has a highly variable composition and a reduced strength, when compared to clear ice. Accordingly, ice observations are usually taken with a special coring auger so that the composition of the ice can be carefully examined and the different layers measured and evaluated. The thickness of all near-surface bubbly ice is reduced to an equivalent thickness of black ice, and added to the thickness of actual black ice observed in the lower portions of the ice core, yielding an effective ice thickness. Tables and charts, such as Figures 46 and 47, are then used with this effective ice thickness to determine the bearing capacity of floating ice (Transport Canada 1985, U.S. Army 1962, USAF 1958, 1968). It must be borne in mind that an ice thickness measurement at a particular spot on a pond, lake, river, or along the coast is indicative of conditions at that location only. The ice thickness elsewhere on the same body of water may be greater or smaller, and highly influenced by the depth of snow cover, circulation of water beneath the ice and other factors. Accordingly ice thickness measurements should always be taken at several locations, i.e., not just the middle of the lake, which may be more wind swept and hence snow free.

Trails and roads that cross lakes involve operations on both floating ice sheets and ice frozen to the bottom along the shores. Since the amount of water within the pore space of soil deposits is much less than in a unit volume of lake water, the depth of freezing near the shore is much greater than in the middle of the lake. There are no available charts, graphs or formulas for computing the bearing capacity of a combined ice and frozen bottom layer. One approach would be to measure (by coring) the depth of ice and frozen ground beneath the ice and assume this combined thickness to be entirely black ice. Since frozen ground has a greater strength than ice, one could employ an effective depth greater than that of only black ice, the increase being quite judgmental and related to the soil deposit, i.e., whether loose organic silts or clean sands and gravels. Shallow ponds or lakes, which have been partially drained, have the appearance of a marsh or wetlands. These shallow waters freeze to the bottom quite readily and accordingly cannot be considered as floating ice sheets.

Vehicle operations on ice-covered lakes necessitate that all vehicle operators have training or prior experience with regard to the strength of ice as a function of ice thickness and temperature, separation distances between vehicles, how ice is affected by critical speeds, etc. Operators should also know the danger signs associated with the cracking patterns and deflection (dishing) associated with vehicles parked or stopped on the ice. This training should also include how to escape from vehicles that break through the ice. Many vehicles have rooftop escape hatches just for this purpose. Side doors are often blocked by the ice, or water pressure is so great that one cannot open the doors once the vehicle has submerged. Escape via windows is often the only way to exit some vehicles, even into frigid waters. Survival techniques for immersed victims should be known by all travelers and extra dry clothes and sleeping bags ready for use in all vehicles. Recovery equipment, including heavy cables or chains, should be readily available and the front, rear and sides of all vehicles should be equipped with hooks or clevices. Since there is always the chance that the breakthrough will occur in stages, or in shallow water, quick action can often make vehicle recovery simpler and easier. Accordingly all operators should be trained in recovery procedures and should practice the duties they would perform in emergency situations.

Winter traveling over ice often becomes routine, and much preferred by drivers, it being analogous to coming off a gravel road onto a paved highway. Speeds across the ice are normally much greater than across the tundra. However, like snow, ice is only seasonal in nature and increasing solar radiation in the spring will begin to warm and weaken the ice. A compacted snow layer on the ice not only blocks this radiation, but provides much better traction for the vehicles. Even with the compacted snow on the ice, there will eventually be thawing and melting. When this happens care should again be exercised, for the ice begins to weaken at the surface and often rutting will occur in the slush there. The slush layer, however, hides the degeneration occurring deeper within the ice. This degeneration is called "candling," in which a film of water develops between the crystal boundaries of the ice. Eventually the ice consists of unconnected vertical crystals, much like candles floating in a vertical mode. Accordingly there is a requirement to carefully observe ice conditions in the spring, as opposed to ice thickness. During some spring thawing periods the ice degeneration may be quite rapid, whereas in most breakups there may be a brief warm spell, followed by colder weather. Advantage, if necessary, can be made of late night and early morning traverses of the ice, avoiding the weaker conditions during the midday and afternoon.

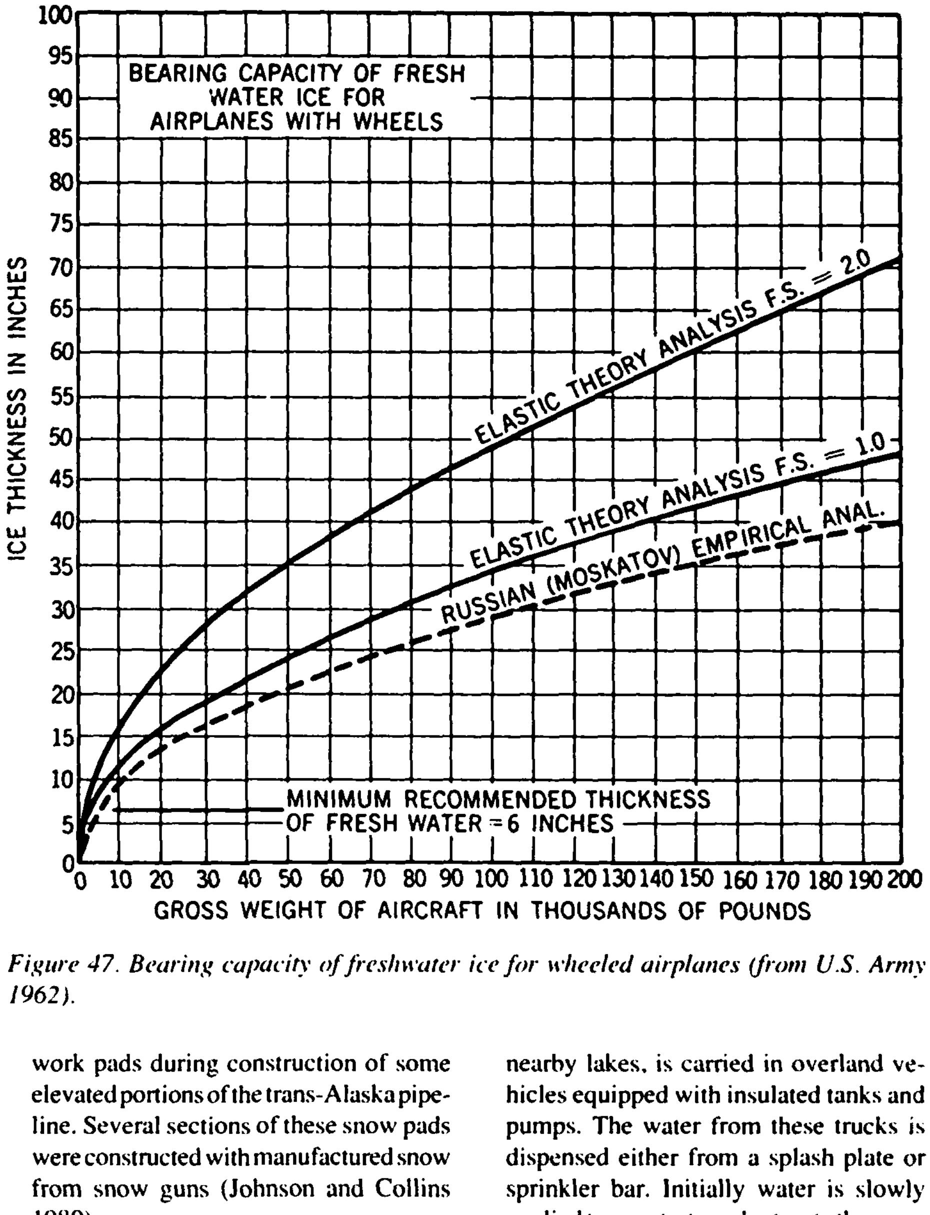


Figure 47. Bearing capacity of freshwater ice for wheeled airplanes (from U.S. Army 1962).

Snow and ice roads

Snow or ice roads, as opposed to trails, are prepared roadways suitable for conventional wheeled vehicles, which might range from pickup trucks to dump trucks (Johnson 1979, Adam 1978a and b). Such roads are used around camps during the winter, and as temporary roadways to borrow sites, an airstrip, or a nearby frozen lake. In several cases (Inigok and Tunalik) snow/ice roads were used to bring in sand and gravel, unavailable at these deep well sites, for the construction of all-season airstrips, roads and drill pads (Fig. 48). Snow roads also served as work pads during construction of some elevated portions of the trans-Alaska pipeline. Several sections of these snow pads were constructed with manufactured snow from snow guns (Johnson and Collins 1980).

Snow roads are constructed by first compacting the snow already in place on the tundra. The initial compaction may consist of a series of passes with the same vehicle, or multiple passes by different vehicles, i.e., a low-pressure vehicle followed by tractors, or just tractors making multiple, offset passes. The initial compaction is directly related to the depth of the snow, its density and temperature. The compacted snow is then either allowed to age harden and become stronger or followed by the direct application of water (Abele 1990). The water, from nearby lakes, is carried in overland vehicles equipped with insulated tanks and pumps. The water from these trucks is dispensed either from a splash plate or sprinkler bar. Initially water is slowly applied to penetrate and saturate the compacted snow as deeply as possible, such that a thick, firm layer is built up after it freezes. Too much water applied at this stage creates holes, with the water draining directly to the underlying ground surface. Too little water creates only a thin ice crust that breaks up under subsequent construction traffic. Thus, the correct initial application of water is important.

After water has been applied, and frozen, the road is covered with more snow, particularly to build up any depressions. This snow is harvested from local lake surfaces or wherever snowdrifts can be

Figure 48. Dump truck, with "pup" trailer hauling gravel on ice road at Tunalik.

Figure 49. Ice road at Tunalik, scarified by grader for better traction.

found. The snow is graded out, compacted and then successively watered to build up an increasingly thick layer of ice. The thin layers of applied water freeze virtually on contact, with little or no lateral flow.

Ice roads are similar to snow roads, in that the initial preparation is the same. However, rather than relying on snow and repeated application of water, chipped ice is employed to build up any depressions and the overall thickness of the road (Fisher 1977, Adam 1978b). The ice is harvested by tractors with rippers from local small lakes that have frozen to the bottom. The crushed ice, resembling pea stone, is then pushed into piles, transported, depositeu on the roadway and graded. Such a layer of crushed ice, after being watered down and allowed to freeze, produces a very deep and strong pavement. The watering requirements, when using crushed ice, are only about 25% of those required when using snow.

Once the snow/ice road has reached a thickness of 12 to 18 in. and construction traffic has in effect proof-rolled the roadway, a road grader is then employed to scarify the smooth ice surface, providing good traction for the regular-tired traffic (Fig. 49). Rescarifying must be done periodically, as the surface gets smoother under repeated traffic and solar warming. Tire traction on such a roadway is excellent, particularly at extremely low temperatures. Weak spots in the roadway are patched with a slush of snow or ice, watered and allowed to freeze. Additional snow that falls or drifts onto the roadbed is incorporated into the roadway by compaction and watering. Low snowbanks to each side of the road are helpful during the watering process and also serve as visual guides for drivers.

Dump trucks with pup trailers hauled 132,000 tons of gravel on the 37.5-mile ice road between the Colville River and the Inigok well site in a 38-day period (Schindler 1988, Mitchell 1981). The vehicles averaged 35 mph along the road. This road utilized as many lakes as possible to reduce the amount of snow road construction. While chipped ice was used to great advantage, this road still required more than 35,000,000 gallons of water to build and maintain. Normally repairs to the roadway were made during 4-hr breaks, the trucks working in two 10-hr shifts. Potentially heavy maintenance on the steep grade on the west bank of the Colville River was minimized by the use of a gravel overlay (Fig. 50). The gravel was removed in the spring, just prior to shutting down the road. This ramp required more than 20 ft of snow, as fill, to provide a uniform grade.

Typically the routing of a snow road will include frozen lakes to the greatest extent possible, because they require little or no construction effort in late winter, as compared to snow/ice roads on the tundra. Mid- to late-winter use of frozen lakes usually requires the compaction or removal of the snow cover, there normally being a sufficient thickness of ice to support the construction equipment and the vehicles that will follow (see Chapter 6), although the thickness of the ice should be checked by appropriately spaced borings across each lake. While a small snowbank or berm along the route across the lake can be helpful as a visual guide for drivers, such snowbanks should be kept low, so that they do not cause snowdrifts to develop across the roadway. Deep snowbanks along roadways across lakes can also create a load on the floating ice, causing the ice to deflect and sink. Deep snowbanks also insulate the ice, retarding further ice growth, and can cause longitudinal cracks to develop along the much colder ice in the cleared roadway. Thus every effort should be made to spread out any deep snowbanks on lakes, allowing the snow to drift over and past the roadway. Trail markers are also used on the ice, being set in drill holes within the ice or snowbanks. Lakes are often used as passing zones or pull-off areas.

Ice roads across rivers, lakes or sea ice can be thickened in the early part of the winter by flooding the surface of the ice with water pumped from beneath the ice, as will be discussed under the section on airfields on frozen lakes in Chapter 6.

Multiple use effect

Winter trails repeatedly used, year after year, can create objectionable damage to the tundra. Perhaps the greatest distress in evidence today has been caused by overland operations, including operations without a snow cover, just to the south of Barrow (Fig. 51). Typically such scars are concentrated, as the vehicles attempted to travel along ridges between lakes or around one or both sides of a large lake. While care was taken to avoid similar damage to the tundra when using Lonely as a base of operations, there are scars from the multiyear trails particularly to the east of Teshekpuk Lake. Efforts were made to vary the routes in this area (Fig. 52) to avoid the concentrated effects from repeated use of a single trail. Ironically, the greatest distress was apparently caused not by repeated winter operations, but by the isolated springtime passage of a few vehicles over low wet spots.

Bases of operations have historically been located along the coast of northern Alaska and will undoubtedly continue to be located there in the future, because of the easy access to sea transport and the availability of airfields at active or abandoned DEW line stations. There are currently only a few bases for inland operations, except along the Haul Road. Old inland bases, such as Umiat, could be reactivated. Trails emanating from such bases of operation should be carefully planned to facilitate access to new winter trails.

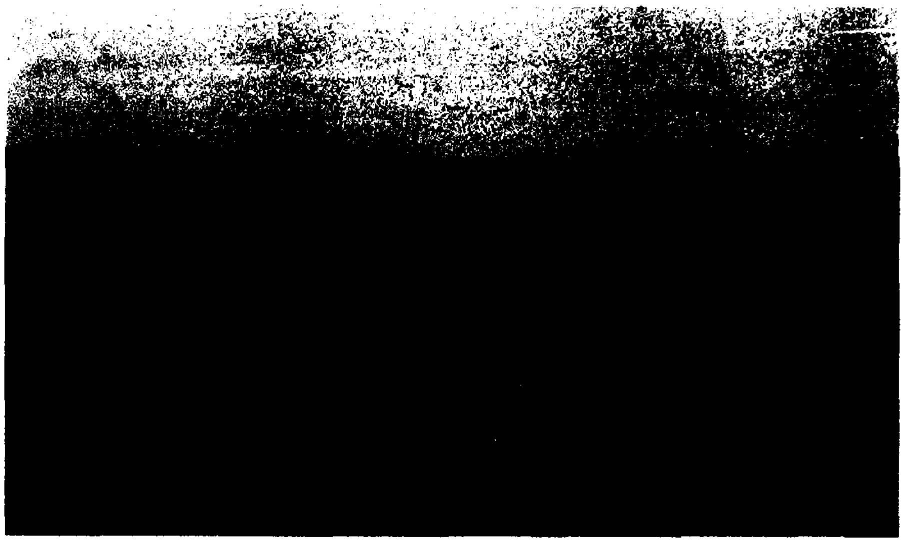


Figure 50. Steep grade on snow/ice road, temporarily covered with gravel for better traction, Colville River to Inigok well site.

Figure 51. Old trails south of Barrow that have filled with water and create new drainage channels.

Rehabilitation of repeatedly used trails may include the application of fertilizer. During the summer of 1981 two Cessna Agwagons (Fig. 53) were employed to spread fertilizer along more than 350 miles of trails radiating from Barrow and Camp Lonely, and between well sites (Schindler 1988). The response to the fertilizer was almost immediate, and recovery of these more frequently used trails is also expected to be quite rapid,

Figure 52. Scars caused by multiple passes of vehicles in the winter along shore of lake, south of Lonely.

with perhaps little residual effect of the stress after 10 years, provided they are not restressed in the interim.

Summary

Cross-country movements in northern Alaska have changed dramatically over the years. Previous overland moves during the summer months by tracked vehicles, sleds and wagons created scars on the tundra, which have persisted for 40 years or more. Such summertime operations are no longer permitted. Wintertime operations on trails have also changed. Current restrictions allow such operations to commence in early winter, when the ground has been frozen to a depth of a foot or more and there is at least 6 in. of snow. Bulldozing of snow to make and maintain winter trails is no longer permitted, drastically reducing the damage to the vegetation and the delicate thermal balance of the active layer and underlying permafrost. Great emphasis is currently placed on route selection and initial preparation of the trail to further minimize surface disturbance. Limitations on trails also include curtailment of operations in the spring.

Winter trails usually include frozen ponds, lakes, rivers or offshore ice, since they require little preparation, are smooth and level and cause essentially no environmental damage. Ice thicknesses sufficient to support heavy equipment are critical and may not develop until midwinter, i.e., several months after overland operations are possible. Thus proper planning and appreciation for the growth of ice as a function of time, and the influence of snow cover and air temperatures are important. The bearing capacity of floating ice as a function of thickness can be determined from published graphs that have been presented in this chapter. Measuring the thickness of the ice, at appropriate intervals, and equating white ice with the stronger black ice are important to safe operations on floating ice for vehicle and aircraft operations. Safety considerations when operating on ice are equally important.

Snow roads are thickened with successively applied layers of snow or chipped ice, which are watered and frozen into a strong and smooth pavement that permits the use of conventional-tired vehicles. Winter roads are normally limited in length, usually between the drill pad and airstrip and/or local borrow pit and water source, although snow roads as long as 37.5 miles have been successively used.

Winter trails and snow roads, as currently employed, cause minimal damage to the tundra. The most common distresses are "winter kill" from the compacted snow and ice, plant damage by the initial trail or road making equipment (especially turning vehicles) and late spring usage. Aerially applied fertilizers or limestone can hasten the recovery. Old trails, as shown on existing maps, usually should be avoided. Multiple-use trails radiating from fixed bases of operations have the greatest potential environmental impact.

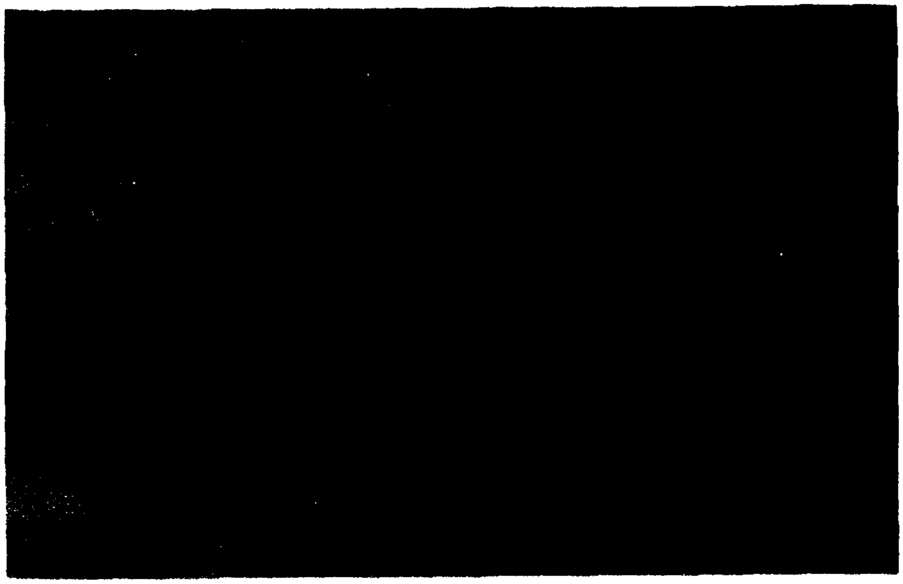


Figure 53. Applying fertilizer with airplane (Agwagon). Top: flying low over former construction camp site at Lisburne well site. Bottom: closeup of bottom hopper of plane.

CHAPTER 4. DESIGN AND CONSTRUCTION OF ROADS

Roads, as opposed to winter roads, are used for year-round travel by conventional vehicles. They are typically employed at deep exploration well sites to connect the all-season airstrip to the drill pad. Sometimes secondary roads are constructed to borrow pits, water supply points, or to coastal beachheads. Gravel roads constructed in support of deep explorations are of minimum width and depth, for their design life is normally only a year or two.

When oil and gas have been discovered in a new area, the roadway network becomes more extensive, linking production drill pads within various sectors with the gathering facilities, the base camp, airport and shore-based facilities. Simultaneous with such development work is the construction of a road network to link the new oil field to existing facilities, i.e., the trans-Alaska pipeline and the Haul Road, as exemplified by the Kuparuk and Endicott fields. Such roads are constructed to much higher standards, with a life expectancy of perhaps 25 or more years. Some of these semipermanent roads are utilized for conveying extremely heavy building modules.

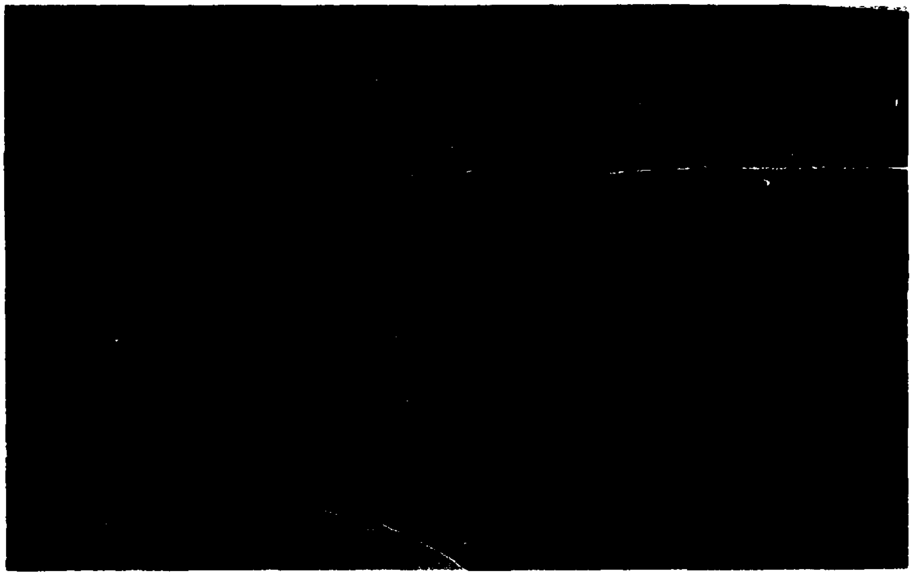


Figure 54. Old and new roads at Umiat. Old road in center leads to wells in hills at upper right.

Figure 55. Old (1947?) photo of gravel road at Umiat, showing effect of thawing ground ice, after only a few years (from Ferrians et al. 1969). Road shown in center of Figure 54.

Design considerations

Functionally, temporary roads are designed to connect point A to point B, such as a drill pad to an airfield. If other facilities are to be linked to the roadway, then the routing of such roads is seldom straight. Topography, drainage and stream-crossing locations will also influence location of the road. Design considerations for such temporary roads typically include the normal specifications for secondary roads, with respect to horizontal and vertical curves, and sight distance. If the roadway is to be a single lane, then appropriate vantage points are selected for the location of pulloffs where vehicles wait until the approaching traffic has passed. The distance between such pulloffs is a function of the anticipated volume of traffic and the sight distance to the next pulloff.

Arctic roads have special design considerations with respect to the presence of permafrost, particularly permafrost that contains large volumes of ground ice (Lotspeich 1971). The influence of the presence of permafrost can be best appreciated by examining roads constructed in northern Alaska (Fig. 54). One of the earliest attempts at road building was at Umiat. Figure 55 is a classic photograph, taken only a few years after the road was built, which has been extensively used to illustrate the problem of building roads in the Far North (Ferrians 1965). The thawing and subsequent settlement over the polygonal ice wedges is clearly evident by the undulations in the road. However, when the 1947 photo is compared to conditions in 1981 (Fig. 56), we see very little additional change, the undulations being somewhat broader and deeper, with water now finding a clear channel across the road at the ice wedges. Since this old road was abandoned, rather than being continuously upgraded with more gravel in the low spots, it perhaps now serves as a good example of how natural revegetation occurs on abandoned roads in the Umiat area.

Another example of early road building can be seen in Figure 57. This road, just west of the Deadhorse airport, at Prudhoe Bay, is often overlooked by arriving passengers who are more interested in viewing the oil field and its associated facilities. This abandoned road also serves as a prime example of the effect of a thin gravel overlay, virtually creating twin ditches or canals along what used to be the shoulders of the road. This early attempt at road building is in direct contrast to the many miles of well-maintained roads within the Prudhoe Bay area.

There are two approaches to the design of roads in permafrost areas: 1) provide full thermal protection to maintain the permafrost condition, or 2) provide for limited thaw penetration into the underlying subgrade. Typically the permafrost condition is maintained by placing a sufficient thickness of gravel such that the in-situ frozen ground is insulated by the gravel, as shown in Figure 58. Typically all roadways are constructed as fill sections; cuts are avoided. The vegetative mat on the ground surface is left in place and acts initially as an insulator. The vegetation is compressed by the weight of the gravel fill and continues to consolidate with time, losing much of its insulating characteristics. Nevertheless, it serves an important function until the normal thermal conditions of the road have been established and the roadway becomes less pervious to the infiltration of meltwater and rain.

Permanent roads, designed to preserve the permafrost condition, are typically 6 ft in depth. In some situations they may require more or less fill, depending on in-situ soil and ground ice conditions. Deep fills are commonly used to build up low spots in order to maintain a minimum thickness, without cuts, on adjacent higher ground.

Temporary roads are normally designed to permit a limited amount of thawing into the subgrade. The maximum depth of such thawing usually is designed to coincide with the depth of thawing of the active layer prior to construction of the road. Normally such temporary roads are 3 to 4 ft thick, being slightly thicker across areas containing ice wedges or massive ground ice and thinner when crossing ground containing gravels, fractured rock or bedrock.

The thickness of gravel required to fully protect the permafrost, or allow limited thawing into the frozen subgrade,

Figure 56. Old road at Umiat, in 1981, from approximately same position as Figure 55. Note brush growth.

Figure 57. One of the first roads built in Prudhoe Bay area, near Deadhorse airport. Note ponding and slumping along shoulders.

Figure 58. Haul Road just north of Galbraith Lake. Buried gas line at right, Brooks Range in background. Note dust from vehicles in center.

can be calculated by several methods (Berg 1976, Lachenbruch 1959). The design calculations employ the freezing and thawing indices, thermal properties of the gravel and in-situ soils, and the mean annual ground temperature. Gravel thickness requirements can also be based on the evaluation of existing roads in the particular area, such as in the Prudhoe Bay area, at operating or abandoned DEW line sites, villages, etc. The latter method typically involves borings, test pits and probings in the fall, when thaw depths are at a maximum.

Thermally, the design of gravel roads is focused on conditions near the centerline of the road. From a permafrost standpoint, however, the shoulders and side slopes are often the most sensitive (Esch 1983). The sideslopes have deep snow covers that insulate the slopes and adjacent tundra, retarding deep frost penetration. While this deep snow could potentially insulate the sides of the road in the spring or early summer, this effect is often insignificant because the snow is often covered with dust and quickly thaws. The snow accumulation along the road also contributes to a greater-than-normal volume of water along the road. When augmented by additional meltwater and runoff from adjacent drainage areas, this concentrated flow along the road can cause deep thawing. Deep thawing along the edges of the road can cause the side slopes to slide or otherwise collapse, since they are normally poorly compacted as compared to the middle of the roadway. This collapsing mechanism can be further accelerated by the thawing of any near-surface ice wedges. Ultimately, this encroachment can extend into the roadway itself, producing the conditions shown in Figure 57.

Since ditches along the sides of the road would only aggravate this situation, they are never used. The best protection from the effects of water is to avoid areas with large side-hill drainage, routing the road along ridges or topographic highs, or running with the drainage, rather than across it. Water impounded along or flowing beside the roadway is, whenever possible, directed away from the road at strategic intervals, or, if necessary, conveyed under the road in culverts. While there will always be the requirement to "fine tune" the drainage along a road during the first year or two after construction, there is really no substitute for good siting. Although good siting requires very accurate surveying, the extra effort is usually cost-effective with respect to life-cycle costs.

Roads in northern Alaska are not unlike roads elsewhere in that they have some sections that are easy to build and maintain and other sections that are difficult to build and very costly to maintain. Careful planning and design can often reduce the frequency and severity of these bad sections.

Winter construction

Road construction can be advantageously accomplished during the winter months. The advantages include the use of snow roads to transport gravel from borrow pits. Placing the gravel in the late winter also starts the thermal cycle in the frozen phase, essentially trapping the cold in the ground with the insulating layer of gravel. The disadvantages include the extra costs associated with ripping and crushing frozen material in the borrow pit and the higher costs associated with winter work in general (cold, darkness, snow, etc.). Frozen fill normally cannot be compacted to high densities and may even contain snow or ice that further contributes to higher than normal void ratios (Crory et al. 1978). When this material thaws, it consolidates and has a reduced strength. The advantages and disadvantages of winter road construction, however, must be considered with respect to the entire project. It may be necessary to build the roads in the wintertime to allow other prime construction activities to continue throughout the summer months.

Winter construction of roads actually begins in the summer, with surveying, soil explorations, permafrost investigations and the assessment of watersheds and drainage. Once the route and borrow pits have been selected and staked out, the work is left dormant until the ground surface has refrozen and is snow covered. At remote sites the early part of the winter is usually devoted to setting up the camp (Fig. 59), with only skeleton crews remaining during the Christmas–New Year holiday period. After the holidays the work force builds up in stages. Once the borrow pits are open, and the rippers and crushing equipment are producing, the project quickly escalates to include a fleet of dump trucks that haul the gravel over snow roads to one or more points on the roadway (Fig. 60). Sometimes, when the borrow material has a poor gradation or contains oversized cobbles, a screening and/or crushing plant is set up. Processed material may not be required for the entire depth of the roadbed, allowing the use of regular borrow or oversized material in the base. However, select material is required in the top foot or two of the road to produce a strong "pavement" that can be easily maintained by road graders. Strange as it may sound, the crushing and screening of frozen material works best when air temperatures are low, there being less caking by the frictional heat produced in the crushing (Brooks 1983a).

Actual construction of the roadway proceeds at a relatively rapid pace with one and sometimes two bulldozers advancing the gravel placed by the end dumping trucks. Typically the base is constructed first, with the upper wearing surface being placed in a subsequent operation. When good gravel is readily available and used for the entire embankment, placement is done in one operation, using lifts of a foot or more. Snow in advance of the initial fill placement is rarely removed or even purposely compacted. This avoids disturbing the vegetation beneath the tundra beyond the toe of the road.

It is presumed that the snow and vegetative cover will be compacted by the weight of the gravel fill. Settlements on the order of 4 to 6 in. are assumed to happen in the first summer, due to the presence of snow and consolidation of the organic mat. Consolidation is also assumed to take place within the initially frozen embankment itself as it thaws and is compacted by traffic. Full compaction of the frozen fill during winter construction is difficult, because the compressive loads are primarily conveyed to the larger particles and frozen lumps. Accordingly most of the compactive effort is provided by the bulldozers and the loaded trucks during construction. Once each lift has been allowed to age harden (a few hours to a day), the frozen fill acts more like a concrete pavement, resisting any further compaction. Deep compaction during the following summer is also difficult to achieve, because of the overall depth of the fill section. Accordingly greater emphasis is placed on the selection of the bank run gravel and the quality of the crushed and screened material to be used for the surface course.

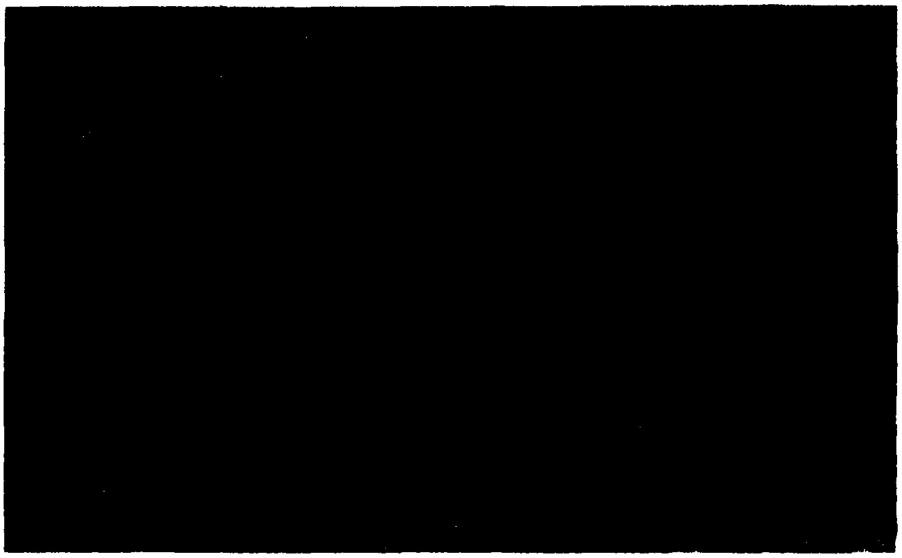


Figure 59. Temporary construction camp at Inigok, with all units on sleds.

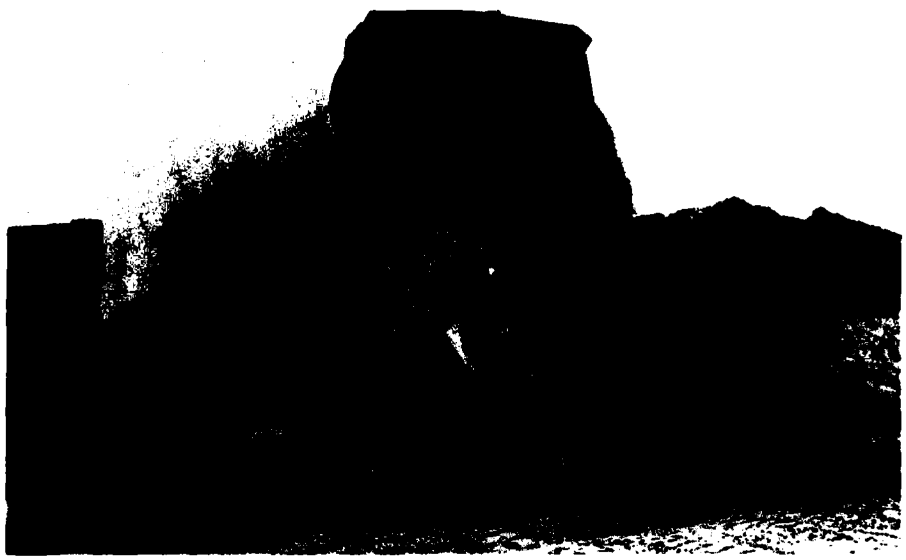


Figure 60. Loading ripped and crushed frozen gravel at borrow pit at Tunalik.

Surface compaction is usually accomplished with segregated or smooth wheel rollers (Chap. 6, Fig. 85). During the initial spring melting period, grading and rolling is done periodically to achieve a smooth and dense surface, fill in any local depressions, and remove any potholes or puddles. Additional fines may also be applied later in the spring, being mixed with the surface course to produce a hard, smooth and virtually waterproof pavement. Normally, little reworking of the side slopes is done during construction or subsequent summers, so that any chance of disturbing the toe of the slope or the adjacent tundra is avoided.

There are no long-term distinguishing features of a road constructed during the

Figure 61. Road from Ivotuk airstrip to Lisburne well, showing timber bridge across Otuk Creek. Seismic train temporarily stored, for summer, in center.

Figure 62. Stockpile of gravel, just north of Galbraith Lake, for road and work pad maintenance.

Figure 63. Construction of Haul Road during the summer, with all equipment working on gravel. Note depth of initial lift.

winter, as compared to roads constructed only in the summer months. A portion of the 7-mile-long gravel road at Ivotuk/Lisburne is shown in Figure 61, the first summer after winter construction.

Summer construction

Summertime construction of gravel roads can and has been used on several projects in northern Alaska. The advantages and disadvantages of summer construction are virtually the opposite of those described for winter construction. While there are exceptions, one usually finds new summer roadwork associated with the wider, deeper, longer, and more permanent roads. This permits the use of large dump trucks and even "belly-dumps" to transport the gravel. Since all operations are confined to existing roads, including access roads to the borrow pits, the entire operation is similar to that found farther south, i.e., conventional Alaskan road construction.

Borrow pits for summer operations may include frozen gravel. Stockpiles are sometimes allowed to thaw for weeks or longer, including some that have been purposely allowed to drain and dry for a year or more. While crushing may be necessary with some material, typically only screening has been required along the Sagavanirktok River. Stockpiled material for both the Haul Road and pipeline work pad is shown in Figure 62.

New roadways constructed in the summer are advanced by end-dumping and pushing the fill ahead with dozers. Figure 63 is a photo of the Haul Road under construction. If the tundra and underlying soils are thawed, soft and wet, the initial lift of gravel may have to be several feet thick to support the weight of the tractors. Accordingly, there is normally little chance of fully compacting the initial lift. Consolidation of the organic surface mat and the thawed in-situ soils at depth is normally very quick, beginning before the final lift has been placed. Secondary consolidation of the organics and thawed active layer is typically only several inches. Additional settlement associated with the subsequent thawing of the permafrost at depth can be significant, especially when ground ice is present. Abnormally deep thawing of the active layer can occur from midsummer construction. Late summer construction appears to have only a minor effect, probably because there is just not enough time to cause substantial additional thawing before the start of the fall freeze-up, which in some areas begins in late August.

Road construction during the spring breakup period is normally limited to high and dry ground. The virtual sheet of water found in low or poorly drained areas during the spring can turn a thin layer of new gravel into a fluid morass of mud. Accordingly, construction in such wet areas during this period is normally delayed until the water subsides.

Drainage structures

Drainage structures for temporary roads consist of culverts, bridges and low water crossings. Design, construction and maintenance of these structures are critical to the integrity of the road and to the permafrost adjacent to the road (Brown et al. 1984). The thermal effects of standing and running water must be understood and appreciated, because water can initiate thaw settlement and erosion that can destroy the road. The loss of a section of the roadway can quickly suspend all work, including drilling.

Drainage considerations begin with site reconnaissance and planning. While standard engineering considerations, such as watershed area, drainage paths and stream flows (Kane and Hinzman 1988) are an integral part of the roadway design, one must also recognize and provide for the unique aspects of such arctic roads. These include the general provision that there will be no side ditches, at least in the tundra-covered areas. Whenever possible, surface runoff should be diverted away from the road. When this is impossible, the water should be conveyed, by culverts, under the road. The velocity and volume of water running beside the toe of the road should be carefully evaluated, providing, for example, for a series of culverts at discrete intervals, rather than large culverts at great distances. The location and sizing of culverts should also consider conditions at both the inlet and outlet of the culvert, because thermal and hydraulic erosion, siltation and scouring can occur at both ends. One must also appreciate how much snow will accumulate along the sides of the roadway over the winter, particularly on the uphill side of the road. Some roadways should be thought of as snow fences. Similarly such elevated roads should be considered as dikes, with a frozen core, capable of impounding large volumes of water in the springtime. One should always keep in mind the potential effects of impounded water along the road, because some tundra vegetation may be damaged or destroyed by a wetter environment.

Culverts should be considered in three distinct phases: 1) during the original deployment, 2) during the first summer after the snow is gone and actual drainage can be seen and reassessed, and 3) in subsequent summers when perhaps the roadway and culverts have settled or other factors have influenced the effectiveness of the system. Understandably a good initial design can substantially reduce the amount of remedial work and costly repairs to the road and to the adjacent tundra. Normally culverts are separated into two design groups, those conveying drainage water, which is primarily intermittent, and those installed in flowing streams, which must consider the passage of fish at all stages of stream flow. Both groups employ culverts that are 25 to 50% larger than required for peak flow. In some situations the culvert size may be 200% of peak flow. The primary reasons for using greater-than-normal diameters are possible errors associated with limited climatological data and the loss of cross section due to ice or gravel.

Culverts are normally made of corrugated metal pipe (CMP), although common pipe and casings have been used from surplus drilling supplies. Concrete or plastic pipe is normally not used because of the potential for severe bending as the road settles with time. Typically CMP is not insulated as a pipe, but in some cases board insulation has been placed as part of the bedding, in an attempt to limit the amount of thawing.

Figure 64. Culvert on road at Tunalik, protected by sand bags.

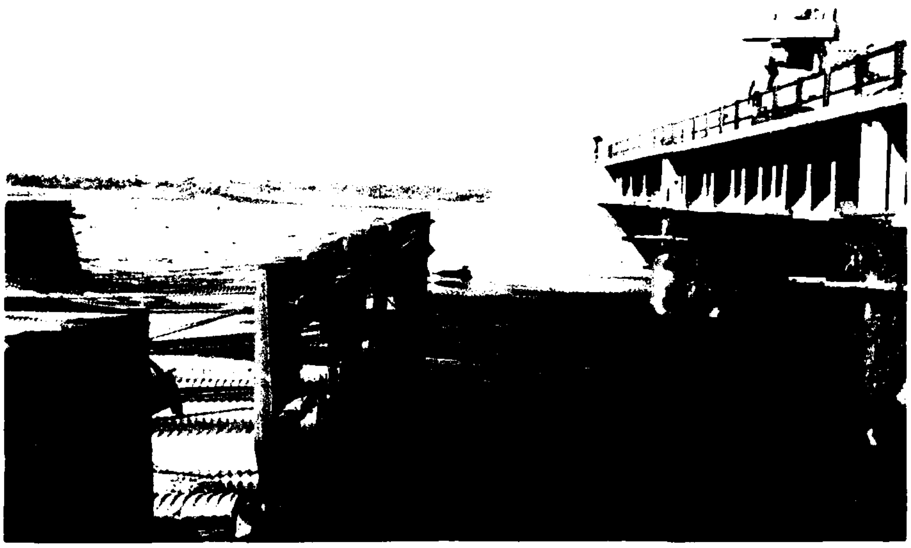


Figure 65. Collapsed culverts on main channel of Kuparuk River crossing, at left, and bridge replacing culverts at right. (Photos courtesy of G. Johns.)

Backfilling and compaction techniques are important to ensure the lateral stability of the CMP and to prevent piping along the culvert. Piping can be a serious problem when using frozen fill. In this regard it may be necessary to utilize a special backfill around the culvert, particularly when the normal roadway fill consists of coarse or oversized gravel, or quarried rock. The ends of the culverts are protected with sand bags or riprap to prevent sloughing of the side slopes and to prevent scouring (Fig. 64).

Because of the propensity of many culverts to be filled with ice, or otherwise be blocked, dual culverts are often used in critical areas. The primary culvert is low, while the smaller secondary culvert is high and to the right or left. Dual culverts are also useful when a fish passage must be maintained in the lower culvert, while the higher culvert remains dry through the latter portion of the summer.

Large culverts have been used for crossing rivers and large streams with mixed success on the North Slope. One of the major problems is floating ice, which builds up and chokes off the inlets during spring floods. Perhaps the most spectacular failure was the large multiculvert crossing of the Kuparuk River (Fig. 65). This crossing was replaced by a bridge. Low water crossings are rarely employed on active roadways. Typically they are used only after culverts have been removed, as will be discussed in Chapter 9.

Summary

All roads in northern Alaska, even the Haul Road, are of unpaved gravel. While permanent roads are designed as thick embankments, to limit or prevent the thawing of the underlying permafrost, many of the temporary roadways are thin and cause the permafrost to thaw and subside. The thinner embankments normally have a useful life of only several years but provide satisfactory service with minimum maintenance. Limiting the thickness and width of such roadways also minimizes the volume of gravel required and hence the size of the borrow pits.

Both temporary and permanent roads on permafrost are constructed by advancing the fill by end dumping directly on the tundra, burying the organic mat that serves as an insulating layer. Care is taken not to further disturb this vegetative subgrade or the vegetation on the sides of the road. Cut sections or ditches are avoided whenever possible. Roads may be constructed in the winter or summer; however, all equipment is required to work from the new embankment. While oversized material and even quarried material may be used in the base, the top course is usually select material that can be readily graded and compacted. Most roadways experience substantial settlements during construction and subsequent summers, requiring regrading and occasionally additional gravel. All gravel roads experience substantial settlements, but thin embankments experience the greatest differential and overall settlements.

While gravel roads should be located on high ground to direct drainage away from the embankment, there usually are sections that require culverts. Since side ditches are prohibited, the culvert locations must be carefully selected. Consideration must be given to the effect of ponding water and the thermal and hydraulic erosion that might occur at the inlet and outlet of each culvert. Sometimes additional culverts are installed specifically to handle spring runoff. They are located above and to the right or left of the main culvert. Flow through culverts during the spring breakup can be very high, even with an annual precipitation of 5 in. or less. Large culverts in streams or rivers can be blocked with floating ice in the spring. The culverts can fail if ice is not removed in a timely fashion, as demonstrated by failure of the initial Kuparuk River crossing.

The abandonment of roads, including culverts and bridges, is discussed in Chapter 9.

CHAPTER 5. DESIGN AND CONSTRUCTION OF AIRFIELDS

Airfields are vital to transportation in the Far North. For more than a decade it has been possible to move exploration drill rigs, and the associated supplies, camp and construction equipment, from one remote area to another using C-130 aircraft. Temporary airfields are also essential to all exploration drilling, even when the drill rigs are brought in and out on trails.

Temporary airfields are practical, prudent and advantageous solutions to the siting and construction constraints of a specific location. Temporary airfields can differ from permanent airfields in several respects. For instance, the orientation of the runway may be based on strong winter winds, if the operational period will be only during the winter months. Since they are private airfields, these temporary airfields can be closed to all traffic in storms, strong crosswinds or poor visibility. Similarly, state and federal guidelines for the design of airports can be waived in some circumstances with respect to lateral obstructions (drill rig) and even approach obstructions. Some temporary airfields are constructed with access from only one end of the runway, at least for large aircraft, the other end being obstructed by a hill or mountain (Fig. 66). This is not unique to the North Slope, for there are several airfields elsewhere in Alaska that have only one-way access and have been operational for more than 25 years. While every attempt is made to comply with normal airfield standards, there are situations where this would be impossible, prohibitively expensive, or require that the airfield be many miles from the well site. Nevertheless, all variations from standard practice are carefully evaluated by all parties, including the aircraft owners and their insurance companies. Temporary airfields are not expedient nor are they to be otherwise construed as lacking in good engineering or workmanship, for many lives and millions of dollars are involved in every takeoff and landing (Crory 1988a).

For purposes of this chapter the types of airfields can be grouped according to the construction material used, or their location, as follows:

1. Ridges, beaches and gravel bars
2. Conventional gravel fills
3. Insulated gravel fills
4. Rock fills
5. Dredged fills
6. Other types of fill.

Figure 66. Airstrip at Killik well, constructed with quarried rock. Brooks Range, in background, obstructs approach from the south end.

Snow and ice runways are discussed separately in Chapter 6.

Design considerations

Typically, design considerations for temporary airfields are an integral part of the overall plan to drill any exploration well. It is normally considered essential to have a short takeoff and landing (STOL) runway, about 760 m long, near the drill rig. The STOL aircraft (typically the DeHaviland-Canada Twin-Otter) is normally kept at this short airstrip and used only for short flights to pick up small parts and supplies, crew changes and for medical emergencies. Usually this aircraft is under the direct control of the drilling foreman.

Shallow explorations along the coast, or near lakes, can be scheduled for winter drilling only, when ice can be utilized for the runways (Mitchell 1983a). Inland sites, which do not have lakes, utilize the tundra, ridges, beaches and gravel bars for STOL and sometimes larger aircraft. Many of these expedient runways were utilized in the early exploration programs on the North Slope. Some of these runways were used only in the winter, when frozen and snow covered. Others were, and are still, used in both the summer and winter. Many of these runways required very little initial preparation, although some spot grading or filling was required. Some gravel bars have large cobbles or flat shingle stones, which do not grade or compact well. Accordingly, small aircraft using these runways during the summer use oversize "tundra" tires. During the winter, when these runways are covered with compacted snow, the aircraft can use regular tires or skis.

The majority of the permanent airstrips in northern Alaska have been built using gravel fills. Many of these airfields, especially those close to the coast, utilized beach gravels that unfortunately were uniformly graded, with well-rounded pebbles and cobbles. Sometimes the oversized materials had to be screened and/or crushed to produce a suitable gradation for the 1.5-in. maximum size used in the surface wearing course. Some surface courses also required a blending with silt-and sand-sized particles. Good surface courses are critical to achieve a smooth, durable and high-bearing capacity runway that will not rut or ravel. Many pilots have indicated that well-maintained gravel airstrips in northern Alaska are smoother than paved runways elsewhere in Alaska.

Gravel fills for such runways are normally placed directly on the vegetation to retain the insulating effect of the near-surface organics, in a manner similar to that previously described for gravel road construction (see Chap. 4). Cuts are typically avoided. The gravel fill can be placed in either the summer or winter, using end dumping to avoid disturbing the vegetation and permafrost. The design depth of the gravel fill for the runway, taxiway and parking apron usually ranges from 1.5 to 2.0 m. The depth of gravel is based on analytical procedures to limit the depth of thaw to either the base of the gravel or the top of the original permafrost table, thus avoiding potential settlements associated with the thawing of ground ice. In some areas, where the in-situ soils consist of gravels, the organic layer is stripped off and the area is allowed to prethaw for an entire summer before placing the fill. The airfields at Lonely and Peard Bay are good examples of gravel fills on tundra, while Sagwon and Umiat (Fig. 67) are good examples of runways on gravel bases.

When there is limited gravel available to provide the full depth of conventional gravel fills, insulated gravel airfields are employed to protect and preserve the permafrost condition (Kachadoorian and Crory 1988). Currently there are three such insulated runways on the North Slope—at Inigok, Tunalik and Ivotuk—as shown in Figures 68, 69 and 70, respectively. All three of these airfields were constructed in the late winter, placing an initial lift of frozen sand or gravel as a base, directly on the tundra (Fig. 71). The Inigok runway, because of existing grades, had both cut and fill sections. The frozen fine sand from the cut section was incorporated into the base of the fill section. Once the base had been carefully graded and compacted to a smooth surface, it was covered with insulation. The high-density (60-psi) polystyrene board insulation, in 2 × 8-ft sheets, was hand placed with staggered joints in two layers (Fig. 72). The thickness of the insulation was based on analytical methods (Crory et al. 1978) that, on the basis of design freezing and thawing indices, would prevent any thawing beneath the insulation. Accordingly the insulation thicknesses used on these three airfields ranged from 4.0 to 7.5 cm. The integrity of the board insulation could have been jeopardized if thawing and differential settlements occurred in the frozen base material fill, particularly if water were allowed to seep into the cracks between the insulation boards. To avoid this possibility the boards were covered with a thick, reinforced plastic membrane and the insulation was slightly crowned to drain to the shoulders, as shown in the typical cross section

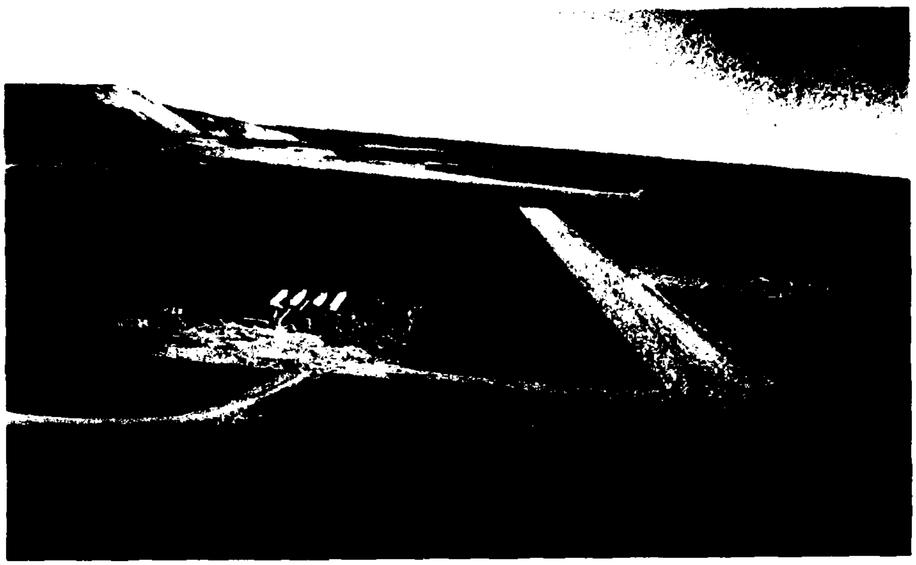


Figure 67. Umiat airfield showing temporary parking area and construction camp for Seabee well.

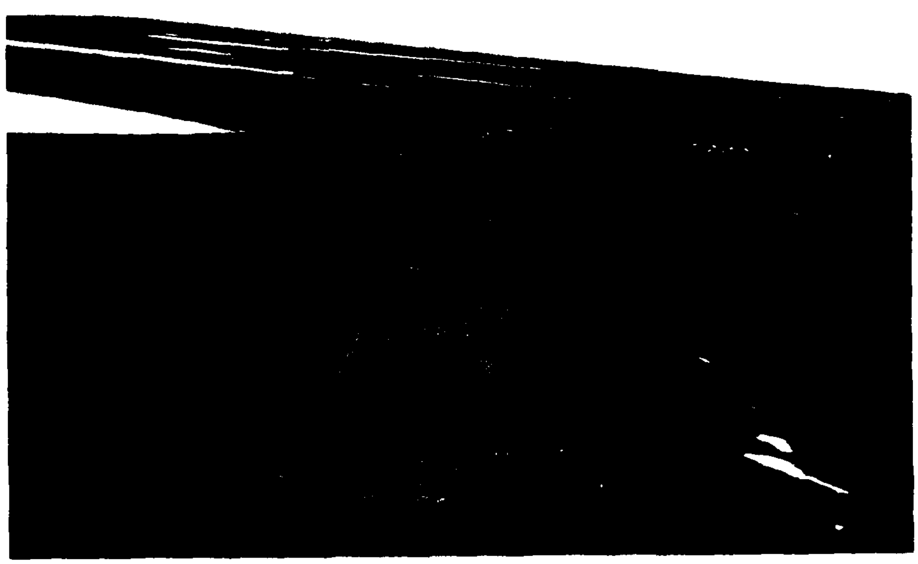


Figure 68. All-season insulated gravel runway at Inigok.

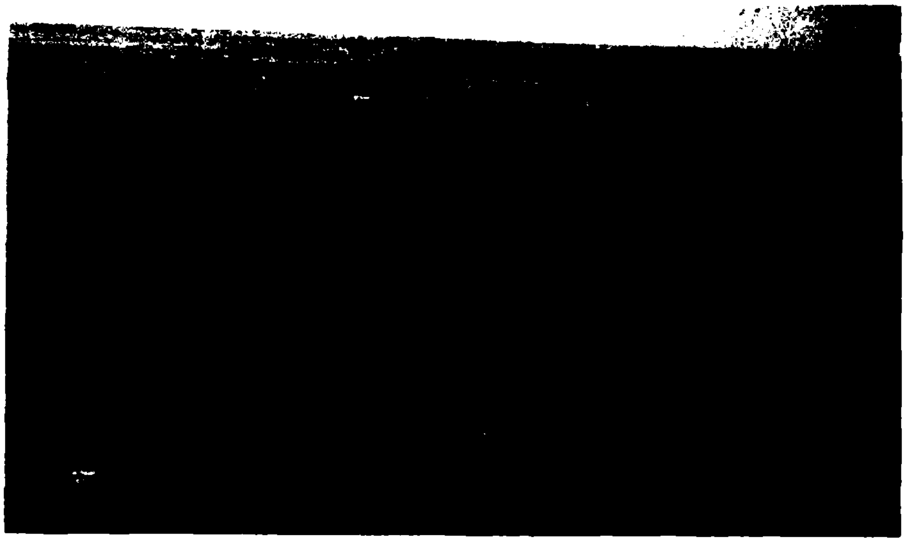


Figure 69. Insulated all-season gravel airfield at Tunalik. Note surface scar from winter road at left.

Figure 70. Insulated all-season gravel airfield at Ivotuk. Note absence of any construction scars around runway.

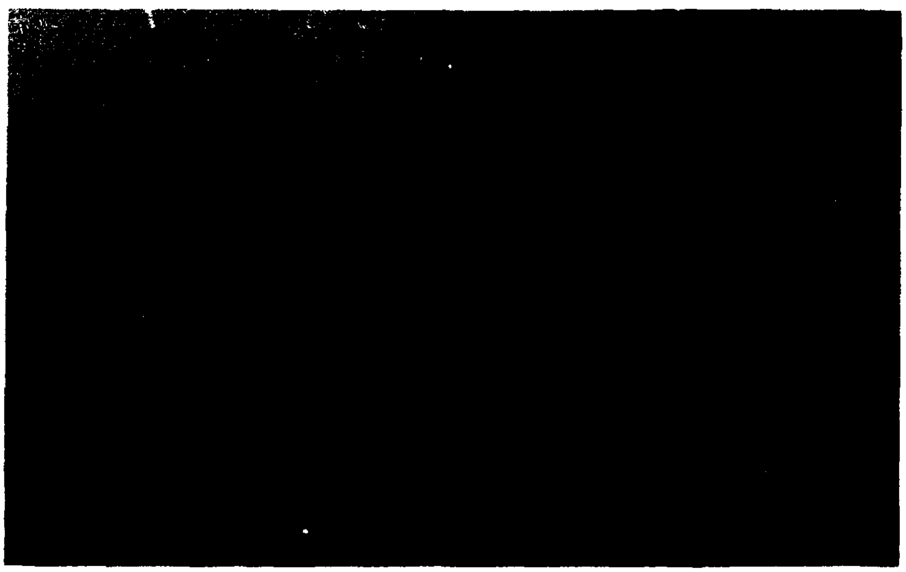


Figure 71. Insulated runway at Tunalik while under construction during late winter.

in Figure 73. The insulation also extended into the shoulders and overruns at each end of the runway, to minimize edge effects.

Select gravel is placed atop the rigid insulation by careful end-dumping, and advancing the gravel with a bulldozer with a high blade (Fig. 74). This operation is critical to avoid shoving or otherwise displacing the insulation boards, which were not spiked, staked or otherwise secured. The initial lifts of gravel were typically 12 to 15 in. thick. A minimum thickness of gravel is usually specified to protect the insulation from being crushed by construction traffic. The minimum cover, based on tests at the Waterways Experiment Station (Burns 1980), is 30 cm of gravel for insulation having a compressive strength of 60 psi. The total thickness of gravel above the insulation, including wearing course, is primarily based on the quality (gradation) of the gravel and overall thermal requirements (in combination with the insulation). Typical thicknesses of gravel above the insulation ranges from 18 to 30 in.

Runways constructed in the winter with frozen gravel (with or without insulation) normally experience a critical period during the first spring thaw. During this period the gravel must be repeatedly recompacted as it progressively thaws out. Initially this may be difficult, due to excess moisture from melting snow or ice on the surface or incorporated in the gravel. Regrading during this period may also be required to fill any depressions that form. Once thawing has progressed to the extent that there is vertical drainage, the surface usually dries out quickly. The evaporation rate on clear days, with the long summer daylight hours, can be very high, at least at inland locations. Abnormally wet spots on the runway should also be carefully examined during this initial spring melt, because they could be indicative of unsuitable material. Several wet and soft spots were discovered in the Ivotuk runway (Fig. 75) and had to be carefully removed (because of insulation) and replaced. The wet spots were found to contain material that had been

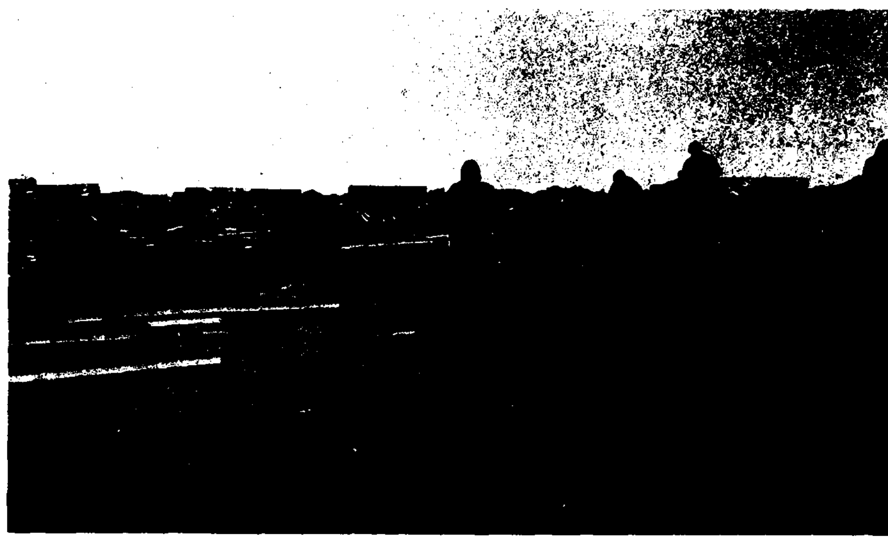


Figure 72. Placing board insulation in late winter for all-season airfield.

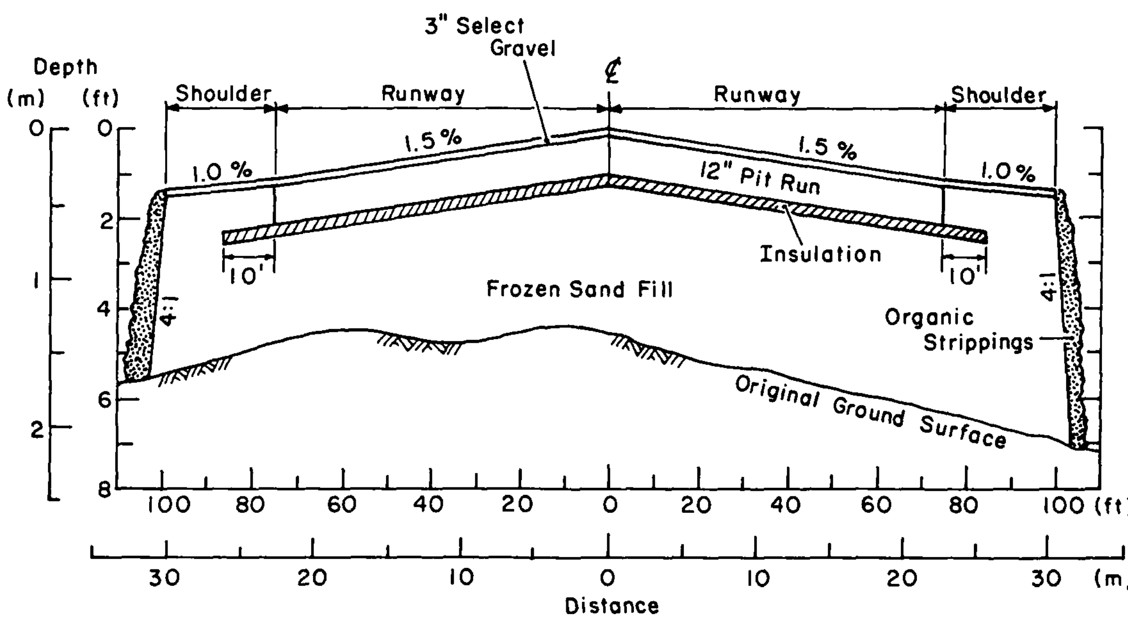


Figure 73. Typical section through insulated gravel airfield at Inigok.

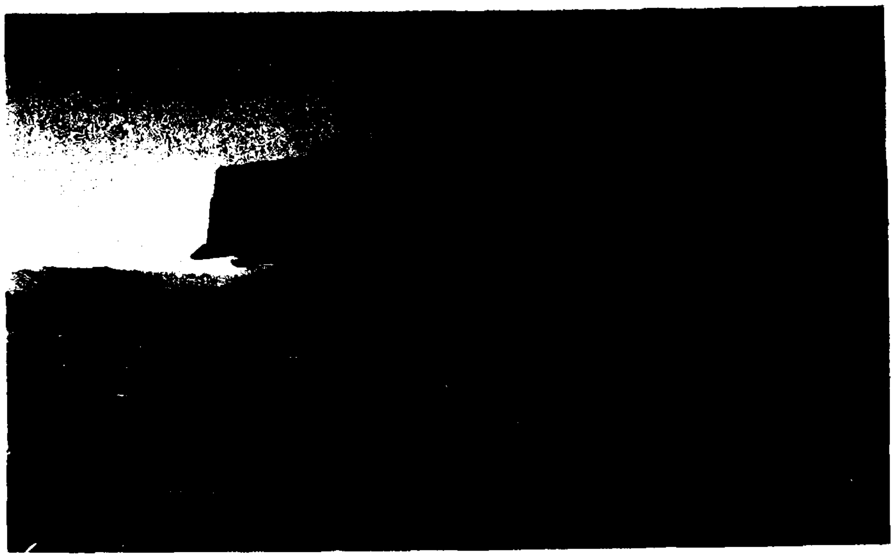


Figure 74. Advancing gravel atop insulation by use of a bulldozer to avoid shifting insulation boards that were not secured by pins.

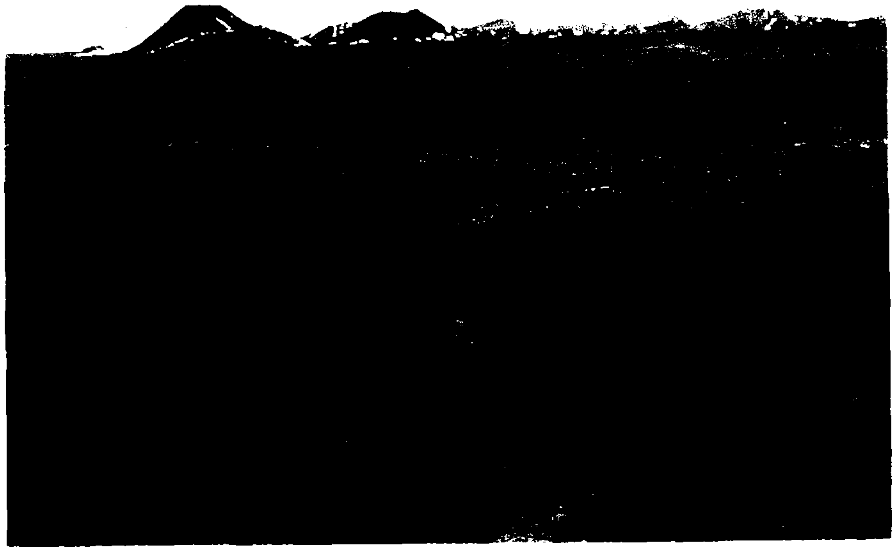


Figure 75. Ice found atop insulation in wet spots on Ivotuk runway, in fill that was designated for shoulder but placed on runway by mistake.

Figure 76. Hilltop quarry at Killik well site and access road to runway.

designated for use only on the shoulders, being unsuitable for the runway because of a high percentage of silt.

Quarried rock can also be used for runways (Johnston 1982), even when gravel sources are within reasonable distances. A good example of such a runway is at the Killik well site, to the southwest of Umiat, on the very northern edge of the Brooks Range (Fig. 66). While one option for runway construction was to obtain gravel from the Killik River Valley, to the east, this would have necessitated winter roads, winter construction and extensive rehabilitation of the borrow area. Instead, the use of quarried rock from a local hill was selected as more cost-effective and allowed summertime construction. The quarried material was conveyed over a short connecting road (Fig. 76). Although 10 to 15 m of rock was removed from this hilltop quarry it retained the same appearance as the original hill, which had little or no vegetative cover. The northern end of this runway required 4.5 m of fill to maintain permissible longitudinal grades on the 1600-m runway. The most difficult construction aspect of this runway was in finding sufficient quantities of select material for the surface coating. Normally 8 to 12 in. of topdressing is employed for the final grading and compaction. Thin surface courses on rock fill are often susceptible to the development of "rat holes," wherein the surface fines are washed down into the voids of the rock fill.

The recent development of small, transportable dredges has provided an economical method of constructing runways during the summer months, particularly at villages located along the coast or on large rivers. An airphoto of the first runway constructed with dredged material, at Nuiqsut, is shown in Figure 77. In this case, the dredged material was pumped directly to the airfield site, with excess water being returned to the Colville River by a separate line. The runway was constructed using dikes, which included geofabrics, to contain the dredged material. These were important features in protecting the adjacent vegetation and permafrost (LaVielle et al. 1983). Such

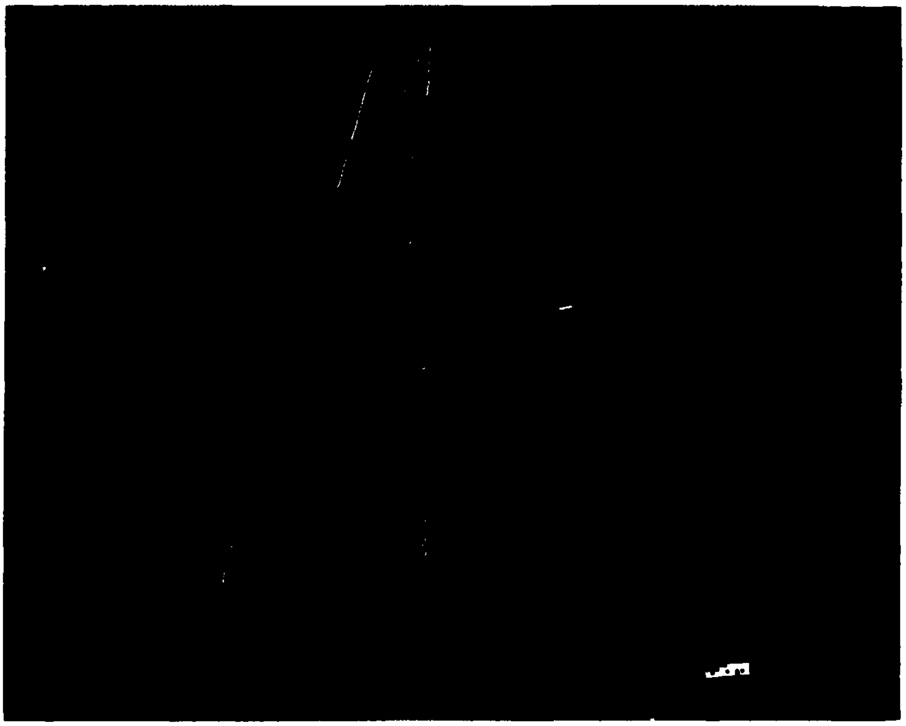


Figure 77. Airfield at Nuiqsut under construction using dredged material. Pump station at lower right.

dredging operations can also efficiently and economically generate large volumes of sands and gravels, which can be stockpiled on gravel bars or beaches for immediate or later use. While careful geotechnical and hydraulic studies are required to ascertain the quality and quantity of available gravel, the potential impact from such dredging operations is normally considered lower than that from borrow pits along the shore. The bedload of rivers and the littoral drift along the coast are important considerations for the natural replenishment of the dredged material.

Landing mats have been effectively used at the Point Barrow airfield for over 40 years to stabilize the beach sands and gravels. The matting was of the pierced steel plank type, used extensively during and immediately following World War II (Reed 1958). While the matting has been distressed by corrosion from the salt water environment and often damaged by snowplows, it has provided excellent service, far beyond its intended life. Extruded aluminum matting was considered for the Inigok runway, since there were no local gravel sources (Crory et al. 1978). Accordingly a series of test sections were deployed at Inigok, with some of the mats being placed directly on the undisturbed tundra (Fig. 78) and others on the frozen fine sand of the former borrow pit (Fig. 79). Some of the matting was underlain with various thicknesses of insulation, while other sections had none (Crory 1988b). Some test sections were green or olive drab in color, while other sections were painted white to minimize solar radiation. Although the field tests indicated that insulated matting would work in such an environment, to date there have not been any runways built with such mats on the North Slope. Because of the initially high procurement costs, and the requirement for hand placement and retrieval, these mats were considered practical only when they could be successively used on three or more temporary airfields. Landing mats, however, can be effectively used to pave taxiways and parking areas, particularly when gravel is in limited supply. Mats also

Figure 78. Placing military landing mat directly on tundra at Inigok.

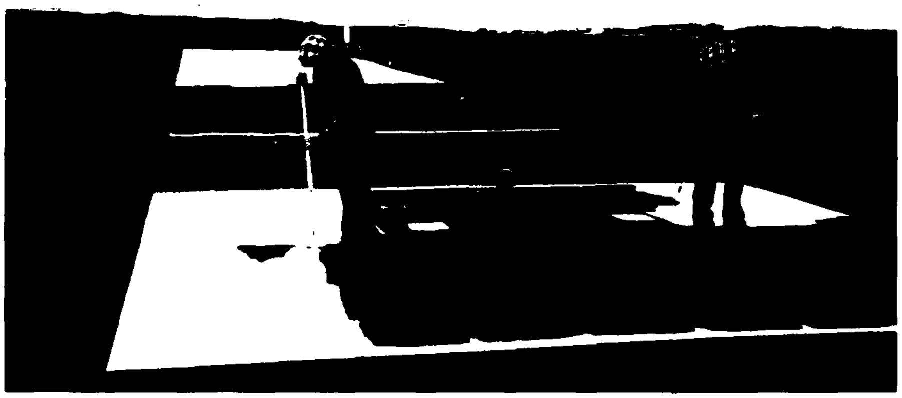


Figure 79. Insulated and uninsulated military landing mat, on sand at Inigok, with men painting some sections, with white paint to reduce solar effect. Warm early June day.

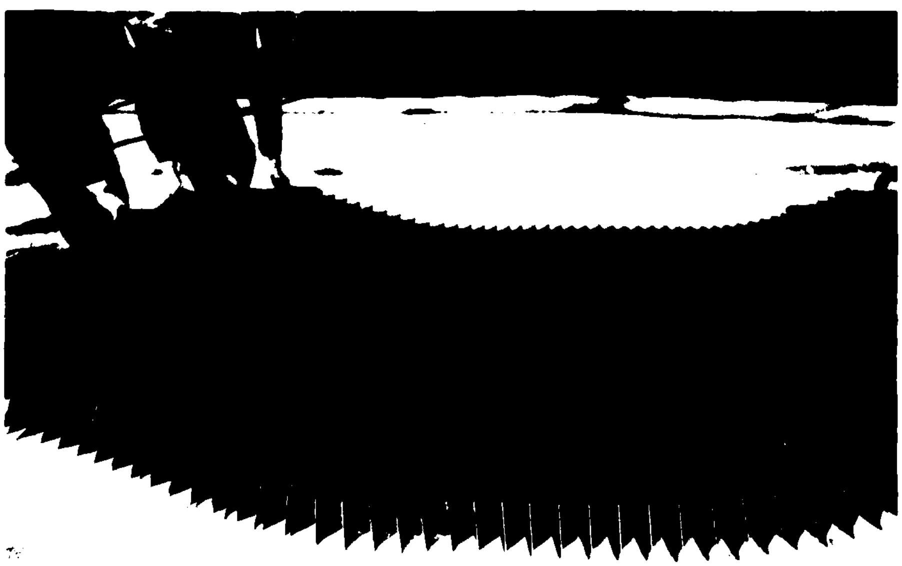


Figure 80. Treated paper geogrid which opens up to form interconnecting cells for soil stabilization.

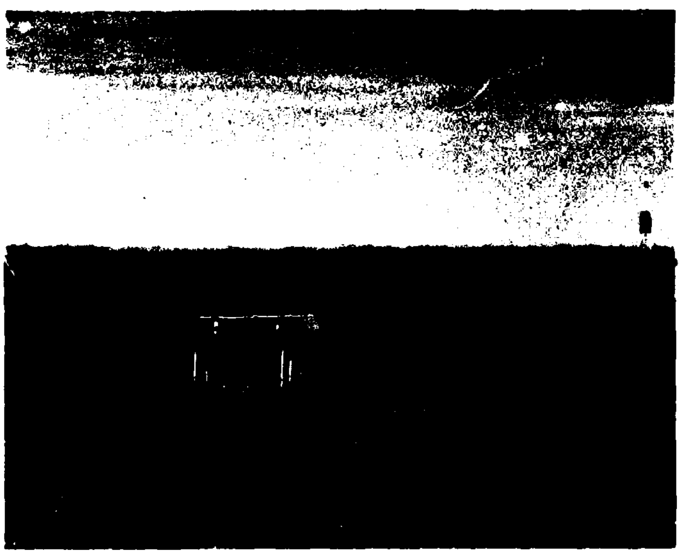
make excellent helicopter pads. Such landing mats, when placed directly on the tundra, will kill the underlying vegetation, but will not damage the underlying permafrost because the organic mat is left intact. This same killing effect on tussock grasses has also been noted when using planks or boardwalks on the tundra. If fertilized, the grass should recover in about five years.

Geofabrics and grid confinement systems (Fig. 80) are emerging alternatives for airfields, overruns, shoulders and parking aprons, particularly when good gravels are limited. These grids also offer new ways of stabilizing soils, etc., and can be helpful in erosion control and reestablishing vegetation.

Construction considerations

Constructing a temporary airfield to accommodate large cargo aircraft, like the C-130, is a large construction project, compounded by the remoteness of these sites. Such airstrips are also expensive, ranging from 25 to $50 million each, depending on the availability of gravel, the topography and the construction options. Typically a "Herc" strip is 5200 ft long, with 200- to 500-ft overruns on each end of the runway. The runways are normally 150 ft wide and shoulders extend 10 to 20 ft beyond the temporary runway lights that mark the limits of the runway. To provide adequate lateral clearance between the runway and any aircraft or equipment on the parking apron, the taxiways are normally 200 to 400 ft long. Parking aprons vary in size, but normally are large enough (60,000 ft^2 or more) to accommodate at least two aircraft. A temporary radio/weather/ control tower is typically located on the far edge of the parking apron (Fig. 81) and is elevated on piling such that there is an unobstructed view of the runway. Because the runways will be used at night and in inclement weather, navigational aids are provided, including a non-directional beacon (NDB), vertical angle slope indicator (VASI) lights (Fig. 82), and strobe lights to define the ends of the runway. Usually the airfield is equipped with its own generator, near the parking apron. The parking apron also has fuel for the generator and for aircraft. Fuel is stored in tanks or bladders with dikes, or in double-walled tanks (Fig. 83), or it is supplied by fuel trucks. In full operation these airfields can be very busy at times, with helicopters, small aircraft and the Hercs shuttling in and out with cement, drilling

Figure 81. Weather shack on parking apron at Tunalik runway. Drill rig at well at right.



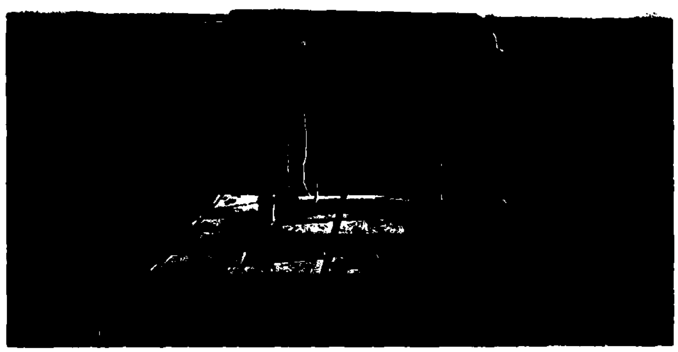


Figure 82. VASI light on timber pile and sill for approach aid at all-season airfield at Inigok. Left: side view. Right: end view.

Figure 83. Double wall fuel tanks, designed to fit in C-130, which can be moved by trucks.

Figure 84. Collection of airplanes at Ivotuk airstrip. C-130 in background is actually parked on north end of runway.

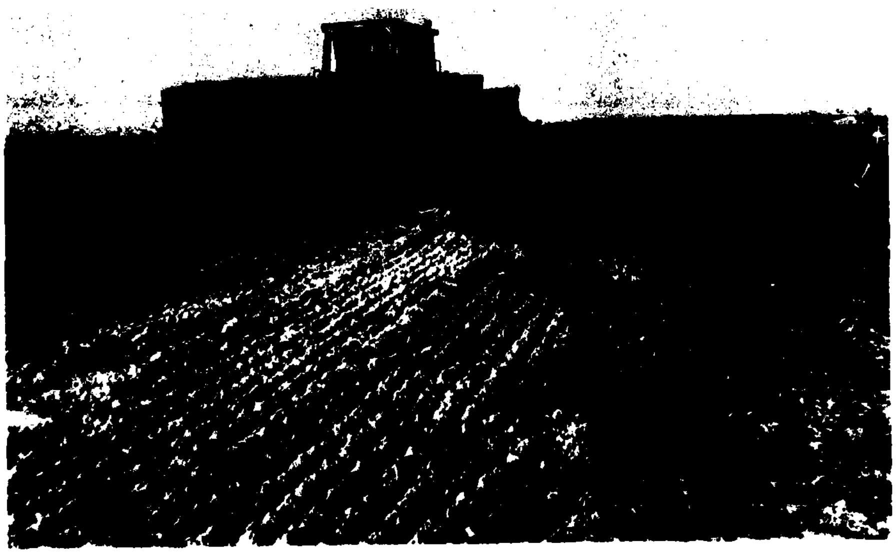


Figure 85. Compacting frozen sand for base of airfield at Inigok, using heavily weighted segregated wheel roller.

mud, fuel and other sundry items (Fig. 84).

Under average conditions, a temporary airfield like the one described above will require 240,000 to 250,000 yd^3 of gravel, assuming an average thickness of 6 ft. To this one must add the volume of gravel required for the roadway to connect the airfield to the well site, which can range from about 14,000 yd^3/mile, for a 4-ft-thick road, to 23,500 yd^3/mile for a 6-ft embankment (assuming a 10-ft-wide roadway with 2-ft shoulders). Normally construction of the airfield, road and drill pad is done simultaneously, with the construction equipment being shifted to the different elements as required.

Winter construction

Winter construction of airfields in the Far North usually begins soon after New Year's Day and continues until mid- or late May. Often the primary reason for this schedule is the requirement to use winter roads to transport the required quantities of gravel. Thus in addition to the higher costs normally associated with winter work, one must also appreciate the higher unit costs associated with the gravel, particularly when long distances are involved. Thus the critical path for the construction schedule is to have all the material in place, or stockpiled on site, before the spring breakup.

Previously conducted soil explorations define the extent of the overburden and the quality and quantity of sand, gravel or rock to be used as borrow. Typically there are several borrow sites, and the mining plans for each include restoration (Woodward-Clyde Consultants 1980). The overburden of surface organics is ripped and bulldozed to designated storage areas for later use. Fine-grained soils in the overburden can often be utilized in the shoulders of the runway, for blending into the surface course, or restoration of the borrow pit areas. Ripping frozen sands and gravels at depth usually requires a D-9 dozer or larger, and wear and breakage of ripper teeth is often extremely high. Unsaturated frozen sand and gravel deposits are easier to rip than when fully saturated. Hilltop or ridge deposits are often unsaturated to depths of 6 to 12 ft and relatively easy to rip, crush and handle when frozen. They also tend to have little or no vegetation or organics.

The borrow pits are developed by dozing the ripped material either in large stockpiles or windrows, where front-end loaders convey the material to trucks. If the ripped sand or gravel is in large chunks or blocks, sheep's foot rollers and/or segregated wheel rollers are employed in the pit or on the runway to break up the large masses (Fig. 85). While this material is indeed frozen it can be handled much like thawed sands or gravels.

If insulation is to be used, the base course is compacted to achieve the densest and smoothest state possible. Once a thousand feet or more of the base course is ready, the insulation placement begins. Gravel is placed atop the insulation as soon as the membrane has been installed. One does not leave the insulation unprotected from the wind, or to be covered with snow. During placement of the insulation at Ivotuk, a sudden and violent storm arose and blew some of the uncovered insulation away, some pieces being found more than 10 miles away.

Uninsulated gravel runways are often built with two to three layers of different gravels, each being placed separately. The initial lift is often of oversized material or bank-run gravel. The second layer is more select and may include crushed and screened material. This second layer is carefully graded and rolled to achieve a predesignated elevation before placing the third layer, which is the select, well-graded, finish course. Rerolling and regrading of this finish course continues well into the spring as the material thaws.

Summer construction

Construction of runways during the summertime normally employs local gravels, or quarried rock, which are usually transported over relatively short lengths of gravel roads; hence no operations are made on the tundra. The borrow pit operations typically involve frozen soils. Usually the overburden is stripped off the borrow area to allow thawing to progress into the gravels. As thawing occurs the gravel is scraped off, stockpiled, and allowed to drain. This is called the thaw-scrape method and is used extensively in permafrost areas.

The thawed gravel is then placed on the runway by end dumping, preserving the insulating effect of the surface vegetation, if it is left in place. Since the tundra and underlying organics may be thawed at the time of fill placement, the initial lift may have to be several feet thick to support the weight of fully loaded dump trucks and bulldozers.

Runways constructed during the summer months are usually permeable enough to drain vertically, while the well-graded surface course is less permeable, and sloped to drain. Thus during dry periods one may be obliged to add considerable quantities of water to achieve good compaction during construction, especially when fine-grading the surface course. During rainy periods, particularly in August, one can do little except wait until the water drains and evaporates.

Summary

Exploration work in remote areas requires a STOL runway reasonably close to the drill pad for crew changes, supplies and medical emergencies. If the drill rig is to be moved to or from the site by airlift, a longer "Herc" strip is also required. Airstrips for shallow wells, drilled during a single winter are usually constructed on the tundra, using compacted snow, or on the ice of a nearby lake, as discussed in Chapter 6. Winter airstrips can also be constructed on frozen beaches, sand spits, gravel bars and ridges, typically relying on snow and the repeated application of water to form a smooth frozen pavement.

Insulated and uninsulated gravel runways are constructed for deep wells, which require a year or more to drill, such that the airfield can be continuously operated in both winter and summer. Accordingly, the runway design is based on maintaining the permafrost conditions at shallow depths, avoiding differential settlements associated with the thawing of permafrost. All-season airfields, however, are very expensive, particularly when local gravels are not available.

CHAPTER 6. TEMPORARY AIRFIELDS ON SNOW AND ICE

Airfields constructed on snow and ice are often referred to as *winter airstrips*. Such airstrips play an important role in exploration of remote areas. Snow runways are constructed on the tundra, beaches, gravel bars or ridges and are essentially wide winter roads. Ice runways are built on freshwater lakes and rivers, or on sea ice in bays along the coast. Snow runways have a service life of 6 to 7 months, while ice runways typically are functional for only 5 to 6 months.

Temporary airstrips on snow or ice are designed to accommodate specific aircraft, having specific runway length requirements. Typically, a runway 1700 to 2000 ft long is used for STOL aircraft, like the Twin-Otter, while 5200-ft runways are used for C-130 cargo planes. Overruns for these runways typically range from 50 to 300 ft. Because snow-covered landscapes make depth perception difficult, the runway and overrun lengths are very important. Similarly, runway markers and airfield lighting systems are necessary on these temporary airfields. The markers are usually frangible plywood signs along one or both edges of the runway, with threshold lights or markers at the ends of the runway. Spruce trees, cut to a height of 6 to 8 ft, have also been imported and planted in snowbanks to mark the edges of the runway and thresholds. Painted barrels have been positioned along the approaches, in prescribed groups at specific distances, to provide both alignment and depth perception.

Finding a suitable location for a snow or ice runway is an important, and sometimes a critical, aspect of an exploration schedule. Once a proposed exploration well site has been designated, the search for possible runway locations begins immediately. The first step is to assemble the best available maps and climatological records of the area. Climatological information (see Chap. 2), includes the direction of prevailing and storm winds during the fall, winter and spring, depth of snow and ice thickness as a function of time, air temperatures and freezing indices, etc. The prevailing wind direction is important to the alignment of the runway. Snow depth and the normal periods of heavy snows are important considerations in both snow and ice runways. *Early and deep snows are required for building snow runways on the tundra, while these same conditions will retard the rate at which ice freezes on lakes, the snow acting as an insulator.* Average daily temperatures are also important during the runway construction period, not only with respect to the efficiency of men and equipment, but the compaction and age hardening of snow, the rate at which ice freezes, etc. Freezing indices (both average and extremes) are primarily of interest in forecasting the freezing rate of lakes or sea ice (see Fig. 44). Air temperatures are also important with respect to scheduling when the snow or ice runways can be expected to soften, thaw or otherwise be rendered unserviceable in the spring.

The search for suitable snow or ice runways begins in the office with the soils, vegetation and topographic maps. *Usually the search is not for one airstrip,* but two, a STOL runway close to the well site and a Herc strip further away. Since building a 5200-ft snow runway is time consuming and expensive, one normally considers lakes, even 10 miles or more away, for the Herc strip. If there are no ice runways available for the Herc strip, then consideration is given to moving the drill *rig only by winter trails.*

Figure 86. Teshekpuk Lake in the spring, showing large area suitable for ice runway. Note ice ridge that traverses lake on diagonal.

Design and construction of temporary airfields on ice

Finding suitable lakes within the coastal plain for STOL runways is relatively easy for there are many lakes. These lakes are often large enough (Fig. 86) to accommodate Herc strips and the siting problem sometimes evolves as to where on the lake to place the runway. The more general case is finding a lake with sufficient length, in the prevailing winter wind direction, for the 5,200-ft "Herc" runway, near the well site.

Airstrips on floating ice rely solely on a sufficient thickness of ice to support the specific aircraft. One must appreciate that this viscoelastic/plastic layer of ice is floating on water and that the flexural strength of the ice is influenced by several factors, including temperature, snow inclusions, cracks, salinity, etc. One must also remember that ice, under temperature changes, expands and contracts. Ice also cracks when subjected to rapid cooling. While low-temperature-induced cracking may be random on clear ice, the cracking can be concentrated and oriented by the presence of snowbanks along the edges of the runway. Floating ice also deflects under both static and dynamic loads. Deflection under static loads includes a dishing effect under parked aircraft or vehicles within a radius of influence, which is a function of the temperature and thickness of the ice and imposed load (USAF 1968). The ice cracking pattern is initially in a radial direction, followed by circumferential cracks and then failure, if the aircraft (or vehicle) is not moved to a different location. Static deflection of ice is also caused by deep snowbanks. Dynamic deflections, caused by fast-moving aircraft (or vehicles) are actually bow waves in the ice, which create quick stress reversals, causing the ice to crack. These dynamically induced cracks are of particular concern at the boundary between floating ice and shorefast ice. Since the latter is virtually rigid, this boundary experiences the greatest stress cracking. The critical speed range for dynamic stresses in ice is between 10 and 20 mph. Accordingly, one should try to stay above or below this range. When obligated to operate within this range, such as during takeoffs and landings, these speeds should occur only on floating ice (away from anchored ice). Locating the runway with respect to floating and shorefast ice is thus important.

Airstrips on floating lake ice rely on a sufficient thickness of natural ice, or ice built up by successive floodings atop the existing ice. As previously discussed in Chapter 3, and Figure 45, data are limited on when natural ice can be expected to achieve a given thickness, and when it will degrade to the point that it will no longer support operations in the spring.

The thickening of ice can be accelerated by the timely removal of virtually all snow within the areas to be trafficked. Understandably, removal of the snow cover early in the season can be more beneficial than waiting until midwinter. Snow removal on lakes can often begin in early November, when the ice is only a foot or more thick. The ice thickness, however, must be sufficient to support the weight of the specific snow removal equipment. Table 1 provides guidance on the required thickness of ice to safely support men and equipment. The continuous removal of all new snow from the ice will also produce greater ice thickness, when compared to the rest of the snow-covered lake, because of the lower ice surface temperature. Normally the ice thickness would be measured at selected intervals across the lake, before removing any snow, and periodically (twice weekly) thereafter to monitor the thickening of the ice.

Normally, a minimum ice thickness of 4 ft is required for C-130 operations. For preliminary planning purposes, Figure 45 shows that 4 ft of ice would normally be expected to naturally develop on a coastal zone lake by mid-January, even with a snow cover. However, this thickness might not be achieved under natural conditions during a mild winter until two months later. Accordingly, if one removes the snow cover from such lakes during late November and December, 4 ft of ice will probably have formed by early January. Should the ice thickness monitoring program show that the required minimum thickness will not be achieved by a scheduled date, one would be obliged to revise the start of flight operations, operate with reduced aircraft loads, or commence over-ice flooding several weeks before the starting date.

Artificial thickening of ice is accomplished by flooding the surface of the existing ice with water pumped from beneath it. These surface layers of water freeze very quickly, being directly exposed to the cold air and wind. Snow should be removed from all areas before flooding the ice, since snow can inhibit the lateral spreading of the water on the ice and can substantially increase the time required for refreezing if the snow is deep. Soft or weak layers caused by snow are also undesirable because they can cause local surface failures. Thus every effort should be made to remove all snow and allow sufficient time for any layers of water beneath the new ice crust to refreeze before attempting any flooding or reflooding.

Flooding of lake ice is accomplished by drilling holes in the ice, just large enough for hoses, pipes or pumps. The pumps may be housed in a heated truck to avoid freeze-up problems. Freezing problems can also be avoided by using submersible electric pumps run by truck-mounted generators. Submersible pumps are primarily selected to have high volume and low pressure, since they operate at very low heads. Flooding is often done only in the vicinity of each hole so that no significant lengths of hoses or pipes are required. Other devices used to lift the water from such holes include the use of outboard motors or impellers (Archemedes' screws).

Table 1. Ice load-carrying capacity for personnel and equipment (adapted from U.S. Army 1962).

	Total weight (tons)	*Minimum ice thickness [in.*	*(cm)]*	*Minimum distance between loads [yds*	*(m)]*
Person on skis or snowshoes	0.1	2	(3)	5.5	(5)
Person on foot	0.1	2	(5)	5.5	(5)
Two-wheeled vehicle	0.8	6	(15)	16.5	(15)
Wheel-borne loads up to	3.5	9	(25)	16.5	(15)
Wheel-borne loads up to	6	12	(30)	22	(20)
Wheel-borne loads up to	10	16	(40)	28	(25)
Wheel-borne loads up to	15	24	(60)	33	(30)
Caterpillar-borne loads up to	3.5	8	(20)	16.5	(15)
Caterpillar-borne loads up to	10	12	(30)	22	(20)
Caterpillar-borne loads up to	12.5	16	(40)	28	(25)
Caterpillar-borne loads up to	25	24	(60)	44	(40)
Caterpillar-borne loads up to	45	28	(70)	55	(50)

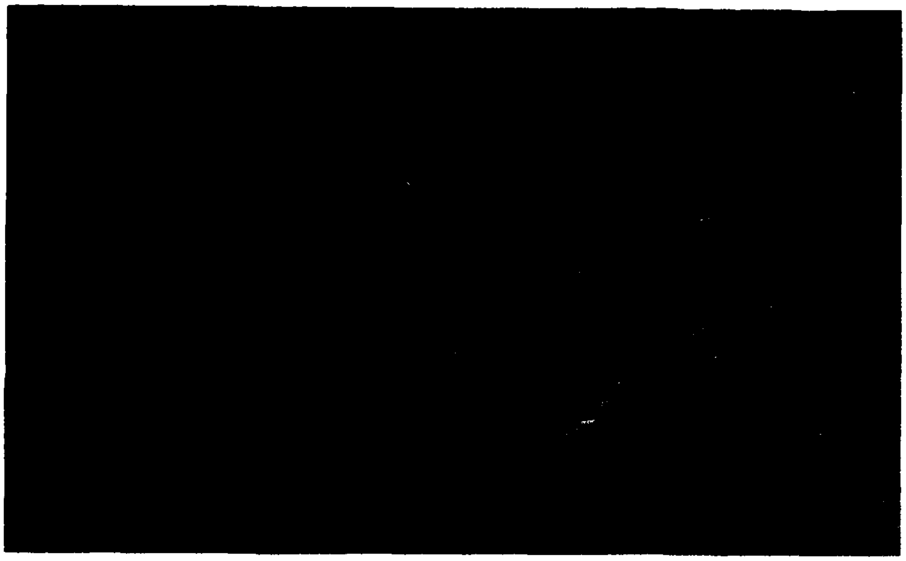


Figure 87. Former winter airstrip at E. Karupa no. 1 well site in old drained lake bed. Runway and parking apron accentuated by green grass.

Flooding is accomplished with a series of holes along the runway, taxiway, and parking apron, with the spacing of the holes a function of the diameter of each pool created on the ice. Initially the pools are 150 to 200 ft in diameter, but can be increased to 250 or 300 ft in subsequent lifts. Each flooding consists of 2 to 4 in. of water atop the ice, at least near the central portion of the pool. The weight of the water on the ice causes the underlying ice to depress, and a rim of slush or cuttings around the hole is helpful in preventing the return flow of water into the hole immediately following the pumping.

If flooding is to be employed, one must pre-plan the location of all holes to provide for optimum flooding with the particular equipment to be used. Concern must also be given for the depth of water beneath the ice at each location. There must always be a sufficient depth of water between the bottom of the ice and the lake bottom sediments, such that no sediments are pumped onto the ice, which would accelerate melting in the spring. Thus careful pre-selection of the location of the airfield on the lake is important with respect to flooding for ice growth.

Flight operations on frozen lakes often commence with light aircraft as soon as the runway can be cleared of snow. Normally the required minimum thickness of ice is confirmed by a series of small drill holes along both sides of the runway centerline, at about 200-ft intervals, and extending along the taxiway and parking area. The parking area is often the critical area for heavy aircraft, because the ice there is subjected to extended loadings and may have to support the combined weight of the aircraft and any heavy equipment close to the plane during loading or unloading. Accordingly, parking aprons are often located on bottom frozen ice, i.e., close to shore.

When an airstrip is constructed on a shallow or partially drained lake, one must wait until the frost penetrates through the ice into the underlying soil, not just until the ice is frozen. The combined thickness of ice and frozen soil that will be required to support an aircraft in such situations will depend primarily on the soil conditions. Hence, knowledge of the sediments below thin ice is important for non-floating ice runways. One should also realize that submerged soils contain only a fraction of the amount of water contained in a unit volume of water. Since the major portion of heat removed in freezing is associated with the latent heat of water, these saturated soils will freeze much faster and deeper than just plain water.

In an unusual case at the Awuna medium-depth well site, a lake and a tundra snow runway were used, in combination, to provide the required runway length during the first winter for a "Herc" strip (Brooks 1983b). A shallow slope at one end of the lake allowed this combination to be employed. Another airfield constructed at the East Karupa no. 1 well site (Fig. 87), could be best described as having been in a drained lake. Drained lakes usually have limited areas of aquatic grasses, as opposed to tussocks. The extent and abundance of these flooded aquatic grasses are a function of how long ago the lake drained and the extent to which it was drained. There are many drained lakes within the coastal plain and the environmental disturbance of placing a runway across such aquatic grasses appears to be small. However, one should be concerned with the possible emergence of a pingo under or beside runways in such lake bed environments.

Design and construction of temporary airfields on the tundra

There have been dozens of temporary airfields on the tundra, constructed entirely with compacted snow and/or chipped ice (Mitchell 1981). The majority of these airstrips were built for STOL aircraft and located close to the drill rig or construction camp.

Preparations for constructing tundra airstrips begin with the site selection, normally made during the summer months using a helicopter. The locations for the tundra airstrip are virtually unlimited at some drill sites, although there are always some constraints. While normally one would try to find a location near the drill pad, the lateral clearances must be considered. One must also be aware of any plans for trails, for a trail crossing the proposed runway or too close to it would be undesirable. Since tundra airfields are built without any earth moving, existing topography is very important. Ideally the proposed site should have natural longitudinal and transverse grades that are within normal airfield standards. When considering various alternative sites, one must also consider the types of vegetation and polygonal ground features, because high tussocks and some polygons are difficult to flood with water and they are poor surfaces for compacting snow. Potential nearby sources of water (or chipped ice) are investigated and marked out in the field. The prime and sometimes alternative runway sites are carefully surveyed (for contoured drawings) and staked out.

Tundra airstrips are constructed in much the same manner as winter roads. Special attention is given to the initial compaction of the existing snow cover, using a minimum of turnarounds. Scars or sheared-off tussocks visible in the following summer can often be directly related to the degree of care and attention given to this initial compaction effort. Accordingly, initial compaction efforts can often be best done with low tire pressure vehicles, like the Rolligon. At other sites, without tussocks, the initial compaction can be accomplished with wide-tracked bulldozers, or other tracked vehicles that make a series of parallel passes back and forth, reversing rather than turning around at the end of the runway. Typically borrowing snow from the surrounding tundra is avoided and greater reliance is placed on importing snow or ice from other areas to fill in low spots and thicken the keel of the runway.

STOL runways can be constructed using only compacted snow, allowing sufficient time for age hardening (Abele et al. 1968) and then sequentially saturating the compacted snow and building up a layer of ice using water trucks. Manufactured snow or chipped ice can also be placed on the compacted snow and saturated with water to form a thick frozen pavement. Flooding the area with water, pumped from a nearby lake, can also be used to build up a thick layer of ice on the tundra (Brooks 1983b). The method of construction is an integral part of the design of each tundra airstrip and establishes the requirements upon which the construction equipment is selected. Rarely does one have all the equipment at the site to change construction techniques.

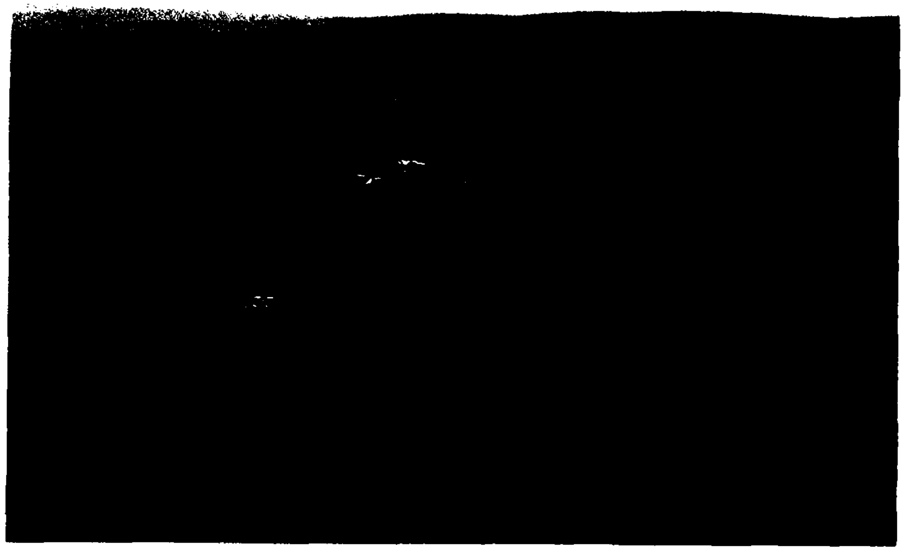


Figure 88. Old airstrip on ridge at Knifeblade well site. Note fuel drums for more recent operations.

The biggest problem to be addressed in tundra airstrips is compacting the snow between and around tussocks and otherwise making sure there are no cavities beneath the compacted snow surface. Normally this is addressed in the initial compaction and water flooding program. While it may take several days to completely freeze this initial base course, because of the amount of water involved, it is worth the wait. Even after subsequent application of water or lifts of chipped ice and water, it is good practice to carefully proof roll such runways with high tire-pressure vehicles. Such proof rolling can disclose weak spots that can be quickly repaired by local flooding or with chipped ice or slush before flight operations begin.

Temporary snow airfields may be constructed in support of explorations on ridges, coastal beaches or gravel bars. Ridges usually are well drained and have large areas of exposed weathered rock or frost-shattered boulders (Fig. 88). Because of the limited area with suitable grades, most ridge runways are often limited to STOL aircraft only.

In general no earthwork is needed to prepare runways on ridges, although some limited excavation work could be considered if there were an isolated stone rubble pile or isolated exposure of bedrock. Typically airstrip construction on ridges is similar to that used for tundra airstrips, both employing compacted snow. However, such elevated sites usually have only limited water available so that snow is the principal construction material. Usually there are deep snowdrifts in the vicinity of these ridges where snow may be obtained, deep deposits being clearly identified by persistent snowbanks that last well into the summer months.

Many coastal sections of northern Alaska have essentially no beaches (Fig. 25), but areas with beaches and sand spits can provide suitable areas for airstrips, particularly STOL length runways. Normally these require little or no earthwork, although some driftwood may have to be picked up. Some of these beaches, particularly low-lying sand spits, are capable of supporting light aircraft as soon as they freeze, with the snow cover acting as a binder to the surface pebbles. Water may also be employed to saturate and bind the beach sands or gravels, particularly any high and dry zones away from the water's edge. Beaches and sand spits, however, can be subjected to ice pileups (Fig. 89), which can occur in only a matter of hours, in the winter or summer. Information on potential ice pileups should be sought from local natives, who

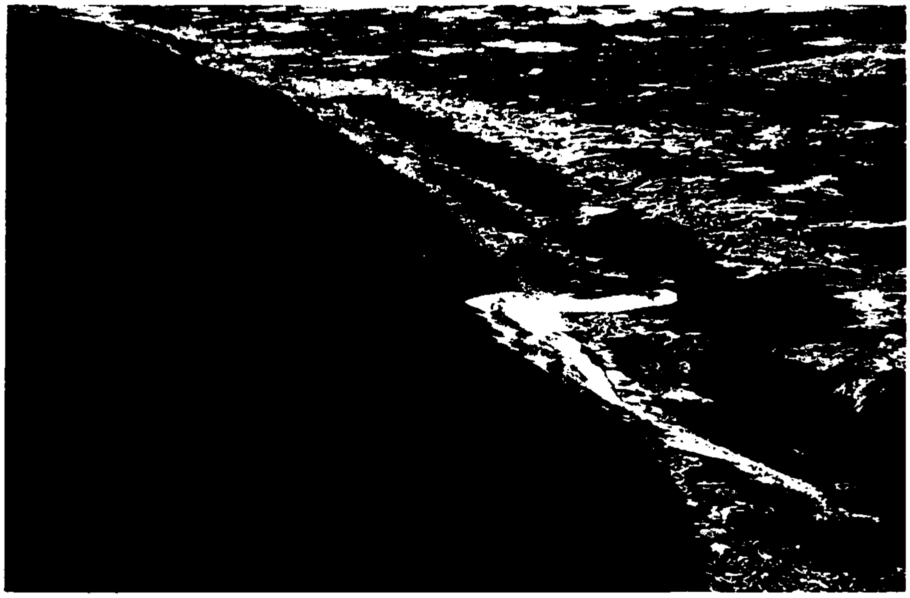


Figure 89. Sea ice piled up on Deadman's Island. Ice-free area to left protected by barrier islands.

are familiar with the specific area. Kovacs (1983) and others have published several papers on ice pileups along the north coast.

Floodplains and gravel bars along the major rivers can provide prime locations for temporary winter airfields. Typically these sites are subject to flooding in the springtime. Portions of the area may be covered with brush, usually quick-growing willows and alders.

Temporary airstrips along such rivers are normally sited with respect to the sand or gravel deposits. Limited earthwork, where required, can be accomplished in late summer or early winter, including the clearing and removal of all obstructing brush. Typically the volume of such earthwork is minimal. The major construction consideration is the potential ramification of blocking any existing channels, which must be reopened before the next spring flood. Normally such airstrips are put into service only after the ground has frozen and the snow has been compacted.

Old gravel runways along rivers can be reactivated as required. Many of these old runways have been overgrown with willows and alders and some have experienced repeated floodings over the years that has covered them with a veneer of silt. There may also be shallow sloughs or channels bisecting the runway. Many of these old river runways appear to be potentially useful only as winter airstrips, being poorly situated with respect to flooding, and accordingly not considered appropriate for upgrading to all-season airfields.

Summary

Airstrips for STOL runways are constructed on the tundra where there are favorable longitudinal and transverse grades. The existing snow is first compacted in place after the ground has frozen. Additional snow or chipped ice is then added in lifts, each lift being watered and frozen. After a smooth ice pavement has been produced, the surface is scarified to produce a rough chipped surface for good traction. Runways can also be constructed on the tundra by water flooding, if water sources are reasonably close.

Airstrips can also be constructed on frozen lakes, rivers and coastal sea ice. The minimum ice thickness requirements vary with aircraft, being typically 4 ft for C-130 aircraft. In early winter, ice thickening can be accelerated by removing all snow. If the rate of ice growth is slow, the ice may be thickened by applying water to the surface in thin layers.

Operating aircraft on frozen lakes is different from operating them on snow runways because floating ice deforms under dynamic and static loads, the former creating bow waves, the latter producing a dishing effect, particularly under parked aircraft. Deep snowbanks along the runway insulate the ice and the weight of the snowbanks produces significant static loads. Floating and grounded ice also react differently to loads, because the grounded ice is supported by frozen soil.

Runways constructed with snow and ice are useful only during the winter, melting away each summer. Hence, they should normally be built only for shallow winter exploration wells, although there have been situations (Awuna) where such runways have been employed during two successive winters during the drilling of a medium-depth well.

CHAPTER 7. DESIGN AND CONSTRUCTION OF DRILL PADS

Drill pads are used as platforms for the drilling of exploration and production wells. Typically production wells on the North Slope are long, thick, rectangular gravel pads (Fig. 90). The production wells are in a row, facilitating the movement of the drill rig down the long pad, and making it easy to connect the production lines. The production wells are directionally drilled from these common pads, with the series of wells being capable of covering a relatively large area, and at producing depths of 4000 ft or more. Neighboring production pads may be a mile or more away.

Production drill pads on the North Slope are interesting, especially with respect to long-term thawing and subsidence around each well, as heat from the wells radially warms the deep permafrost. However, these guidelines are focused on exploration drill pads, which are exclusively used for the drilling of single, usually vertical, exploration wells.

Basic requirements for exploration drill pads

Exploration wells are located by seismic information, and normally there is a specific target for each well. For the purposes of these guidelines the proposed target depths can be subdivided into three types of exploration wells:

- Shallow wells (less than 10,000 ft)
- Medium wells (between 10 and 15,000 ft)
- Deep wells (more than 15,000 ft).

The designated target depth of the exploration well is directly related to the time required to drill to such a depth. Schindler (1988), in his summary of explorations in NPRA from 1975 to 1982, provides data on the time required to drill 36 exploration wells (Table 2). When the duration of the actual drilling time (exclusive of mobilization and demobilization) is plotted against well depth (Fig. 91), we can appreciate how long it takes to drill shallow, medium or deep exploration wells in this area. As expected, the data in Figure 91 are not a simple linear relationship and there is a substantial scatter or band to the data. This is to be expected, for drilling rates are different for different rock types and some holes experience more sloughing, caving or gas kicks. Typically problems appear to get worse as one goes deeper; however, recovering lost bits or stuck tools can occur at any depth. Similarly, the number of hours or days required for core sampling, logging and flow testing of various strata can also contribute to the overall drilling time.

Shallow explorations, which constitute the largest percentage of wells, can be drilled in a relatively short period of time. As shown in Figure 91, a well to a depth of 5,000 ft or less can be completed in 25 to 50 days, and one to 10,000 ft in 45 to 90 days. Accordingly, such shallow wells can be drilled in a single winter, with ample time for cross-country movements and other mobilization and demobilization activities. The data on shallow wells also suggest that two explorations can be accomplished by the same drill rig during

Table 2. Drilling time vs depth for exploration wells in NPRA.

No.	*Well name*	*Spudded date*	*Release date*	*Drilling days*	*Well depth (ft)*
1	Cape Halkett 1	24 Mar 74	"Early" May 75	45 (?)	9,000
2	E. Teshekpuk	12 Mar 76	7 May 76	56	10,664
3	S. Harrison Bay 1	21 Nov 76	8 Feb 77	79	11,290
4	S. Barrow 13	17 Dec 76	16 Jan 77	30	2,534
5	S. Barrow 14	18 Jan 77	3 Mar 77	34	2,257
6	W.T. Foran 1	6 Mar 77	24 Apr 77	49	8,864
7	Atigaru 1	12 Jan 77	29 Mar 77	76	11,535
8	S. Simpson 1	9 Mar 77	30 Apr 77	52	8,795
9	W. Fish Creek 1	14 Feb 77	27 Apr 77	73	11,427
10	Drew Pt. 1	13 Jan 78	13 Mar 78	59	7,946
11	Kugrua 1	12 Feb 78	29 May 78	106	12,588
12	N. Kalikpik 1	28 Feb 78	14 Apr 78	45	7,395
13	S. Meade 1	7 Feb 78	17 May 78	109	
		3 Dec 78	22 Jan 79	159	9,945
14	Ikpikpuk 1	28 Nov 78	17 Apr 79	140	14,210
		25 Dec 79	28 Feb 80	205	15,481
15	Inigok 1	7 Jun 78	22 May 79	349	20,102
16	S. Barrow 16	28 Jan 78	17 Feb 78	20	2,400
17	S. Barrow 17	3 Mar 78	13 Apr 78	41	2,382
18	S. Barrow 19	18 Apr 78	16 May 78	28	2,300
19	Tunalik 1	10 Nov 78	4 Jan 80	420	20,335
20	Pard 1	27 Jan 79	13 Apr 79	76	10,225
21	J.W. Dalton 1	7 May 79	1 Aug 79	86	9,367
22	E. Simpson 1	19 Feb 79	10 Apr 79	50	7,739
23	Seabee 1	1 Jul 79	21 Aug 79*		
		16 Oct 79	15 Apr 80	232	15,611
24	Lisburne 1	11 Jun 79	2 Jun 80	354	17,000
25	Walakpa 1	25 Dec 79	7 Feb 80	44	3,666
26	E. Simpson 2	29 Jan 80	15 Mar 80	45	7,505
27	W. Dease 1	19 Feb 80	26 Mar 80	35	4,170
28	S. Barrow 20	7 Apr 80	10 May 80	33	2,356
29	Awuna 1	29 Feb 80	8 May 80	69	5,300
		5 Dec 80	20 Apr 81	205	11,200
30	Koluktak 1	23 Mar 81	19 Apr 81	27	5,882
31	S. Barrow 15	23 Aug 80	18 Sep 80	26	2,278
32	S. Barrow 18	22 Sep 80	14 Oct 80	22	2,135
33	Walakpa 2	3 Jan 81	15 Feb 81	43	4,135
34	N. Inigok 1	13 Feb 81	4 Apr 81	50	10,170
35	Kuyanak 1	13 Feb 81	31 Mar 81	46	6,690
36	Tulageak 1	26 Feb 81	31 Mar 81	33	4,015

* Drilling suspended, due to labor dispute, from 21 August until 16 October 1979.

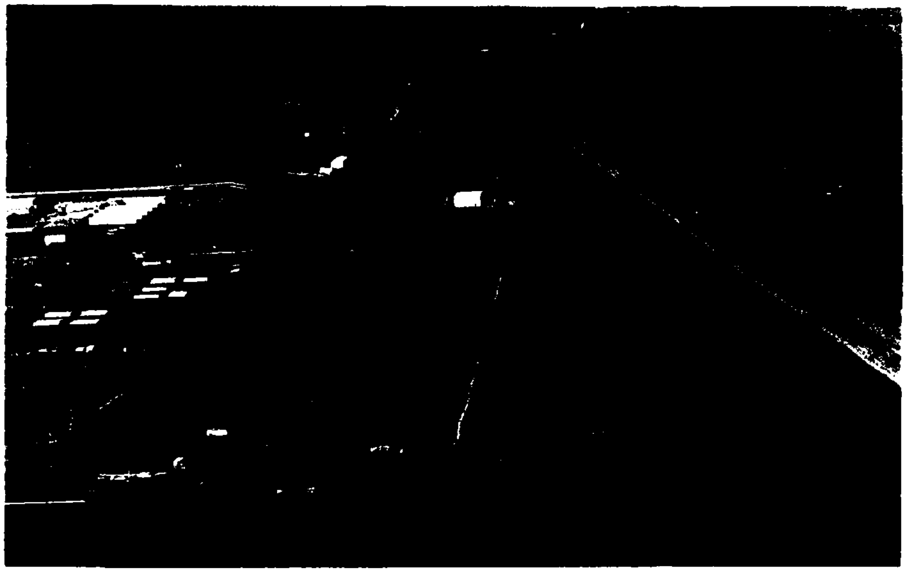


Figure 90. Kuparuk oil field, ARCO camp at left, production well pad in center, airstrip at right.

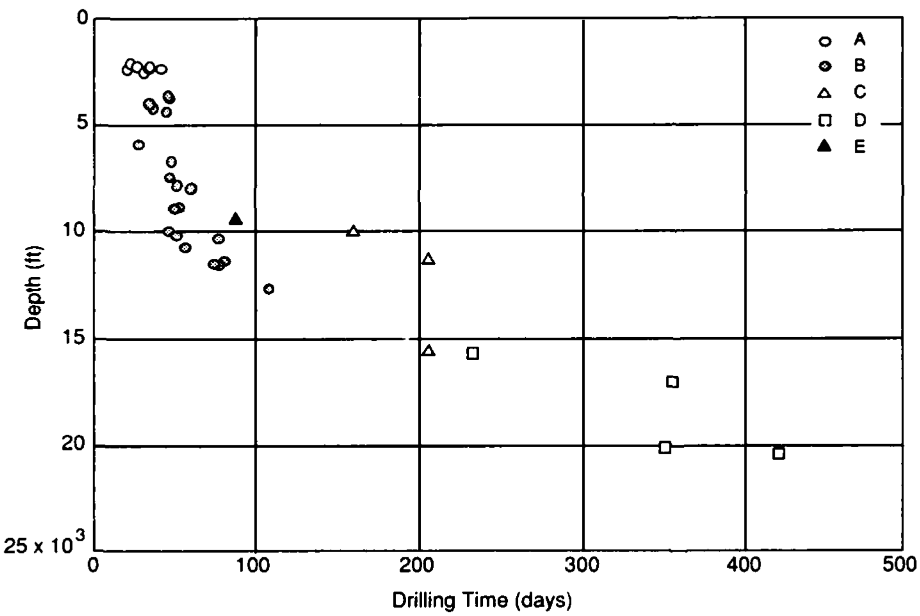


Figure 91. Drilling time vs depth for exploration wells in the NPRA. (A = So. Barrow gas wells, B = one winter only, C = drilling suspended during summer, D = all-season deep wells, E = coastal road access from Lonely.)

the same winter, if the wells are not too deep (less than 10,000 ft combined). Several of the South Barrow gas wells, listed in Table 2 and shown as a unique group in Figure 91, were drilled in the same winter. These wells, only to about 2,500 ft deep, were quite close to each other.

Drilling of medium-depth wells normally requires the entire winter or several winters to complete, with drilling in the latter case being suspended during the intervening summer. Longer drilling periods can also be achieved by having the rig stacked at the site, from the previous spring, or leaving the rig at the site at the end of the season, or both. Ironically, in such situations the constraint is not the overland move but having an operational snow or ice runway available during the drilling period.

Drilling of medium-depth wells during two winters is substantially more difficult than the drilling of single-season, shallow wells. Much of the difficulty can be attributed to the additional work required to shut down the drilling for the summer and restart it again the next winter. Incomplete wells must be left secure, for normally there is no one left at the site to monitor or accomplish any work. Accordingly, such wells must be secured against possible blowouts, as might be caused by gas hydrates. In such cases, this means setting and cementing a casing to the bottom of the existing hole, such that the well can be valved off. This avoids not only potential blowouts but sloughing or caving in of the drill hole.

Deep explorations are drilled continuously without any planned summer suspensions. Accordingly, such wells require year-round access by either gravel roads or all-season gravel airstrips. As shown in Figure 91, the three deepest wells in NPRA (at Inigok, Tunalik and Lisburne) required 350 to 420 days to drill to depths of 17,000 to 20,335 ft. Because of the extremely high drilling costs and the associated costs of gravel roads and runways, deep wells are relatively few in number, usually being reserved for new areas where the geology is unknown or confusing.

Drill pads for exploration wells have many common elements, but are seldom identical. Shallow exploration wells, drilled in one winter only, normally have drill pads that are relatively small in area. Because of their brief period of use, most drill pads for shallow wells can be constructed from compacted snow or chipped ice, which is thickened and strengthened by repeated applications of water, much like a winter road. When such drill pads are used, the only earthwork required is the excavation of the reserve pit, with the excavated material being used for dikes around the reserve pit and flare pit. This excavated material is later used to backfill and cover over the reserve pit when drilling has been completed.

Locally available soils from the reserve pit and nearby borrow pits have been employed for the construction of drill pads for the deeper shallow wells and medium-depth wells (Mitchell 1983b). The size of the reserve pit increases with increasing well depth. Typically gravel is not employed in the preparation of drill pads, unless readily available. Accordingly, pads are often made from frozen fine-grained soils, which are useful only while they are frozen. When they thaw out in the spring, they typically turn very muddy, for normally an accumulation of snow is packed down on the surface during the winter. As thawing progresses during the summer, excess moisture drains laterally or evaporates, leaving the silts or sands in a very loose state, incapable of supporting any traffic. At shallow wells this poses no operational problem, because the rig has either been moved to another location or has been left disassembled and stacked for removal the next winter. In medium-depth wells such pads are normally unserviceable; they are reused only when the pads refreeze the following winter. These pads have been called *winter pads* or *thin pads* and are typically 2 to 3 ft thick, with the thickness often being related to the volume of material generated in the digging of the reserve pit (Brooks 1983c, Mitchell 1981).

Deep explorations, requiring continuous drilling for a year or more, require a stable platform or working surface. They differ from the thin pads described above in that they are typically surfaced with gravel and experience little settlement upon thawing, at least in the critical first or second summer. Some of these thick pads have been underlain with board insulation, and are similar to the insulated airfields described earlier (Wellman et al. 1977). When gravel is limited, the base of the pad may be constructed with select sands or other soils. The overall thickness of such pads is normally 3 to 5 ft thick. Normally thick pads have a larger surface area, since all equipment and supplies must be stored on the pad, not on the surrounding tundra.

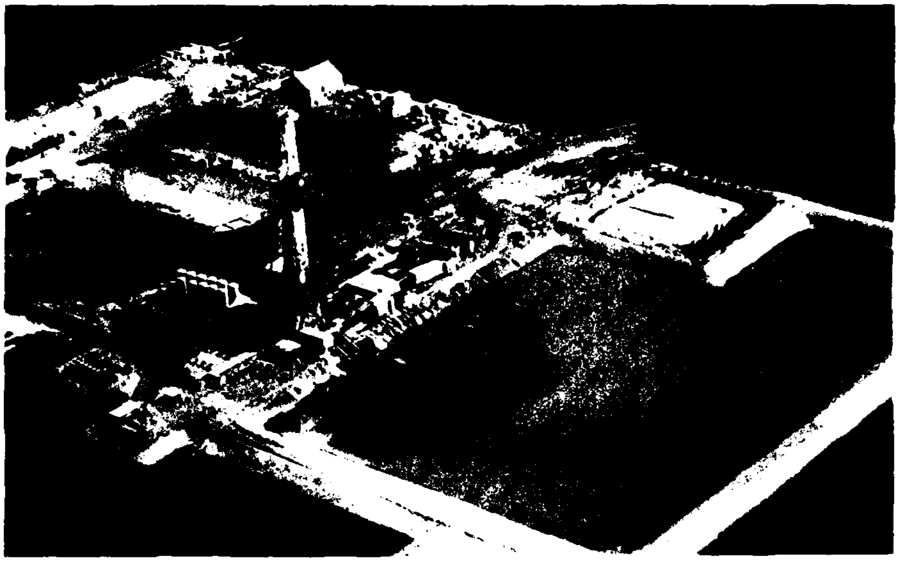


Figure 92. Drill pad during active drilling of deep well at Inigok.

Figure 93. Lisburne well site just after drill rig had been removed at completion of well. Drill camp still on site. Note different levels.

Layout and design

The basic layout of a drill pad can best be appreciated by an aerial view (e.g., Fig. 92), showing the basic positioning of the various components. Normally the well location is fixed by the company's geologists and they usually are reluctant to move it more than a few feet. When construction of the drill pad will be very difficult, the engineering staff negotiates with the drilling staff to relocate the well, or use directional drilling. However, it would appear from an inspection of drill sites that innovative drill pad designs can accommodate even very difficult terrain, as exemplified by the Lisburne and Killik wells in the Southern Foothills (Fig. 93 and 94). On the other hand, many well sites are in relatively flat terrain, where

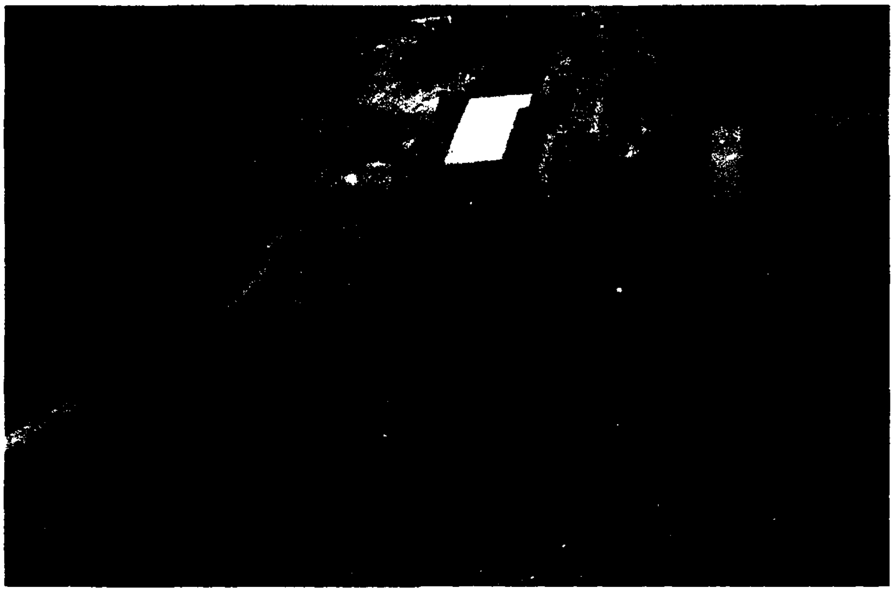


Figure 94. Killik well site before the start of drilling, showing lined reserve pit.

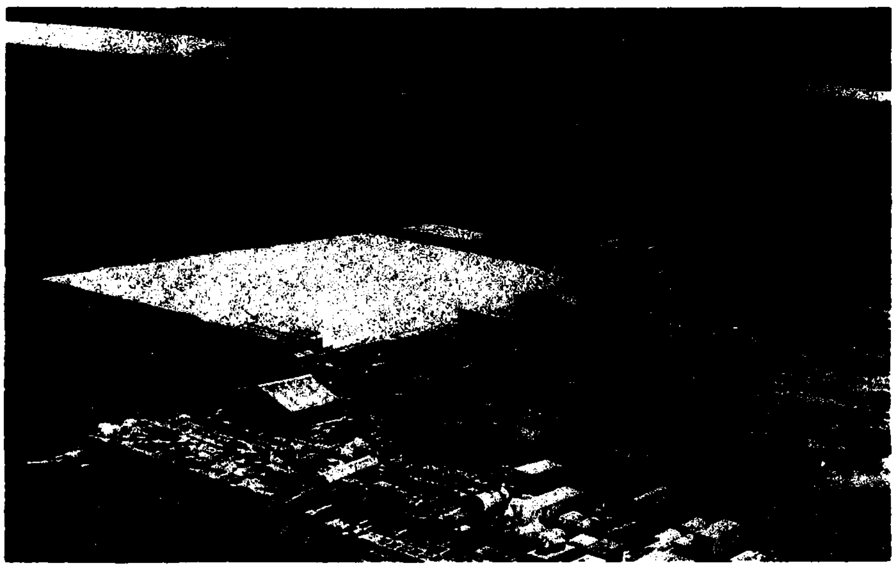


Figure 95. Drill pad at Awuna, which was drilled during two winters with no drilling during intervening summer.

there are unlimited options in the positioning of the drill pads (Fig. 95 and 96).

The layout of the drill rig is the first design concern. The basic footprint of the rig is usually rectangular (about 95 × 225 ft) and may be oriented in any direction, except that the orientation establishes the position of the reserve pit and the rest of the pad layout.

In Figure 97, the position of the reserve pit is to the left of the rig, and the mud storage and pump houses are to the rear. Normally the area to the front of the rig is used for rigging the mast up and down and handling the drill pipe and casing, although some of this space may be later occupied by the geologist's "shack" or other modules. The large, central area of the pad is often considered open space, but is actually used for the storage, layout and inspection of the drilling pipe and casings. (Fig. 98). Normally one edge of this central area is dedicated storage for drilling mud, cement, vehicles and the like. The modular drilling camp is located on the opposite end of the pad from the drill rig. Typically this camp is for the exclusive use of the drilling crew, direct support personnel (like haulers and pilots) and a few visitors. Construction crews normally have their own separate camp. The distance between the drill camp and rig determines the overall length of the drill pad, usually being a minimum of 250 ft for shallow wells and 350 ft for deeper wells, for safety reasons (H_2S and fire). Similarly the position of the camp with respect to the rig is also predicated on wind direction, the camp being preferably upwind of the drilling. Overall dimensions of drill pads for deep wells are about 550 × 800 ft (Fig. 97); shallow-depth well pads may be as small as 300 × 500 ft. The larger size of the reserve pit and the requirement to store more pipe, mud and other supplies contribute to the larger dimensional requirements of medium and deep well pads.

Drill rigs require stable and strong foundations to support not only the weight of the rig, but the tremendous loads imposed by the weight of the long drill pipes and casings, particularly on deep wells. Since the drill rigs cannot settle or tilt with time, they are normally supported on timber piles with large continuous timber beams capping the piles (Fig. 99). The positions of the piles are usually different for each drill rig, but are typically in a series of long rows, employing 200 or more piles, installed in augered holes 20 to 30 ft deep. The augered holes for the piling are 4 to 6 in. larger than the nominal pile diameter, and the annulus is backfilled with a sand- (or silt-) water slurry and allowed to naturally freeze (i.e., no refrigeration). Complete freezeback of the piles usually takes only a matter of hours, or days at most, in such cold permafrost.

Because of the radial heat flow from deep wells, the timber piles are normally kept 8 to 10 ft away from the well. While the cellar box and conductor pipes are often insulated, the area surrounding the well is thermally very sensitive. Accordingly, deeper (45-ft) piles are employed around the well and spanned by a steel box frame. This steel frame is usually supported by 12 or more of the longer piles, typically in groups of three at each corner.

The entire area beneath and immediately surrounding the drill rig is often underlain with rigid board insulation and covered with one or two layers of a thick plastic membrane to prevent water from filtering into the joints in the insulation. The insulation board is cut to fit around each pile and the membrane is carefully cut and wrapped around each pile to ensure against leakage at these points. The insulation is normally sloped slightly toward the reserve pit to provide drainage.

The area beneath the drill camp, at deep wells, is also underlain with 4 to 6 in. of the same insulation. The foundation for the camp consists of large timber sleepers set on the insulation or a covering layer of gravel. The drill camp modules are assembled on these sleepers, such that there is an air gap of 6 in. or more between the floor and the gravel surface to provide for the dissipation of some of the building heat. The drill camps are not elevated on piling as normally found with permanent buildings on permafrost, because such camps are temporary and, if necessary, can be adjusted by jacking and shimming.

Sometimes, at deep well sites, the central area of the work pad is also underlain with insulation board, typically 2 to 4 in. thick. The remainder of the pad is uninsulated, although in some special situations (i.e., when the base of the pad is frozen sand) the slope between the drill rig and reserve pit has been insulated (Fig. 100).

The size of the reserve pit is designed to match the depth of the exploration, large pits being required for the deeper wells. The drill cuttings are deposited on one side of the pits via chutes (Fig. 101). The reserve pits usually are unlined excavations, typically 5 to 10 ft deep below original ground. Most reserve pits are designed as shallow excavations, relying on length and width to provide the required volume, since it is the walls of the pits that can experience the greatest problems. The warm drill cuttings and water deposited on the drill rig side of the reserve pit thaw the underlying permafrost, even when this slope is insulated, with the insulation merely reducing the rate of thawing. The drill cuttings, however, stabilize this slope as the deposited material gets thicker and thicker. The side slopes of the reserve pits are 2:1 or 3:1, and even flatter in some cases. At deep wells these interior slopes are covered with a blanket of gravel (3 ft thick or more), and the perimeter of the reserve pit is surrounded by a dike (Fig. 102). The dikes, con-

Figure 96. Seabee well site during active drilling. Note tapering reserve pit dike, with fuel bladders at left of pit.

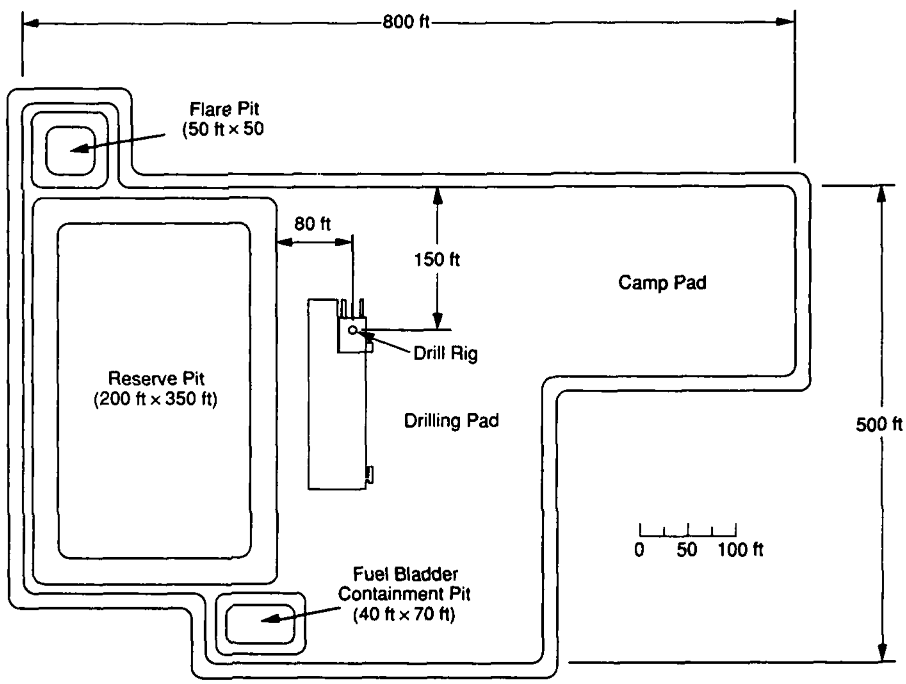


Figure 97. Typical drilling pad.

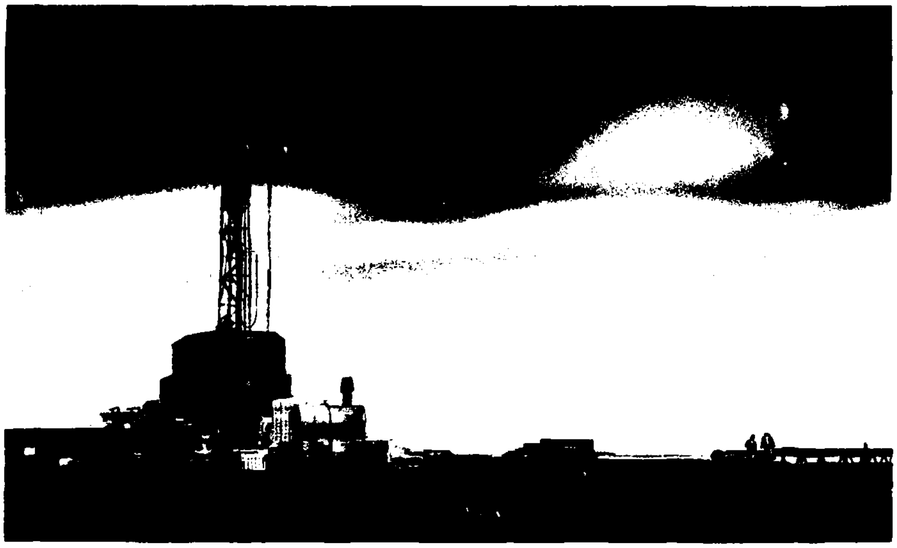


Figure 98. Tunalik drill pad during active drilling with drill casing stacked in center of pad.

Figure 99. Installing timber piles in permafrost at Tunalik to support drill rig.

Figure 100. Placing insulation on slope of reserve pit at Seabee well, next to pile foundation for drill rig.

structed with frozen material, are pervious when thawed and not designed to contain water (or to keep water out in some cases). The dikes merely insulate the rim of the pit and act as a convenient storage area for material that may be used to fill in any local slumping. Since the weight of the soil in the dikes could create an additional load, and cause the submerged slopes to fail (when thawed), the height of the dikes is purposely kept low and correspondingly wide. Dikes around the reserve pit and the nearby flare pit are also designed as stockpiles for the restoration efforts after a well site is abandoned.

Some innovative changes to the design of reserve pits and the disposal of drill cuttings are currently being tried on the North Slope. Instead of wide and shallow pits, the current interest is in small diameter but deep pits. Similarly, efforts are also underway, for both exploration and production drilling, to entirely eliminate reserve pits. This includes the use of transportable mud and cutting grinder plants, which allow for recycling of the drilling mud and reconstituting the cuttings such that they can be later injected into the well or otherwise disposed of, on or off site.

The flare pit is usually located near one corner of the reserve pit (Fig. 93, 96 and 97), and is typically about 50 ft square at the bottom. It too is diked, primarily to provide a nonflammable wall, when flaring is required to burn off any gas from the well. The gas line to the flare pit is usually supported on simple timber blocking. Fuel containment areas are also diked with gravel or frozen soils. Fuel is contained in tanks or fuel bladders, and the fuel pits are lined. Double-walled fuel tanks (Fig. 83), have been used in lieu of fuel pits at some well sites.

Figure 101. Chutes with underliners on slope of reserve pit at Seabee well site.

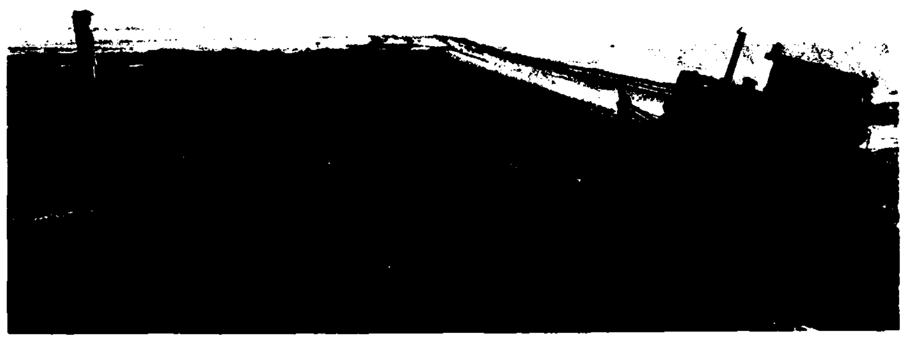


Figure 102. Constructing gravel dike around reserve pit at Seabee well site.

Construction of pads and pits

Virtually all drill pads are constructed during the wintertime (exceptions to this general rule include sites in the Foothills or directly on the coast). The drill pad area is carefully surveyed during the summer, and staked out, such that the wintertime development of the site is orderly and confined to specific areas. Normally the site is also predrilled at several locations, to define the soil and ground ice conditions, usually to depths of 30 to 50 ft. This geotechnical information is important with respect to rippability, pile installation, thaw settlement, erodibility, restoration, etc.

Shallow exploration wells that will employ snow pads are typically located on relatively level ground to avoid deep fills. These pads are constructed in the same manner as snow roads (see Chap. 3). The existing snow cover on the entire drill pad area is first compacted by low-pressure vehicles, wide-track bulldozers and other vehicles and then thickened by successive applications of water. Chipped ice, harvested from local lakes, can be effectively employed to thicken the pad more efficiently. Snow can also be harvested from the surface of local lakes or rivers for this work. Obtaining snow from the surrounding tundra is usually not cost effective and potentially could seriously damage the tundra vegetation. The iced-down snow or chipped ice pads are typically only 12 to 18 in. thick and can, under ideal conditions, be quickly constructed.

For a thin winter pad, all or most of the borrow material is obtained from the reserve pit excavation, which is accomplished by rippers, usually on D-9 or larger tractors. The surface mantle of organics is normally removed throughout the reserve pit area first and either stockpiled or placed along one edge of the pad or pit for later reuse. Since reserve pits normally are not very big, only a limited amount of heavy equipment can work in the pit. Similarly, since the haul distance is very short, much of the excavated material can be placed directly with dozers and front-end loaders, particularly in constructing the dike around the reserve and flare pits.

Simultaneous with the opening of the pit, the augering of piles for the drill rig commences. Augering in frozen fine-grained silts and sands is typically quite fast, ranging from 1 to 2 ft/minute. Accordingly, production rates of 20 to 30 piles/day (double shift) are possible with only 1 auger. Drilling for the cellar box is usually done by augering a series of holes and then hand digging (busting) the frozen soil remaining between these holes, producing an excavation some 10 ft deep and 10 to 12 ft in diameter. Drilling for the installation of the conductor pipe then follows, to depths of 100 to 200 ft. The insulated or uninsulated conductor pipe (typically 42 in.) is then set and grouted into the hole with special quick-setting cements. Concurrently, crews place the board insulation and plastic membrane around the piles and cellar box. Additional fill is then placed atop the insulation. The timber piles are then cut off and long timber pile caps installed. The fill is then extended, higher, to the top of the pile caps, providing maximum lateral restraint to the piles.

While constrained by space, the series of tasks in preparing a thin pad takes only 3 to 4 weeks. Considering the total darkness, low temperatures, wind and snow and typically small crew, this is praiseworthy. The drill pad construction schedule is normally driven by the drilling schedule and the site must be ready to receive the drilling equipment on a firm date. Any delays in starting the drilling could jeopardize reaching the designated target depth.

Facilities for deep explorations usually require 4 to 5 months to construct. Not only are these pads typically larger in size, but they require a gravel surface layer on the top of all fill, including any insulated sections. Since gravel is seldom readily available, this means that snow or ice roads must first be constructed to the borrow sites, often miles away. The construction deadline for deep wells is often based on the arrival of the drill rig in April or May, because the drill rig is often brought overland by snow trails or airlifted, from another drill site.

To minimize the amount of dirt work required for a drill pad, and the subsequent restoration work, there have been several interesting experimental pads under consideration and field testing. These include the use of modular, prefabricated timber mats, with or without an underlayment of insulation. Variations of these experimental drill pads, which are reusable, should be anticipated over the next decade, as explorations continue in other areas of the North Slope.

Summary

Data from the NPRA exploration program, from 1975–1982, provide very useful information on the time required to drill exploration wells in this remote area, as shown in Figure 91. Shallow explorations, to depths of 5,000 ft or less, can be drilled in 25 to 50 days. Wells to 10,000 ft can be drilled, from compacted snow drill pads, in a single winter with the drill rig and associated equipment being moved in and out on snow-covered winter trails or by aircraft.

Medium-depth wells (to 15,000 ft) may require 150 to 300 drilling days and accordingly require that the rig be on site from the previous spring or left on site at the completion of the drilling. Typically medium-depth wells are drilled in successive winters, with the rig idle during the intervening summer. The drilling periods for such wells are often seriously constrained by the availability of an operational airstrip on the frozen tundra or local lake.

Deep wells to 20,000 ft or more require 350 to 420 drilling days and usually are accomplished by continuous drilling, to avoid problems and extra work associated with suspending drilling. Such long drilling periods require gravel all-season airstrips, roads and drill pads.

The size of the drill pads is related to the proposed target depth of the well, but there is always a minimum distance maintained between the drill rig and camp for safety reasons. The size of the reserve pit, used for the cuttings from the well, is also a function of the proposed well depth. The volume of the pit is increased primarily by increasing the surface area without substantially increasing depth, because of the potential for slumping of the side slopes. The current trend is to reduce the surface area and increase the depth of the reserve pit.

Shallow, winter-only drill pads may be constructed in the same manner as snow roads, using snow or chipped ice that is repeatedly watered to produce an icy pavement. Drill pads in the near future will probably utilize modular reusable mats, which can be quickly deployed, and taken up, with minimal damage to the tundra. Medium-depth wells, employing larger reserve pits, use material from the excavation in all or most of the drill pad. Typically this fill consists of fine-grained soils and is useful only when frozen. Accordingly, deep well drill pads are constructed, or at least surfaced, with gravels that remain stable throughout the summer months.

Shallow explorations can be drilled with smaller drill rigs. However, medium and deep wells require large drill rigs and pile foundations. Cellar boxes and conductor pipes require insulation to limit thawing around the top of deep exploration wells, which might jeopardize the integrity of the frozen in-place piles. Insulation is employed under drill rigs, the drill camp, all or at least the central area of the drill pad and on some reserve pit slopes.

CHAPTER 8. OPERATIONS AND MAINTENANCE NORTHERN OPERATIONS

Northern operations require the establishment of many interrelated schedules. The mobilization and preparation of equipment for the crosscountry move, or airlift, begins many months before the actual site work begins. Construction schedules are typically task oriented, and very specific as to start and completion dates. The construction efforts are fully coordinated with the arrival of the drill rig and proposed date for the start of the drilling. The schedules also include demobilization, cleanup and restoration. Early planning and scheduling are essential to coordinate the many elements involved and to obtain the various permits required.

Equipment and supplies

Remote work, with limited accommodations for repairs, requires quality equipment. Vehicles and heavy equipment should be procured with durability and reliability in mind. The equipment selected should also be based on the proximity of authorized dealers, so that parts, and sometimes repair services, can be readily obtained. Many Alaskan firms provide quick and efficient support to North Slope operations and fully appreciate the urgency of each order or request for services.

The typical Northern Alaska operation is supported by a very short and efficient supply chain. The lead mechanic or foreman can place orders via satellite phones or computer networks to either the support base or to Fairbanks or Anchorage. Many of the repair items requested are considered rush orders, since the equipment may already be down. Rush orders placed in the morning often result in the requested items being on the afternoon plane.

The procurement and shipping departments often work long hours to facilitate the shipment of all needed parts and supplies. These departments are also responsible for the handling of inflammables, toxic materials, explosives, etc. Special decals affixed to the boxes are often used to clearly identify items, destination and special handling requirements.

Winterization

Winterization is the common term for equipping vehicles or heavy equipment with special items or kits for operations in extremely cold weather (Diemand 1990, 1991c). Some of these items are installed as optional items when the vehicle is purchased. These items include engine heaters, battery chargers and heating blankets, radiator covers, heavy duty batteries, heaters, defrosters and windshield wipers, insulated cabs or ceilings, hood blankets, etc. Purchasing agents should carefully prepare specifications for the desired vehicle, particularly when seeking competitive bids, for there may be other features that are more than just desirable. Such features include instrument gauges (rather than light indicators), heavy-duty springs and shocks, heavy-duty exhaust systems, large or extra fuel tanks, heavy-duty bumpers, etc.

Normally vehicles have standard transmissions (i.e., with clutches) and virtually all vehicles are 4-wheel drive, with "Positrack" rear wheels. Engines typically have 6 or 8 cylinders, with sufficient power for towing other vehicles. Vehicles are equipped with front and rear towing hooks. While some construction companies prefer to have their equipment painted in the same color, this is sometimes impractical. However, visibility of the vehicles against snow, tundra or a gravel background can be an important safety consideration, particularly on single-lane trails or roads.

Optional or auxiliary items are also available for heavy equipment. These normally include special engine starting kits, especially for diesels, including special primers and ether injectors (Diemand 1991b). Insulated cabs are also available for tractors and graders. Cabs for the latter are equipped with heaters and fans. Heavy equipment is also equipped with extra lights for more efficient night work.

Maintenance of vehicles and equipment

Maintenance is taken very seriously by everyone working in the Far North. This is ingrained, since safety is directly related to reliability. Maintenance is also critical to the availability of the vehicle. Since vehicles are usually limited in number and critical to accomplishing the work, there is a keen interest in proper servicing. Vehicle operators are also more sensitive to checking out all the critical operational features before setting out and alert to any clues to an impending problem. For instance, operators are sensitive to the heat output from defrosters and heaters. When a change in output is noted, either hotter or colder, the operator checks the temperature gage, almost instinctively. Operators will also periodically check the oil pressure and temperature gages. A temperature rise can often be traced to snow blocking the radiator, or a closed radiator cover, not allowing enough air circulation for the ambient conditions. Sticking or malfunctioning thermostats can also be a source of trouble, causing the engine to be too hot or cold. Operators are also sensitive to the brightness change in headlights, between idle and full power, and the amount of cranking power when starting, as indicators of generator/alternator or battery problems. Loss of power on grades and engine knocks or pings are also signs the operators listen for, being symptomatic of poor fuel, carburetor trouble, or even more serious problems within the engine (Diemand 1991a).

Vehicles are often left running when not in use and idle speeds are adjusted to maintain enough RPMs so that the oil pressure is sufficient to lubricate the engine. Vehicles that are not kept running have their engine heaters, battery blankets and trickle chargers plugged into 110-VAC receptacles positioned on the exterior of camp buildings or at special "hitching rails" to maintain sufficient heat and charge for starting. If the vehicle or piece of equipment was inadvertently not plugged in, one typically would not even attempt to start it. Such a vehicle is called "cold soaked" and one would merely plug it in, go back inside, and wait an hour or more before attempting to start it. Heavy equipment and aircraft that are not used on a daily basis, or perhaps not equipped with such auxiliary heating units, may require preheating with a portable hot air heater, particularly at tem-

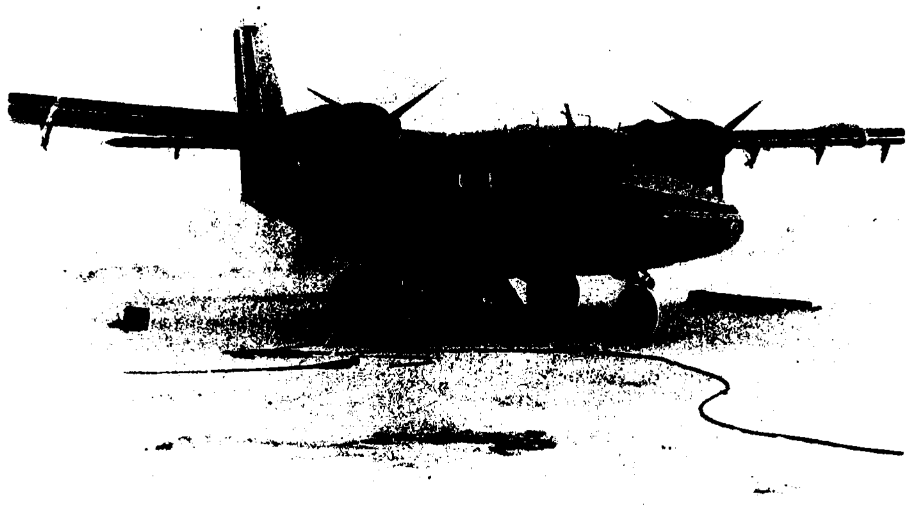


Figure 103. Twin-Otter being readied for winter flight. Note engine covers and external heater.

peratures below 0°F (Fig. 103) (Diemand 1991b). Preheating is normally well worth the time and effort; sometimes it is the only way to start a piece of equipment when it is cold soaked.

Oil spills, toxic wastes and hazardous material

Oil spills associated with exploration work are primarily associated with fuels and lubricating oils, not crude oil. The spills are primarily accidental in nature, although some could be attributed to poor maintenance or improper operational procedures. Accidental spills involve the tipping over of vehicles, usually associated with going over the shoulder of deep embankments, or the rupturing of fuel tanks. Spills are also encountered in the transfer of fuel from fuel trucks, fuel drums, or storage tanks. Fuel drums can also be damaged during transport or handling, with small leaks going unnoticed for hours or days.

Oil and fuel spills, including hydraulic fluids, are not presumed by vehicle and heavy equipment operators to be rare or uncommon, but inevitable. Standing orders are posted for all employees on the prevention of spills and their duties in reporting each spill and assisting in the cleanup. The cardinal sins are doing nothing about a spill and not reporting it. Typically all construction camps and drill rigs have spill contingency plans and equipment to contain and clean the spills. On-site supervisors are responsible for preventing such occurrences, through inspections and changes to equipment or procedures. They are also responsible for mobilizing and directing the cleanup, and for reporting and monitoring the aftereffects.

Normally the cleanup efforts begin with efforts to stop or limit the spill, shutting off valves, pumps or engines which, if continued, would make the spill worse. The next step is containment or catching the fluids. This might consist of plywood, earth or snow embankments, or, in the case of leaks from equipment, simply buckets or pails. Absorbent pads, in storage at several locations on site, are then dispatched and deployed to absorb the spilled material.

Cleanup may involve the removal of impregnated snow, vegetation or soils. Typically spills are confined to the ground surface, by the shallow active layer and the presence of frost and/or permafrost. The affected vegetation may have to be removed, burned or otherwise treated (McKendrick and Mitchell 1978). Documentation on the extent and location of each spill, and the degree of success in the initial cleanup effort, are important to long-term restoration. Construction or drilling personnel are seldom available after the site is abandoned, and written records are vital to long-term monitoring and potential secondary or tertiary cleanup requirements.

Hazardous or toxic material involved in the drilling operations also includes special additives for the drilling mud. Special attention should be given to the handling and storage of such material. Sometimes these additives are for contingency purposes only and may have been moved from site to site and in open storage for many years. Hence, the material should be repeatedly inspected and carefully stored to prevent spillage from disintegrated or broken crates or drums. If actually used in the exploration well, concern for such chemicals or toxic material extends to contamination of the reserve pit and requires plans for neutralizing or otherwise treating the drill cuttings and reserve pit.

Naturally occurring hazardous material may also be encountered in the drilling of the well itself. These include hydrogen sulfide gas and pure sulphur. During the drilling of the deep exploration at Inigok, both of these were encountered. Accordingly, documented information on any material employed or encountered during the drilling are important to the plans for abandonment of the reserve pit.

Crude oil, which may be associated with natural gas, is normally burned off in the flare pit. However, in some situations there can be problems associated with igniting or keeping the flame burning in the flare pit, producing a concentration of crude oil on the bottom of the pit. Accordingly such crude oil accumulations may require special cleanup efforts.

Other hazardous materials around a construction or drill camp include propane, oxygen, acetylene, solvents and paints. All personnel should be constantly alert to the proper methods of disposing of all such material and their containers, including kitchen fats and cooking oils, which are not processed by the portable, containerized waste treatment plant at the drill camp.

Solid waste disposal

While every attempt is made to use reusable shipping containers, typically the knock-down type, there are still a lot of consumable containers of wood, cardboard, paper, etc., which can be best disposed of on site. This is accomplished by the use of a burn basket (Fig. 104). Typically the contents of this basket are burned each day, after the pickup of all trash by the "bull cooks" (those who clean, serve food, etc., around a drill camp). It is burned as a single hot fire, minimizing the amount of smoke. A designated individual is responsible for what is placed in the burn basket, i.e., for avoiding explosive pressure cans, paints or other toxic material. This individual is also responsible for the removal of all small metal parts that are not consumed in the fire, and placing such material in dedicated metal containers for backhaul. Open dumps, as such, are not permitted or used.

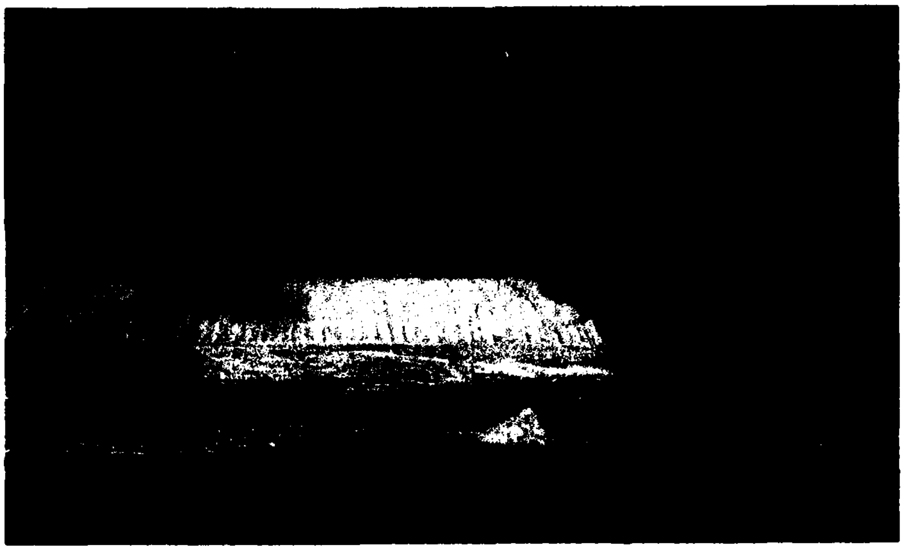


Figure 104. Burning trash at Lisburne well site.

Snow removal

Snow removal is required on drill pads, roads and airfields. However, the degree to which the snow is removed is markedly different from that normally found on pavements elsewhere. In northern Alaska one finds a deep accumulation of packed snow. It is not uncommon to find 4 to 8 in. of densely packed snow on drill pads, roads and even airfields. Light snows and drifting snow are compacted by foot traffic or vehicles.

Snow shoveling is usually restricted to short passageways between buildings or around supplies or equipment. Usually the limited amount of hand shoveling is accompanied by the direct aid of front-end loaders, such that the snow can be hauled to designated areas on the perimeter of the site, rather than just making snowbanks. The major portion of the snow removal around the drill pad is done with front end-loaders, or, in the case of roads and runways, with road graders.

At drill pads and parking aprons, there usually are designated areas around the perimeter for snow storage. Typically these are located in the deepest fill sections, such that there is more storage on the downhill slope, including the adjacent tundra. Care is taken in selecting these snow storage areas to avoid causing large snow drifts or compounding a drainage problem in the spring. Some of these snow storage areas do not melt away until well into the summer.

Snow removal operators should be highly qualified, for they can ruin or damage buildings and stored material. Snowplowing also creates snowbanks, which if not winged back, only aggravate the catch of subsequent drifting snow. Drifted snow or old snowbanks can be very dense and cannot be pushed against most objects without causing serious damage. Snowplowing on roads is not easy, especially during the nearly continuous winter darkness, with drifting or falling snow. Yet the operators must be constantly on guard to remove the snow only from the traveled way. If the snow is bladed off beyond the edges of the roadway, particularly on curves, subsequent travelers can mistakenly believe that the roadway extends to the snowbank and catch a wheel in this softer snow, often being violently wrenched into the snowbank and sometimes over the embankment. While willow switches or stakes along the edges of the roadway can be very helpful, they are often destroyed by snowplowing operations. Careful snowplowing is thus a major factor in safe winter driving.

In the springtime, the compacted snow on the roads and other gravel surfaced areas at deep well sites begins to melt and become rutted. Accordingly the compacted snow is usually removed in an aggressive cleanup campaign. In some areas the compacted snow shears easily away from the gravel surface in large flat blocks. The exposed gravels then absorbs more solar heat and therefore dries out relatively quickly. The underlying principle is to remove the compacted snow so that there is less surface water during the spring breakup.

Temporary airfields, like any airport, require a substantial effort to remove snow. The large volume of snow that falls on a 150- × 5200-ft runway can take many hours to remove with road graders—large plows normally not being provided. These runways usually have light cables laid directly on the gravel surface of the shoulders that require special attention. The early winter snows cover these cables, but eventually the snowbanks along the lights get deep and the accumulated snow must be pushed back.

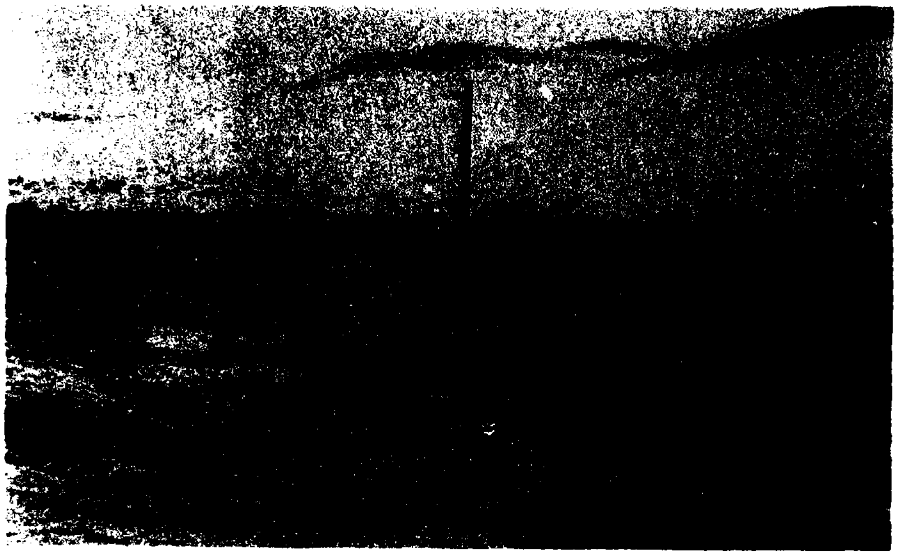


Figure 105. Drilling blast holes to excavate reserve pit at Lisburne well.

Since snowblowing equipment is lacking, these banks are pushed back with dozers or front-end loaders. The snow is literally spread out flat, some 50 or more feet from the shoulders, such that it will not seriously impede drainage. Typically the snow is moved with a high blade, such that it does not catch the light cables or disturb the tundra. Accordingly light cables must be carefully placed along the toe of the embankment and run at right angles from the shoulder to each light, offering the smallest target to the snow removal equipment.

Snow should never be piled up at the ends of any runway. Pilots cannot judge the height of such snow piles and can catch their wheels in them when landing. This is particularly critical on snow or ice runways, although even a gravel surfaced runway looks like a snow runway in the wintertime. Short landings are apparently more common than most people believe, as evidenced by wheel marks in overruns.

Snow maintenance is thus a very important job at an exploration site. It requires dedicated personnel who often must work around the clock to provide a safe working environment.

Explosives

Explosives are used for special seismic studies while drilling exploration wells and are often in place for days or weeks, in anticipation of the drill reaching a prescribed depth. They are installed in relatively shallow drill holes, several hundred feet from the well, and set off when the exploration drill hole reaches one or more prescribed depths. With the seismic equipment in the well, the explosions provide a unique opportunity to reevaluate the seismic data previously obtained, particularly to adjust for permafrost conditions. Sometimes explosives are also used for uphole and cross-hole shots to evaluate the geological structure around the well(s). The explosively loaded holes should be well marked, even when covered with drifted snow.

The use of explosives on the North Slope appears to be an optional excavation method employed only by some construction contractors. Many contractors prefer to simply employ large rippers. Yet several exploration well sites have demonstrated the usefulness of explosives. The difficult multilevel drill pad at Lisburne (Fig. 93) was very efficiently excavated with explosives (Fig. 105 and 106). The weathered bedrock knob at the Killik well also was very efficiently quarried using explosives (Fig. 76).

The use of explosives requires considerable planning and coordination. Typically the blasting crew drills holes in one area while the heavy equipment works in the area previously blasted. Frozen soils, after being blasted, will refreeze and rebond with time; thus, every effort is made to move the material as soon as possible. The amount of explosives per hole and the spacing and depth of the holes is a function of the material, its temperature, limitations on flyrock, desired fracture size, etc. (Mellor 1989). There is always the requirement to conduct a series of test blasts to optimize the amount of explosives, hole spacing, and desired fragmentation (Simpson and Jarrett 1983). While blasting is best left to professionals, there are several aspects that must be planned for and carried out by the general contractor and others. These include the submission of mining plans that specify the use of explosives. The lateral extent and depth of pits mined by blasting may also be different from ripping operations. Heavy equipment requirements may also be quite different. Portable crushing plants may also be necessary, in lieu of crushing in the pit with sheep's foot rollers or segregated wheel rollers. Special transport and storage will also be required for the explosives and blasting caps.

The type of explosives to be employed depends on many factors, including soil or rock type, the drilling method (size of holes), desired fragmentation, etc. Usually there is a personal preference for certain types of explosives by some blasters. Ammonium nitrate and fuel oil (ANFO) and other low-velocity explosives are often preferred for blasting frozen soils. Prima cord and delay blasting caps are effectively used to control the sequence of the blast, dropping the face or faces in the desired location, and producing the desired fracture with minimal fly rock. Because of the extensive use of radios, care must be taken to restrict their use in the area when the holes are being loaded. Normally the electric blasting caps are deployed and set off during the lunch hour or some otherwise scheduled shutdown or maintenance period.

Snow incorporated in the blasted material is insignificant, because the blast-dig sequence is relatively quick. Deep snow, if present, is removed prior to drilling the blast holes. All drill holes should be carefully staked or flagged and covered with plywood or other material, since blowing snow can obscure or fill the holes very quickly. Holes drilled in permafrost during the winter normally have no problem with sloughing or filling with groundwater. To reduce fly rock the holes should be stemmed to prevent the upward venting of the blast. Some blasters prefer to allow the stemming (which consists of cuttings from the hole) to freeze before shooting to achieve maximum confinement. Stemming usually freezes very quickly when using small (3-in.)-diameter holes.

Figure 106. Permafrost after being blasted in reserve pit at Lisburne.

Safety

Working in northern Alaska is not unlike working in other areas of Alaska, except for the wind chill in the winter. On the North Slope the combination of wind and temperature can produce a severe wind chill effect, and workers must be appropriately dressed for such winter conditions. Typically this means that workers should have a wide range of clothing available, from good insulated parkas, pants and boots, to insulated coveralls and jackets. Workers must be able to adjust clothing when performing different tasks, particularly laborers involved in outside manual work. Equipment operators, in heated cabs, require much less bulk and layered clothing, although extra warm clothes should be carried in case of a breakdown. Overdressing can also be a safety hazard. Personnel dressed for outside work should remove parkas and other heavy clothing when in heated vehicles or buildings.

Some individuals are more tolerant than others of the cold; hence the amount of clothing, especially the number of layers of clothing, will vary. All should be aware of the danger of frostbite, particularly on the nose and ears. Hats or caps are helpful in reducing body heat losses, as are face masks and parka hoods. Sunglasses are a necessity when the sun is reflected from the snow. Snow blindness is painful and everyone normally has a pair of good quality sunglasses at all times. All workers have several pairs of gloves. Most prefer thin driving gloves while operating vehicles or equipment, insulated gloves (with leather shells) for outside work requiring finger dexterity, and mittens for extremely cold work requiring only limited use of the fingers. All have extra gloves in camp as spares. Lightweight cotton work gloves are popular for many tasks in the warm months and are usually provided by employers. All workers are aware of the hazard of touching metal tools or other extremely cold objects with bare hands.

Laborers typically work as a crew, or at least in pairs, so that the buddy system can be used in watching for signs of frostbite or hypothermia. Crews normally take frequent breaks to warm up. Crew chiefs must recognize the value of such breaks, or even the opportunity to duck into a vehicle, for a brief respite from the cold and wind. During these breaks the crews plan how they can accomplish the next task or unit of work. Supervisors must also know when to call a halt to some tasks, switching the work to more protected areas until the severe weather abates. "Head counts" are also automatic at coffee breaks and meal times. Supervisors must instinctively be aware of the location of each worker at all times. Workers also watch out for other workers and do not hesitate to check if they see a vehicle parked too long in one spot, or at a strange location. Accidents do happen and the stress of working long shifts, seven days a week, can take its toll, even resulting in heart attacks. Carbon monoxide poisoning in vehicles is also a potential threat. Most vehicles are equipped with simple carbon monoxide detectors, which change color when too much CO is present. They are hung from the rearview mirror or elsewhere in the windshield area.

Safety is stressed not only with respect to personal cold weather injuries but safe vehicle operations. Vehicle operators must constantly be alert when working around laborers, for they may have their heads turned to avoid the wind and their parka hoods may obscure peripheral vision. Vision can also be obscured by darkness and blowing snow, or one may be blinded by vehicle lights. Men on foot, bundled up against the cold, do not move fast and their footing may be less than desirable on snow-covered ice. Strangely enough, most falls occur when entering or leaving buildings and vehicles. Snow on boots, and the accumulation of meltwater on waxed or painted floors can be hazardous. Thus, ribbed rubber runners and rugs are in front hallways or on all floors in many camps. Slipping on snow or ice can also cause serious injuries when mounting and dismounting heavy equipment. Bulky clothes, big boots, and the limited visibility of parka hoods combine to make all movements hazardous with respect to catching clothes on levers, door latches or other protruding parts. Extra caution must also be exercised to avoid having clothing and gloves caught in machinery.

Construction work typically involves vehicles and heavy equipment, and many accidents are associated with their operation. Common accidents involve going off snow-covered roads. Soft shoulders along gravel roads in the summer can also cause the same types of accidents. Accordingly, the use of seat belts is encouraged.

One of the most useful and popular pieces of heavy equipment around construction sites is the front-end loader. Unfortunately many accidents and fatalities involve these vehicles. Since most accidents occur while the vehicle is backing up, this equipment should be given ample working room. Fatal accidents with front-end loaders are also associated with unloaded machines that are being driven, at high speeds, from one area to another. When empty, these machines tend to bounce and weave at high speeds. Downgrades are particularly hazardous, due to the increased problems in controlling such vehicles. Only experienced operators should be allowed to operate such equipment, and supervisors should be constantly alert to prevent unsafe speeds and operations (Alaska DOT 1988).

Summary

Northern operations require substantially greater planning and scheduling. All equipment must be in good working order, for there are only limited facilities for repair in the field and there is only a limited number of vehicles or construction equipment to accomplish specific tasks in a limited time frame. Very short and efficient supply chains are crucial for parts and repair services.

Equipment employed on the trail and working at drill sites through the dead of winter requires winterization. While the specific winterization kits vary with different equipment, some examples of special items have been described, like battery blankets, engine heaters, hood blankets, etc. Standard or optional items that may be specified when purchasing equipment, such as 4-wheel drive, extra fuel tanks, "Positrack" rear axles, etc., illustrate the attention required to provide good quality equipment. Maintenance is also stressed, and several examples are cited of how early signs of distress can be noticed and fixed before the vehicle is out of service.

The handling of oil spills, toxic wastes and hazardous materials is inevitable around vehicles, heavy equipment and drill rigs. All personnel are briefed on their responsibilities and quick actions required to prevent, limit and clean up such spills. Fortunately, frozen ground, snow and ice limit the extent of the spill, at least during the winter months. Absorbent material is stored on site and quickly deployed. All spills should be documented so that cleanup crews in later months, or years, know the location and details of the spill and efforts to clean up or treat the area. Naturally occurring hazardous material, like sulphur, may be encountered when drilling and may influence treatments required in the reserve pit, prior to or after abandonment.

Solid waste and other combustibles are burned on site in a "burn basket," with a hot flame to reduce the amount of smoke. Nonburnable trash is collected in suitable containers and backhauled. Burial of trash is not permitted.

Snow removal is required on the drill pads, roads and airfields. Little effort is made to clean snow down to gravel pavements until springtime, there typically being 4 to 8 in. of compacted snow on all work or traveled areas. Deep snowbanks should be avoided, since they tend to promote deeper and larger snowdrifts in subsequent storms. On runways snowbanks are high bladed out flat, 50 or more feet from shoulders. Snow should never be banked on ends of runways because pilots have poor depth perception when landing on snow-covered terrain.

The brief section on explosives was included as an example of how construction on the North Slope can be quite different from that in other areas. Explosives can be very effective in excavating and quarrying frozen soils and rock.

Working in the cold, wind and darkness requires that safety be stressed at all times. All personnel should have appropriate clothing, including changes and survival items, when working outside or away from camp. Supervisors must be aware of working conditions at all times, providing appropriate warmup periods to avoid frostbite, hypothermia and exhaustion. Carbon monoxide in vehicles is taken seriously. Unsafe vehicle and equipment operations should not be tolerated.

CHAPTER 9. ABANDONMENT OF SITES

Oil and gas explorations in northern Alaska are conducted on land owned by the Federal or State government, or native corporations. Explorations on such lands are controlled by leases and permits, which have stringent stipulations, including provisions for abandonment and restoration, as an integral part of each permit (Hanley et al. 1983).

Planning for abandonment

Plans for abandoning a site begin with the initial planning for the proposed work. For every proposed item of disturbance one must think of a proposed method of restoration. Under ideal conditions one would think of restoring a site to its original condition, i.e., the way it was found. Realistically, this is seldom possible in this environment, but one can stabilize and restore a drill site such that it is environmentally and aesthetically acceptable. In some cases, restoring a site to its original condition would not be in the best interest of future work. For instance, removing a gravel airfield that could be utilized by the land managers, or the other development work in the area, would be counterproductive. Thus, all parties concerned must have a clear understanding of what part or parts of the work will be restored and what portions will be stabilized and virtually abandoned in place. There should also be a clear understanding of when, and under what conditions, responsibility for restoration, or continuing maintenance, will be transferred to the land managers or to third parties who might utilize the facility.

Planning for abandonment is an inte- [illegible] of the exploration program. The [illegible] associated with such restora- [illegible] have a strong influence on [illegible] and when the exploration [illegible] Accordingly, shallow, [illegible] snow or ice pads [illegible] accomplishing

[illegible] with [illegible] abandonment [illegible]

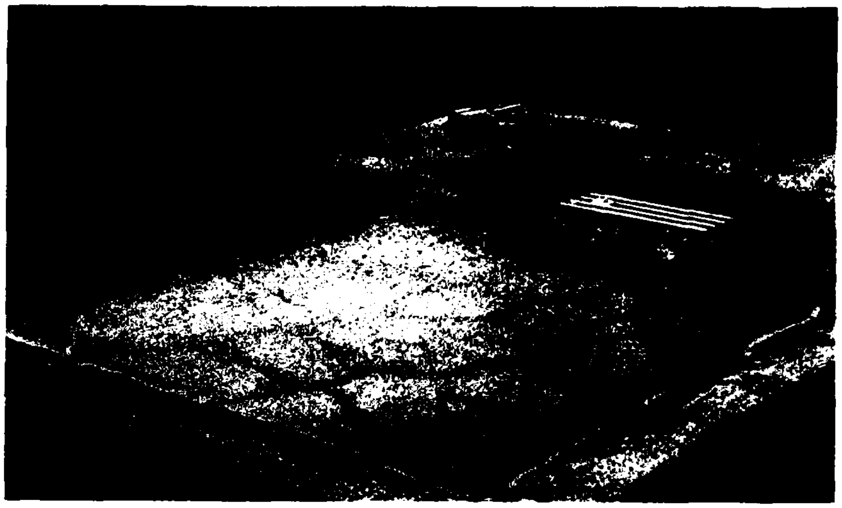


Figure 107. Well site after initial cleanup showing thaw subsidence in bottom and sides of reserve pit, reflecting ice wedges.

a snow drill pad, will primarily concern restoring the reserve pit. When drilling is completed (or at some later date) the dike around the reserve pit is bulldozed back into the reserve pit, effectively burying all the drill cuttings. The snow and ice in the drill pad is simply allowed to melt away in the summer, although it may be beneficial to apply a light application of fertilizer or limestone, in early summer, to aid in the recovery of the native vegetation that was stressed by the snow pad.

Since about half of all drill pads are to be constructed with material from the reserve pit and from local borrow pits, one should consider where all the different materials should be stored for later use in the restoration work. Much of the material from the reserve pit is used in dikes or berms. In other cases some of the material from the reserve pit is stockpiled in the borrow pit for future use in restoring the borrow pit. Calculating the volume of material required to overlay specific areas is accordingly important. Restoration plans for drill pads that employ frozen soils usually assume the drill pads will be abandoned in place, but require revegetation (Fig. 107).

While rarely employed, temporary airfields, roads and drill pads can be removed during the summer months, with all equipment working from the existing gravel surface. No traffic would be allowed once the gravel had been removed, essentially reversing the construction mode. Since the underlying vegetation is dead, one would remove only the upper portions of the gravel embankments, leaving 6 to 12 in. or more of the fill to be revegetated. The primary interest is in removing those embankments, which can create deep snowdrifts and obstruct or concentrate normal surface drainage. The thin veneer of gravel left on the tundra may be revegetated or left to be restored naturally, although the latter may take decades. An example of such partial removal operations is shown in Figure 108.

Cleanup and initial restoration

Cleanup is a constant task during the drilling period and employees are normally sensitive about litter, messy drill pads and camps. Drillers take pride in their camp and the appearance of their drill rig and equipment. Thus every effort is taken to keep the drill site as clean and orderly as possible. Because the drilling period is very short and prescheduled, the crews are fully cognizant of the requirement to pack up and move out. Even in the hectic days of rigging down and mov-

Figure 108. End of runway at DEW Line station at Wainwright, showing section where gravel was removed when runway length was reduced. Orange barrels mark centerline approach.

Figure 109. Old (1947?) aerial view of well site at Umiat while under active drilling. Note disturbance around well site by unrestricted vehicle operations.

ing to another site, there is order and concern for the cleanup and restoration that will follow, even if this work will be done by others, at a later time.

Once the drill rig and camp have been removed, a small contingent of laborers is assigned the job of initially cleaning up the area. Usually this crew must be transported by helicopter since there are no longer camps at the site. Sometimes these initial cleanup efforts must be done in a series of visits, until all or most of the snow has melted. The last cleanup visit is usually in conjunction with the beginning of the erosion control and revegetation efforts.

Much of the initial cleanup is accomplished by hand or with simple tools. This includes cutting the timber sills that supported the drill rig into short lengths, with chain saws, such that they can be hand carried to a burn pile in the center of the pad. Timber piling is also cut off, typically a foot or more below grade, and burned. The tops of the piles are then covered with soil, such that they are permanently buried. All timbers used for the foundation of the drill camp are similarly removed and burned. While every effort is usually made to recover these large timber sills, many are frozen into place and must be left behind for the cleanup crew. There may be other material that is frozen down or buried in snowbanks. Normally all wood is burned. All other material, including metal, is placed in trash bags or other containers and brought out by helicopter (Schindler 1983).

Regrading and filling pits

Initial cleanup efforts with respect to the reserve pit usually begin immediately following the completion of the drilling. This consists of dozing the drill cuttings into the reserve pit and otherwise leveling off the cuttings. This is followed by backfilling the reserve pit with stockpiled material or from dikes around the pit, fuel tanks, etc. The filling and subsequent burial of the reserve pit must be carefully planned and executed, particularly with respect to conditions at the time (snow, ice, meltwater, etc.). Often such efforts must be done in stages, sometimes taking a year or more. To facilitate this work, it is advantageous to leave a small bulldozer at the site for 6 months, or even a year.

Normally reserve pits can be filled in quite quickly. Dozers and front-end loaders work atop the dike, avoiding any disturbance of the surrounding tundra. Typically the reserve pits are regraded with a slightly elevated crown at the center, with all drill cuttings being buried at a prescribed elevation with respect to the final grade. The design intent is to bury these cuttings, so that they will freeze and become permanently frozen, capped by a permanent vegetated cover.

In recent years there have been discussions regarding the disposal of well cuttings back into the well, at the completion of the drilling. The well, of course, cannot accommodate all of the cuttings, since the bulked volume of the cuttings exceeds that of the in-situ rock, and considerable space is occupied by casings and cements. The experimental transportable cuttings grinder plant may provide a means for injecting the cuttings in a stratum below the bottom of permafrost, upon the completion of drilling. Drill cuttings from some wells, particularly production wells, have been mixed with sands and gravels to form topdressing for roads, which can be readily compacted into a smooth pavement. Concerns for the use of drill cuttings in roads usually involve potential dust problems on the adjacent tundra vegetation, including contamination by natural elements in the cuttings, or by drilling additives.

Figure 110. Airphoto taken in 1982 of the same well at Umiat, as shown in Figure 109, from about same position. Note brush and grass on old trails, by natural revegetation.

Figure 111. Abandoned thin drill pad with filled-in reserve pit. Note new grass in tracks that holds moisture and retards erosion.

Revegetation

Revegetation of drill pads, reserve pits and borrow pits is essential to reestablishing ground thermal conditions that will produce a shallow active layer over permafrost. Revegetation is also important in preventing erosion from wind and water, which would destroy or delay the reestablishment of the vegetation cover and potentially impact the undisturbed tundra surrounding the drill site (Johnson 1981, Lawson 1986). The ultimate goal is to reestablish native vegetation that is commonly found at each particular site. In some cases the native vegetation that will predominate after restoration may not be the same as originally found at the site. For instance willows, alders and other shrubs may be the new dominant vegetation, even when such plants are not normally found at the site (Walker et al. 1987). At some locations, such as at Umiat (Fig. 109 and 110), such brush is widespread and thrives in areas disturbed by both man and nature (Lawson et al. 1978).

Revegetation is normally done after all earthwork has been completed, although at some sites this may be done in stages. Drill pads constructed with fine-grained soils require an early vegetative cover to resist erosion. Usually these drill pads require some form of compaction, such as repeated passes of a bulldozer, to stabilize the soils after they have thawed. Typically these sites require little or no harrowing or other tillage; only a wire drag is required to prepare the soil surface for seeding. Limestone and fertilizer, if required, are usually applied during the final stages of this preparation work, using simple hand-held spreaders. The rate of application of the limestone and fertilizer is determined by testing. Some soils, such as at the South Harrison Bay well site, can be very acidic. Grass seeds are then applied, and the surface dragged with a wire mesh to partially cover the seeds. Bulldozers or other tracked vehicles are then employed to compact the soil around the seeds to encourage moisture retention and inhibit erosion (Fig. 111). Planting is normally done in the

Figure 112. Caribou grazing on new grass on former borrow pit at Inigok.

Figure 113. Thaw subsidence at ice wedges and cross drainage on road between well site and airfield at Itkillik.

early part of the summer to achieve maximum growth in the first season. Many drill pads support a quick and lush growth of new grass during the first summer. If site preparation work cannot be accomplished until mid- or late summer, grass seeds are not applied until freezeup so that they will remain dormant until the following spring.

Drill sites that employ gravels or crushed rock may be highly resistant to erosion by wind and water, but provide a very poor environment for natural restoration. Accordingly, such drill pads are also revegetated, but require the surface application of fine-grained soils or organic soils (Power et al. 1981). Surface compaction of this topsoil is essential on such free-draining areas for retaining sufficient moisture for seed germination. In some situations it may be necessary to mulch the seed and/or provide periodic watering during the initial growing period with small gasoline-powered pumps, provided there are nearby bodies of water.

There are a variety of grasses available for initial revegetation (U.S. Dept. of Interior 1988). Typically, a mix of several varieties is employed, the composition of the mix being based on site conditions (soil type, availability of moisture, etc.). Sites that have a high erosion rate normally employ a higher percentage of annual ryegrass. Application rates are usually specified for each mix, such that there is good coverage at the end of the first growing season. Caribou and ground squirrels enjoy the new vegetation (Fig. 112). Browsing by these animals can be severe, which limits the chances that the introduced grasses will grow to full maturity or ever repropagate. Nevertheless, the important features of initial soil stabilization and providing a proper medium for the later reestablishment of local native species can be achieved with this interim grass.

Revegetation, essentially farming, is highly dependent on the weather. Like any seed crop, grass has germination and early growth stages that are particularly sensitive to the availability of moisture. Droughts, or conversely too much rain, can also seriously jeopardize good growth. Accordingly, one should not be surprised at the lack of success in revegetating the first year, but be prepared to reseed the next year or for several years. Monitoring is required to be sure there is no erosion and that the native vegetation is successfully establishing a permanent cover. Refertilization may also be required over a period of years to encourage and sustain the growth of native species. Reworking with hand tools and reseeding may be required in areas that show signs of erosion. Drill sites in the Southern Foothills, which are subjected to heavy downpours in thunderstorms, are more prone to erosion, particularly in the first summer, before a grass cover has been established.

Abandoning roads, culverts and bridges

Snow roads, like trails, are abandoned in place and allowed to simply melt away. No attempt is made to hasten this thawing, such as by ripping, because such activities could potentially damage the tundra vegetation. Cross drainage eventually finds its way across these snow roads, although there may be brief local impoundments during the spring breakup period. Vehicles should not be allowed to use snow roads or trails during breakup, because they inevitably sink through the soft crust and disturb the underlying vegetation.

Gravel roads are normally abandoned in place. Thin embankments in ice-rich permafrost areas typically experience considerable differential settlement (Fig. 113). Much of the road surface sinks to the original ground surface. Cross drainage of abandoned roads is often facilitated by the much greater thaw settlement that occurs over ice wedges. When the ice wedges occur at close intervals (i.e., < 50 ft) the volume and velocity of the drainage across each wedge is low. The subsided gravel at the wedge also protects the area from further thermal and hydraulic erosion.

Culverts are normally removed when the road is abandoned since they, without maintenance, are prone to be clogged with ice, and wash out, as shown in Figure 114. Accordingly they are dug up and the roadway regraded to form a low-water crossing. If the volume of water across this low-water crossing is high, additional low-water crossings may be constructed in the area. Design considerations for these low water crossings include the size of stone or gravel that armors the crossings to avoid erosion. Normally these low-water crossings are installed in a retreating action, with no traffic allowed over the crossing, at least in the summer months.

Temporary bridges are also removed. Typically this work is done in conjunction with the removal of the culverts, in the same retreating action. Sometimes this work is done a year or two after the drill site has been abandoned and revegetated. Removal of the bridge also includes removing all piles within the stream bed, the abutments and wingwalls and any gabions or approach fills. The bridge site is basically returned to its original configuration including the streambed, as opposed to leaving a low-water crossing. Because of the large area typically involved at a bridge site, there usually is a requirement for some form of restoration, including revegetation. Since bridges are normally employed on larger streams, timing of the removal will have to consider fish spawning and migration. Large bridges on the North Slope are found only on permanent roads.

Figure 114. Culvert washed out on abandoned road between Umiat airfield and Seabee well after spring breakup.

At some drill sites there may be an interest in recovering some of the gravel from a road for use elsewhere in the immediate area. There are several examples of this being done in the 1960s at DEW line stations where good gravel was in limited supply after the initial construction effort. Typically this involved changing a road from one lake to another lake, for better water. The roads were taken up in a retreating action, without disturbing the adjacent tundra. Typically about a foot of gravel was left behind, such that there was a thin blanket over the dead and compressed vegetation, as shown in Figure 115. The old roadbeds were left to restore naturally, without reseeding, although this requires many decades.

Abandoning airfields

Winter airstrips on the tundra are effectively abandoned in the spring and allowed to thaw in place. After operations are halted, the site is policed of all trash and all navigational aids are removed, although some wires may not be recoverable until later in the summer. During the spring breakup the cross flow of meltwater, in most situations, cuts its own channel. Once the snow and ice have disappeared, the tundra is usually given an application of fertilizer or limestone, by aircraft, to enhance recovery of the vegetation. No revegetation is necessary.

Airfields on lakes or sea ice also effectively melt away and disappear, although there is always some policing required. Normally the lights are recovered as soon as operations cease, but some connecting power cables may have to be left for later recovery. These wires can sometimes be recovered by a crew operating with a

Figure 115. Abandoned and partially removed road at Lonely DEW Line station.

Figure 116. Pond formed by taxiway at Tunalik, two years after construction. Parking apron is in center, drill pad in background.

small flat-bottomed boat. Since the ice when melting can be quite dangerous, those venturing onto the ice on foot should have life preservers and ropes. Sometimes flotation devices are attached to these power cables, so that they can be reeled into the shore or to a boat, after all or most of the ice has melted. Lakes should be carefully monitored during the melting period to ensure that there have been no fuel spills, because cleanup with absorbent pads will be necessary if an oil sheen is discovered. Abandonment work at such facilities also includes any shorelines that were used for ramp roads or staging areas.

Runways on gravel bars and beaches normally require no revegetation efforts. The major concern during the spring breakup period is the restoration of normal drainage channels, which may have been filled in during the winter. Such areas should be opened as soon as spring melting begins, even if this means ripping frozen gravel. Safeguards for erosion should be the major concern. All wires should be recovered so that they do not pose a danger to animals or boat navigation.

Airfields abandoned on ridges may have to be revegetated, at least in spots, after the snow runway has melted away. Erosion control measures may also have to be initiated in disturbed areas, usually by laborers using simple hand tools.

Historically, all-season gravel runways have been abandoned in place. However, some work is usually required during the abandonment. In some cases this may require the removal of any culverts beneath the taxiway, which normally impounds drainage parallel to the runway (Fig. 116 and 117). The taxiways are converted to low-water crossings, but leaving a gravel berm to indicate that this area is no longer trafficable by aircraft. At some gravel airstrips, particularly those that might be degraded by wind or water erosion, the runway shoulders and even the outer edges of the runway are seeded. The perimeter of the parking apron may also be seeded. Parking aprons have been found to be good parking areas for seismic trains over the summer months (Fig. 118), or as camping areas for summer field parties. The adjacent all-season runway, while no longer maintained, is used by light aircraft in support of these field parties.

To date none of the three insulated runways in NPRA has been removed. The buried insulation would make the gravel removal process very difficult. There are also a number of abandoned (uninsulated) gravel runways at DEW line stations and other exploration well sites. Many of these abandoned runways have given good service over the decades, with virtually no maintenance. Typically these runway surfaces are lacking in fines and have a surface coating of small pebbles. The pebbles apparently are sufficient to resist erosion. The shoulders of many of these old runways have experienced a natural restoration by native species, no revegetation having been applied. Some abandoned gravel runways at inland well sites have experienced severe differential settlement, from melting ice wedges, as shown in Figure 119. Such airfields, marked with big white X's on each end, cannot be used, unless repaired.

Summary

Abandonment planning begins with the initial development of the construction plans. For every planned disturbance there should be a corresponding restoration plan. The long-term restoration requirements can significantly influence the exploration program. Accordingly, winter-only drilling, from a snow pad, is the preferred way of conducting explorations. Drill pads, roads and airfields constructed from snow and ice effectively melt away, with little disturbance to the existing vegetation, although fertilizer and/or powdered limestone may be aerially applied to aid in the recovery. The most frequently encountered distresses from snow and ice construction on the tundra are winter kill, damage from the initial construction efforts and late spring operations.

Restoration plans for drill pads constructed with soils assume that the pad will be abandoned in place but will require vegetation. Revegetation is required to stabilize pads constructed with fine-grained soils, so that they do not deteriorate from wind or water erosion. Pads constructed with gravels, while resistant to erosion, provide a poor environment for natural revegetation by native species; hence, they are usually covered with a topdressing of fine-grained soil and revegetated, at least around the perimeter. The intent of establishing new vegetation, with various grass seeds, is only temporary, allowing native species time to become established. The long-term growth may not be the same as originally found at the site, because most drill pads are elevated and drier than the surrounding tundra. Alders and willows may be prolific growers around the perimeter, even when not commonly found in the area.

Figure 117. Washout of taxiway at Tunalik three years after construction. Fiberglass pipe placed during previous year to drain pond. Note membrane atop insulation.

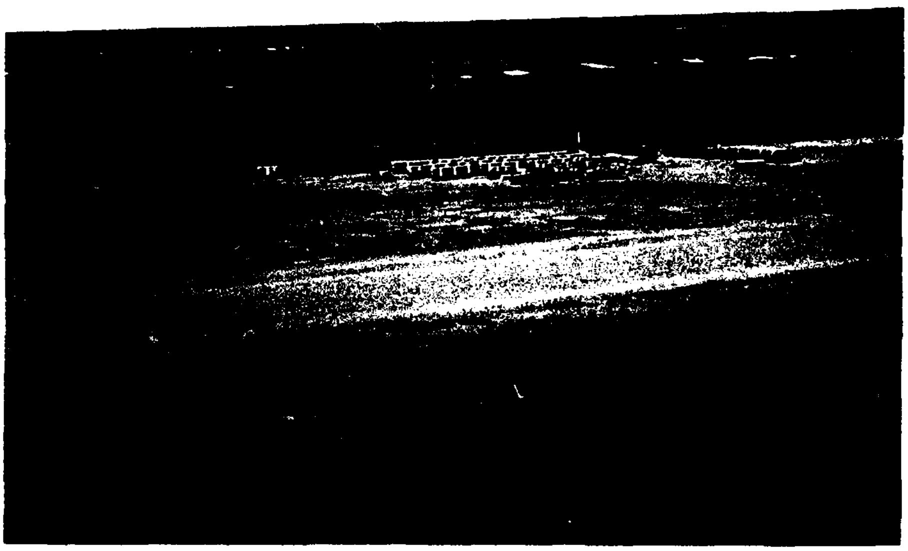


Figure 118. Seismic train parked for summer on parking apron at Inigok. Note thermal effect of fire at old camp site in foreground.

Cleanup of sites includes filling in the reserve pit, usually with material from the surrounding dike. Piling and other timbers are usually cut up and burned in the middle of the pad. Small dozers are often left at the site for grading and compacting the pad after it thaws and dries out. The tractor is brought out, overland, the following winter. Most of the cleanup and initial restoration work is accomplished by laborers with lightweight tools, since they must be transported by helicopters. All trash and unburnable material is brought out by helicopter.

Gravel roads are usually abandoned in place, although some roads have been partially removed if the gravel can be used again in the local area. Abandoned

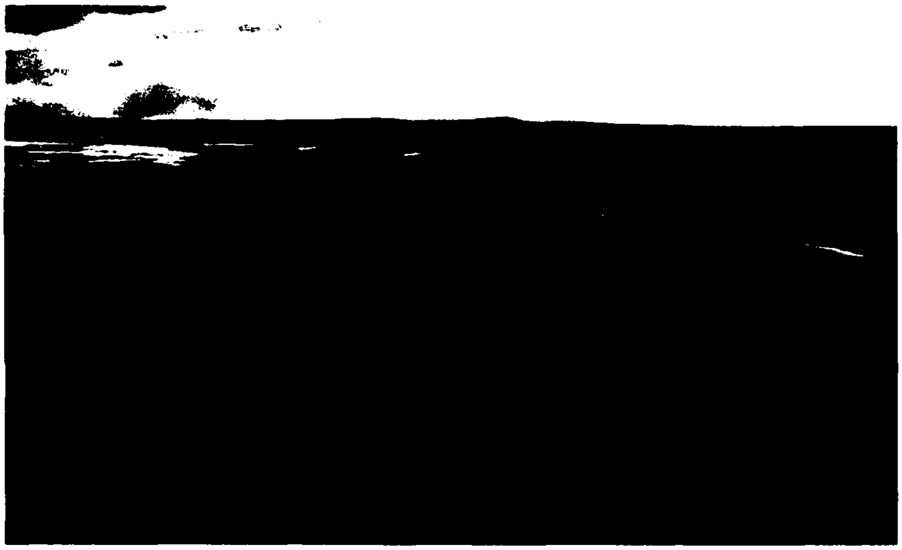


Figure 119. Abandoned airfield at Itkillik Well site. Note thaw subsidence and white X denoting unusable condition.

roads usually settle with time and naturally revegetate, although in some situations they can be effectively revegetated with seeds to establish a quick cover. Culverts are normally removed in a retreating action and replaced with low-water crossings. Bridges are also removed, including abutments, such that original streambed configurations are restored. Such removal work must be carefully scheduled with respect to fish spawning and migration.

Gravel runways and connecting roads to the well site are usually abandoned in place because they may be used by others in future years. Revegetation of the shoulders and outer sections of the runway and parking apron may be necessary to resist erosion, depending on the runway grades. Unmaintained runways can experience localized slumping over ice wedges and accordingly should be marked with big white X's, designating that the runway is not to be used.

Drill sites must be closely monitored for several years after abandonment to ensure or enhance the establishment of new grass and native species, including additional applications of fertilizer, and to correct any erosional damage. The abandonment of the well itself depends on what was encountered during the drilling, i.e., dry holes or significant oil or gas. Typically the well is valved off, or welded shut, with the cellar boxes being left in place (Fig. 120).

Figure 120. Well head with metal cellar box at abandoned well site at Lisburne. Configuration accommodates long-term ground temperature observations.

SELECTED BIBLIOGRAPHY

Abele, G. (1990) Snow roads and runways. USA Cold Regions Research and Engineering Laboratory, Monograph 90-3.

Abele, G., R.O. Ramseier and A.F. Wuori (1968) Design criteria for snow runways. USA Cold Regions Research and Engineering Laboratory, Technical Report 212.

Abele, G., D.A. Walker, J. Brown, M.C. Brewer and D.M. Atwood (1978) Effect of low ground pressure vehicle traffic on tundra at Lonely, Alaska. USA Cold Regions Research and Engineering Laboratory, Special Report 78-16.

Abele, G., J. Brown and M.C. Brewer (1984) Long-term effects of off-road vehicle traffic on tundra terrain. *Journal of Terramechanics*, **21**(3): 283–294.

Adam, K.M. (1978a) Building and operating winter roads in Canada and Alaska. Environmental Studies No. 4, Dept. of Indian and Northern Affairs, Ottawa, Canada.

Adam, K.M. (1978b) Winter road construction techniques. In *Proceedings, Conference on Applied Techniques for Cold Environments*, Anchorage, ASCE, p. 429–440.

Aitken, G.W. (1965) Ground temperature observations, Barrow, Alaska. USA Cold Regions Research and Engineering Laboratory, Technical Report 105.

Aitken, G.W. and R.L. Berg (1968) Digital solution of modified Berggren equation to calculate depths of freeze or thaw in multilayered system. USA Cold Regions Research and Engineering Laboratory, Special Report 122.

Alaska Dept. of Transportation (1988) Front end loaders. *Technology for Alaskan Transportation*, **10:** 2–3.

Berg, R.L. (1976) Thermoinsulating media within embankments on perennially frozen soil. USA Cold Regions Research and Engineering Laboratory, Special Report 76-3.

Bilello, M.A. (1980) Maximum thickness and subsequent decay of lake, river and fast sea ice in Canada and Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 80-6.

Brooks, T.E. (1983a) Design and construction of the Lisburne well site. Husky Oil NPR Operations Inc. (unpublished).

Brooks, T.E. (1983b) Design and construction of the Awuna well site: Husky Oil NPR Operations, Inc. (unpublished).

Brooks T.E. (1983c) Winter drilling pads, 1976–1978; Husky Oil NPR Operations, Inc. (unpublished).

Brown, J. (1967) An estimation of volume of ground ice, Coastal Plain, northern Alaska. USA Cold Regions Research and Engineering Laboratory, Memorandum (unpublished).

Brown, J., F. Nelson, B.E. Brockett, S.I. Outcalt and K.R. Everett (1983) Observations on ice-covered mounds at Sukakpak Mountain, South Central Brooks Range, Alaska. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska*, Washington, D.C.: National Academy Press, p. 91–96.

Brown, J., B.E. Brockett and K.E. Howe (1984) Interac:'on of gravel fill, surface drainage and culverts with permafrost terrain. Report AK-RD-84-11, Fairbanks: Alaska Department of Transportation and Public Facilities, Division of Planning and Programming.

Burns, C.D. (1980) Traffic tests of expedient airfield construction concepts for possible application in the National Petroleum Reserve Alaska (NPRA). USA Engineer Waterways Experiment Station, Technical Report GL-79-2.

Crory, F.E. (1988a) Airfields in Arctic Alaska. In *Proceedings, 5th International Conference on Permafrost, 2–5 August, Trondheim, Norway*. Trondheim, Norway: Tapir Publishers, p. 49–55, Trondheim, Norway.

Crory, F.E. (1988b) Landing mat test sections on permafrost—NPRA. USA Cold Regions Research and Engineering Laboratory (unpublished).

Crory, F.E., R.L. Berg, C.D. Burns and R. Kachadoorian (1978) Design considerations for airfields in NPRA. In *Proceedings, Conference on Applied Techniques for Cold Environments*, ASCE. 441–58, Anchorage.

Diemand, D. (1990) Lubricants at low temperatures. USA Cold Regions Research and Engineering Laboratory, CRTD 90-1.

Diemand, D. (1991a) Automotive fuels at low temperatures. USA Cold Regions Research and Engineering Laboratory, CRTD 91-2.

Diemand, D. (1991b) Automotive and construction equipment for arctic use: Heating and cold starting. USA Cold Regions Research and Engineering Laboratory, CRTD 91-3.

Diemand, D. (1991c) Automotive batteries at low temperatures. USA Cold Regions Research and Engineering Laboratory, CRTD 91-4.

Drage, B., J.F. Gilman, D. Hoch and L. Griffiths (1983) Hydrology of North Slope coastal plain streams. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska*, Washington, D.C.: National Academy Press, 249–254.

Esch, D.C. (1983) Evaluation of experimental design features for roadway construction over permafrost. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska*, Washington, D.C.: National Academy Press, p. 283–288.

Ferrians, O.J., Jr. (1965) Permafrost map of Alaska. USGS Misc. Geo. Inv. Map 1-44.

Ferrians, O.J., Jr., R. Kachadoorian and G.W. Green (1969) Permafrost and related engineering problems in Alaska. U.S. Geological Survey Professional Paper 678, 37 p.

Ferrians, O.J., Jr. (1988) Pingos in Alaska: A review. In *Proceedings, 5th International Conference on Permafrost, 2–5 August, Trondheim, Norway*. Trondheim, Norway: Tapir Publishers, p. 734–739.

Fisher, E.N. (1977) Ice aggregate road test project, Fairbanks field test. Interim Report. Alaskan Arctic Gas Study Company.

Gold, L.W. and A.H. Lachenbruch (1973) Thermal conditions in permafrost—A review of North American literature. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska*, Washington, D.C.: National Academy Press, p. 3–25.

Hall, D., J. Brown and L. Johnson (1978) The 1977 tundra fire at Kokolik River, Alaska. USA Cold Regions Research and Engineering Laboratory, Special Report 78-10.

Hanley, P.T., J.E. Hemming and J.W. Morsell (1983) A handbook for management of oil and gas activities on lands in Alaska. U.S. Fish and Wildlife Service, U.S. Department of the Interior FWS/OBX-80/23, 64 p.

Haugen, R.K. and J. Brown (1971) Natural and man-induced disturbances of permafrost terrain. Environmental Geomorphology. State Univ. of New York, p. 139–149.

Haugen, R.K., S.I. Outcalt and J.C. Harle (1983) Relationship between estimated mean annual air and permafrost temperatures in north central Alaska. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska,* Washington, D.C.: National Academy Press, p. 462–467.

Johnson, L.A. (1981) Revegetation and erosion control observations along the trans-Alaska pipeline. USA Cold Regions Research and Engineering Laboratory, CRREL Report 81-12.

Johnson, L.A. and L. Viereck (1983) Recovery and active layer changes following a tundra fire in northwestern Alaska. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska,* Washington, D.C.: National Academy Press, p. 543–547.

Johnson, P.L. (1979) Snow and ice roads in the Arctic. USA Cold Regions Research and Engineering Laboratory, Miscellaneous Paper 1304, 40 p.

Johnson, P.L. and C.M. Collins (1980) Snow pads used for pipeline construction in Alaska, 1976: Construction use and breakup. USA Cold Regions Research and Engineering Laboratory, CRREL Report 80-17.

Johnston, G.H. (1982) Design and performance of the Inuvik, N.W.T. airstrip. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska,* Washington, D.C.: National Academy Press, p. 577–585.

Kachadoorian, R. and F.E. Crory (1988) Engineering geology studies in the National Petroleum Reserve in Alaska. USGS Prof. Paper 1399, 899–922, Washington.

Kane, D.L. and L.D. Hinzman (1988) Permafrost hydrology of a small arctic watershed. In *Proceedings, 5th International Conference on Permafrost, 2–5 August, Trondheim, Norway.* Trondheim, Norway: Tapir Publishers, p. 590–595.

Kovacs, A. (1983) Shore ice ride-up and pile-up features. Part 1: Alaska's Beaufort Sea coast. USA Cold Regions Research and Engineering Laboratory, CRREL Report 83-9.

Lachenbruch, A.H. (1959) Periodic heat flow in a stratified medium with application to permafrost problems. U.S. Geological Survey Bulletin 1083-A, 36 p.

Lachenbruch, A.H. (1962) Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost. Geological Society of America Special Paper 70, 69 p.

Lachenbruch, A.H., J.H. Sass, B.V. Marshall and T.H. Moses, Jr. (1983) Permafrost, heat flow and the geothermal regime at Prudhoe Bay, Alaska. *Journal of Geophysical Research,* **87**(B11): 9301–9316.

LaVielle, C.C., S.C. Gladden and A.R. Zeman (1983) Nuiqsut airport dredge project. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska,* Washington, D.C.: National Academy Press, p. 689–694.

Lawson, D.E. (1978) Human-induced thermokarst at old drill sites in Northern Alaska. USA Cold Regions Research and Engineering Laboratory, Miscellaneous Paper 1254, p. 16–23.

Lawson, D.E., J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber (1978) Tundra disturbances and recovery following the 1949 exploration drilling, Fish Creek, Northern Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 78-28.

Lawson, D.E. (1986) Response of permafrost terrain to disturbance: A synthesis of observations from northern Alaska. *Arctic and Alpine Research,* **18**:1–17.

Lotspeich, F.B. (1971) Environmental guidelines for road construction in Alaska. Environmental Protection Agency, Alaska Water Laboratory Report no. 1610 GOI 08/71 College, Alaska, 127 p.

Mackay, J.R. (1983) Pingo growth and subpingo water lenses, western Arctic Coast, Canada. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska,* Washington, D.C.: National Academy Press, p. 762–770.

McGown, B.H. (1973) Growth and survival of northern plants at low soil temperatures. USA Cold Regions Research and Engineering Laboratory, Special Report 186.

McKendrick, J.D. and W.W. Mitchell (1978) Effects of burning crude oil spilled onto six habitat types in Alaska. *Arctic,* **31**(3): 277–295.

Mellor, J.C. (1982) Bathymetry of Alaskan Arctic lakes: A key to resource inventory with remote sensing methods. Ph.D. Thesis (unpublished), Univ. of Alaska, 342 p.

Mellor, M. (1989) Blasting and blast effects in cold regions. Part III: Explosions in ground materials. USA Cold Regions Research and Engineering Laboratory, Special Report 89-15.

Michel, B. (1971) Winter regime of rivers and lakes. USA Cold Regions Research and Engineering Laboratory, Monograph III-B1a.

Mitchell, D.W. (1981) On-tundra ice airstrips in NPRA. Construction Technical Paper. Husky Oil NPR Operations, Inc. (unpublished).

Mitchell, D.W. (1983a) Design and construction of the North Inigok well site. Husky Oil NPR Operations Inc. (unpublished).

Mitchell, D.W. (1983b) Design of NPRA winter drilling pads, 1979–1981. Husky Oil NPR Operations Inc. (unpublished).

Onesti, L.J. and S. Kirsch (1982) Erosion rates on disturbed sites in a permafrost environment. USA Cold Regions Research and Engineering Laboratory, Internal Report (unpublished).

Osterkamp, T.E. and M.W. Payne (1981) Estimates of permafrost thickness from well logs in northern Alaska. *Cold Regions Science and Technology,* **5**(1): 13–27.

Power, J.F., F.M. Sandoval, R.E. Reis and S.D. Merrill (1981) Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. *Soil Science Society of America Proceedings*, **45**:124–129.

Reed, J.C. (1958) Exploration of Naval Petroleum Reserve No. 4 and adjacent areas, Northern Alaska, 1944–1953: Part 1. History of the Exploration. USGS Professional Paper 301.

Schindler, J. (1983) Solid waste disposal: National Petroleum Reserve—Alaska. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska*, Washington, D.C.: National Academy Press, p. 1111–1116.

Schindler, J. (1988) History of exploration in the National Petroleum Reserve in Alaska, with emphasis on the period from 1975–1982. In USGS Prof. Paper 1399, p. 12–72, Washington, D.C.

Selkregg, L.L. (1975) Alaska regional profiles-Arctic region. Univ. of Alaska, Arctic Environmental Information and Data Center.

Simpson, J.K. and P.J. Jarrett (1983) Explosive excavation of frozen soils. In *Proceedings, 4th International Conference on Permafrost, 17–22 July, Fairbanks, Alaska*, Washington, D.C.: National Academy Press, p. 1160–1165.

Sloan, C.E. (1980) Reconnaissance snow survey of the National Petroleum Reserve in Alaska, April–May 1979. USGS, Water Resources Investigations, 1980, no. 80-49.

Sloan, C.E., J.P. Meckel and J.W. Nauman (1975) Hydrological reconnaissance of the eastern North Slope. USGS open-file report, 1977, no. 77-492.

Transport Canada (1985) Water/ice aerodome standards and recommended practices. Air Navigation Systems Requirements Branch, TP4884E.

U.S. Air Force (1958) *Ice airfields*. Air Force Manual, AFM 86-5.

U.S. Air Force, Alaska Air Command (1968) *Establishing airfields on ice*. Pamphlet no. 88-1.

U.S. Army (1962) *Arctic Construction*. Technical Manual 5-349.

U.S. Dept. of Interior (1988) Surface disturbance activities in Alaska: A guide to technical aspects of mitigation and reclamation. BLM-Alaska Technical Bulletin, AK-BLM-PT-87-008-1610-933.

Wahrhaftig, C. (1965) Physiographic divisions of Alaska. U.S. Geological Survey Professional Paper 482.

Walker, K.M., J. York, D. Murphey and C.E. Sloan (1986) Digital data base of lakes on the North Slope, Alaska. USGS Water-Resources Investigations report no. 86-4143.

Walker, D.A., D. Cate, J. Brown and C. Racine (1987) Disturbance and recovery of arctic Alaskan tundra terrain—A review of recent investigations. USA Cold Regions Research and Engineering Laboratory, CRREL Report 87-11.

Wellman, J.H., E.S. Clarke and A.C. Condo (1977) Design and construction of synthetically insulated gravel pads in the Alaska arctic. In *Proceedings of the Second International Symposium on Cold Regions Engineering: College, Alaska*, University of Alaska, p. 62–85.

Woodward-Clyde Consultants (1980) Gravel removal guidelines manual for arctic and subarctic floodplains. U.S. Fish and Wildlife Service, Report No. FWS/OBS-80-09.

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This report addresses the unique problems associated with oil and gas explorations in northern Alaska and provides background information on the climate and environment, including the permanently frozen ground that exists throughout the area. Information on exploration efforts in the 1940s and 1950s is also included to demonstrate what happens when summertime operations disturb the surface vegetation and thermal regime of the frozen tundra, being the basis for why such operations are no longer permitted. Separate chapters are provided on the design, construction and operation of winter trails, roads, airfields and drill pads, including a separate chapter on their abandonment. Emphasis is placed on how, why and when to accomplish the various tasks to successfully accomplish an exploration.

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