WHITHER THE OIL OF NPR-4

The well-publicized commercial oil leases on the Alaskan North Slope are expected to yield eventually at least 10 billion barrels. Immediately to the west, separated only by the Colville River, lies the U.S. Naval Petroleum Reserve Number 4, or NPR-4. It is sometimes called Pet-4, but this, strictly speaking, applied to the 1944-1954 exploration program carried out by a Naval Construction Battalion. In view of the 1969 U.S. Geological Survey estimate of recoverable reserves of 9 billion barrels under these federal lands, and probably a low figure due to incomplete exploratory drilling (the true test), this writer wonders about the future of these reserves. At least, in the fast approaching energy crisis, how does NPR-4 enter? He finds it curious in particular to find little published mention of planning for tie-in with the projected trans-Alaska pipeline, for a national emergency. The 1972 revised six-volume Environmental Impact Statement on the Alyeska pipeline relegates consideration of NPR-4 to a footnote, to a reference!

There is no implication here that a Teapot Dome-type problem may arise; the able U.S. Naval Petroleum and Oil Shale Reserves Office administering NPR-4 has too many constraints imposed on it under present law to permit such to happen. However, final responsibility rests in the law-making Congress.

Rather, the opposite could occur; lack of planning may deny use of these fields when needed. Will planning be neglected until an emergency arises? Should plans for roads into NPR-4, gathering lines from the several probable major fields, and transit of the Colville be started now? Of course, up to about the year 2000 commercial fields east of the Colville can always be used while delivery systems from NPR-4 are being readied, should North Slope oil become a truly critical factor in national affairs. But time always moves on. Certainly, construction by commercial interests outside NPR-4 soon will provide much information allowing efficiencies in future NPR-4 exploration and exploitation. But, for example, will the planned bridge across the Yukon serve as a model for spanning the Colville? Are barges in summer and temporary railroads on the ice as used during the siege of Stalingrad in winter useful alternatives? These seem to be too crude. Are the soil problems in NPR-4 pertinent to drilling pads and gathering lines similar or different from the Prudhoe Bay area? A minimum effort now should be a problem definition program.

Tie-in of NPR-4 with the Alyeska line should be planned, but we do not advocate exploitation of NPR-4 now. It should not be used as a short-term expedient, but should be readied as an accessible and usable reserve. A peripheral but pertinent future problem is the question of where Alaskan oil will go, to the U.S. or elsewhere.

Tunis Wentink, Jr.
FINDING FAULTS' WITH ERTS-1 IMAGERY

by Larry Gedney

The following introduction is part of the University of Alaska ERTS-B proposal submitted for the continuance of the investigations begun under ERTS-A. A portion is also taken from the Project 12 section of the ERTS-B proposal. These are included here to give more background to the ensuing article.

---Editor's Note

INTRODUCTION

The Earth Resources Technology Satellite Program, with its demonstrated capability for economical large scale surveys, provides a unique opportunity to narrow a great environmental knowledge gap which impedes planning at a critical juncture in the history of Alaska's economic and social development.

This problem has been recently and forcefully manifested in several ways, chief among which are:
1) The controversy surrounding the proposed construction of the trans-Alaska pipeline from the arctic coast to the southern port of Valdez, and the recent U.S. Appellate Court decision denying the permit for its construction.
2) The deterioration of fisheries resources in the Alaska coastal zones and continental shelf. This results partly from a poor environmental knowledge of these regions.
3) The establishment by Congress and the Alaska State Legislature of the Joint State-Federal Land-Use Planning Commission. This Commission has the awesome task of recommending by 1975 a comprehensive land-use plan for Alaska's 375 million acres, thereby assisting the federal government, the State of Alaska, and the Alaska Native Corporations with the selection of 220 million acres of public domain lands.

The basic data for informed land-use research and planning in Alaska is very sparse and often outdated. Therefore, even the first task of planning in Alaska on a regional basis is laboring under severe handicaps. Alaska is so vast, and the Arctic so varied, that this environmental gap will not be bridged soon by conventional means.

In December 1969, the State of Alaska and the U.S. Department of the Interior co-sponsored a symposium entitled "The Use of Remote Sensing in Conservation, Development, and Management of Natural Resources of the State of Alaska." In his introductory remarks to the symposium, the Honorable Walter J. Hickel, then Secretary of the Interior, said:

"...The conservation, development, and management of the natural resources of the State of Alaska are of concern to all the people of our country. Our nation's largest State is rich in resources vital to our continued well-being and economic growth.

The sophisticated techniques of remote sensing offer advanced cost-effective means of locating, monitoring, classifying and inventorying mineral deposits, recreation areas, forest lands, coastal zones, fisheries, water supplies and energy potential. The highly sensitive instruments of this relatively new field can yield otherwise unobtainable information about the land and its effective use. Under the Department of the Interior's Earth Resources Observation Satellite (EROS) Program, we are beginning to assess what these new tools can do for us from aircraft and satellite platforms. In 1972 the National Aeronautics and Space Administration will launch the first Earth Resources Technology Satellite (ERTS-A) to provide small-scale synoptic and repetitive views of the earth and its resources.

Because of Interior's intimate participation in this experiment, we anticipate that the benefits from these early techniques will be greatest in developing areas. I can, therefore, think of no better place to apply this technology than in Alaska....."

In recognizing this promising potential, and with the wholehearted support of government agencies in Alaska, the University of Alaska proposed in 1971 an interdisciplinary program of ERTS-A analyses involving projects, twelve of which were eventually included in the ERTS-A contract with NASA. All of these twelve projects are reaching the state of fruition, and some have already produced results of considerable importance and utility....

Initial target objects for ERTS-A Project 12 were chosen largely on the basis of comparing current seismicity maps (Prepared at the Geophysical Institute) with the most recent information on faults and fault systems which could be obtained from the U.S. Geological Survey and other sources. Linear zones of epicenter concentrations where no faults were mapped were obvious objects of interest. At least two of these lineaments have subsequently been identified as major faults by independent workers. However, the most significant findings have come from areas in which the investigators had not expected to find anything of particular interest. They have identified in these areas such previously unmapped features as faults, joint systems, and other structures which aid in the interpretation of the nature of the tectonic deformation in central Alaska.

The interpretive methods used were simple and straightforward. They included visual analysis of the ERTS images and projection of the 70mm positive transparencies so that group discussions could be held, manipulation of the 70mm negatives using different exposure times to best display the particular object of interest, and the construction of false color scenes by reconstituting color images from the individual black and white photographs.

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BACKGROUND

Along most of the highly seismically active Aleutian chain, earthquakes result as two crustal plates collide, with the southern plate underthrusting the northern plate along the line of the Aleutian Trench. Underthrusting of the type seen in the Aleutians has been thought to occur exclusively in oceanic trench-arc systems. However, as seismographic coverage in Alaska has improved in recent years, it is now being found that underthrusting is continuous from the Aleutian Trench, through Cook Inlet and along the eastern flank of the continental Alaska Range as far north as Mt. McKinley, with focal depths as great as 250 km.

Contrasted with this, north of Mt. McKinley and the Alaska Range there is a broad zone of shallow seismicity at least as far north as the southern Brooks Range. Focal depths here seldom exceed 40 km, and there is no evidence of the type of underthrusting that is seen in the south, although the areas are laterally contiguous. Since 1904, eight earthquakes of between magnitude 6.0 and 7.8 have occurred in the Alaskan interior. Since shallow earthquakes are potentially more hazardous than deep ones because they are closer, a matter of primary concern to this investigation was to combine seismic data with ERTS imagery in order to identify features with which to define the stress system responsible for the seismicity of the Alaskan interior. A logical outgrowth of the findings will be a better understanding of seismic risk across the area, with its obvious implications to land use planning and basic building codes.

SOME PERTINENT FINDINGS FROM ERTS 1 IMAGERY

In October, 1968, an earthquake of magnitude 6.5 occurred in the Minook Creek Valley northwest of Fairbanks. Figure 1 is a mosaic composed of portions of six ERTS-1 images. Figure 2 is a key to the ERTS mosaic; the solid lines indicate faults already mapped, while the broken lines represent faults not recognized prior to ERTS imagery. Minook Creek appears in the upper left center at approximately 65.4° N., 150.1° W. Prior to the 1968 earthquake, this feature was not recognized as a fault. Since that time, aftershock studies, source mechanism studies, and geologic field mapping have revealed that it is, indeed, a left-lateral fault. Had ERTS imagery been previously available, this conclusion would undoubtedly have been reached long ago. The extreme sharpness of the stream incision, the textural and tonal differences across the valley, and the series of parallel fractures in the surrounding mountains would have left little doubt. Although the left-lateral nature is not obvious on the Minook Creek fault, the third parallel feature to the east shows it quite well, with truncation of mountain lobes on both the north and south sides of the ridge line.

On closer inspection, one sees that the Minook Creek fault is only part of a large scale fracture system involving many other linears. Parallel features can be seen in the mountains across the Yukon River, where they affect tributary drainage, and two long lineaments are seen in the Kuskokwim Mountains to the southwest. Textural changes occur across the latter two, although they are lost in the alluvium of the Tanana River at their northern ends.

An almost equally impressive set of conjugate fractures intersects the Minook Creek complex at an angle of 55°, and strikes southeast to the Alaska Range. This is roughly the dihedral angle at which most brittle substances would be expected to fail if compressive stress is applied in a direction bisecting the two sets of fractures. In this case the direction is at an azimuth of about 345°, roughly perpendicular to the trend of the Alaska Range. The conjugate set of
CONCLUSIONS

While much of what has been said to this point has dealt with tectonic setting, the real point which should be made is this: It is possible, with ERTS imagery, to delineate seismically active faults which may otherwise go unnoticed. Certainly the Minook Creek fault (site of the magnitude 6.5 earthquake in 1968) would have been recognized long ago, had ERTS imagery been available, and its freshness of appearance would have labeled it as being recently active. In addition, the fact that the 1968 earthquake occurred within less than ten miles from the site of the proposed Rampart Dam would have been a factor in formulating its design characteristics. Further, it bears pointing out that the site for the proposed Rampart bridge and trans-Alaska oil pipeline crossing of the Yukon River is very near the Minook Creek fault if it extends to the north, and that the proposed route also crosses the two strong lineaments in the upper top center of Figure 1. Particularly in Alaska, where these areas are remote and accessible only at great time and expense, ERTS imagery shows great promise as an aid in construction planning, zoning, and seismic risk evaluation.

FIGURE 2. Key to ERTS mosaic: solid lines indicate faults already mapped, broken lines represent faults not recognized prior to ERTS imagery.

The implica­tion is clearly that earthquakes in this area are the product of compressive stress radiating outward from around the great bend in the Alaska Range, and that this stress system has resulted in the formation of a conjugate shear system with earthquakes occurring along the individual fractures. A mechanism of this sort agrees well with the fault plane solution obtained for the 1968 earthquake, and with one obtained for a magnitude 6.0 earthquake near Fairbanks in 1967. For the latter event, a nearly north-south azimuth of compressive stress was obtained, nearly perpendicular to the Alaska Range at this point, as was true with the Minook Creek event. The question which now arises is, "What causes the compression?" A possible explanation is that the forces which caused the Alaska Range to "buckle," forming the great 90° bight in the range at Mt. McKinley, are still at work. The primary cause may be axial compression on the "ends" of the range, or it may be a result of deformation resulting from collision with the northwesterly moving Pacific plate. Whatever the basic energy source, it would seem plausible that further buckling of the range would result in outwardly directed compressive stress around the outside of the bend, and would probably result in the kind of conjugate fracture pattern that has been discussed.

HICKEL REPORT NOW AVAILABLE

Geothermal Energy: A Special Report by Walter J. Hickel, published by the University of Alaska and sponsored by the National Science Foundation (RANN), is now available for ordering. Copies of the report can be ordered for $4.85 apiece or microfiche can be ordered for 95 cents. The accessions number, P.B. 216423, with the money should be sent to:

United States Department of Commerce
National Technical Information Service
Springfield, Virginia 22151
FIGURE 1.
1. Pilgrim Springs
2. Geyser, Spring Basin and Okmok Caldera

ALASKA’S GEOTHERMAL RESOURCE POTENTIAL

By Robert B. Forbes and Norma Biggar

GEOTHERMAL ENERGY IN THE NATIONAL INTEREST

Until the last few years, the United States has not shown much concern or interest in the assessment or development of its geothermal resources. More recently, however, possible world-wide energy shortages, growing pollution problems and the awakening of a national environmental conscience have developed an accelerated interest in geothermal energy. This new cognizance has been reinforced by the Congress, with the passage of the “Geothermal Steam Act of 1970” (84 Stat 1566), which authorizes and delineates geothermal resource “provinces” and “areas,” and defines leasing and regulatory policies for federal lands.

U.S. Geological Survey Circular 647, “Classification of Public Lands Valuable for Geothermal Steam and Associated Geothermal Resources” (Godwin, et al., 1971), presents the criteria for determining which Federal Lands are classifiable as geothermal steam and associated geothermal resources lands, under the Geothermal Steam Act of 1970 (84 Stat 1566). This report includes a map of Alaska showing lands classified for geothermal resources, as of December 24, 1970 (Figure 1).

GEOTHERMAL GRADIENTS AND HEAT FLOW

Sub-surface temperatures rise with increasing depth in the earth, but depth/temperature relations (thermal gradients) are not the same, as measured at worldwide localities. Although the thermal gradient is a rather good parameter for evaluating geothermal potential, heat flow, a somewhat different value, may be more meaningful for inter-regional comparisons. Heat flow is expressed as micro-calories/cm²/second, and differs from measurements of the thermal gradient as it considers the thermal conductivity of the rocks in which the measurements were obtained; and it also includes a time function, which expresses the rate at which thermal energy or heat is being conducted upward toward the surface of the earth.

Various lines of evidence indicate that the thermal gradient is not linear from the crust to the core of the earth. In this discussion, however, we are not too concerned about the deep structure of the earth, as the first 10 kilometers of the crust constitute the zone of economic importance for geothermal energy resources based on present technology.

The average thermal gradient, as determined from drill holes, mine workings, etc., is about 30°C/kilometer. The thermal gradient is believed to be greater in the oceanic rather than the continental crust in areas of "normal" heat flow. There is no significant difference in average heat flow as determined for ocean floors and the continents.

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GEOTHERMAL ANOMALIES

There are, however, "hot spots" in both oceanic and continental settings, and these are critical targets in the search for geothermal energy resources. Such hot spots are usually characterized by anomalies where the heat flow is from one and a half to five times that of the world-wide average of 1.5 (1.5 microcalories/cm²/second). These areas, as presently recognized, are coincident with belts of active or recent volcanism and orogeny. Such belts are usually located along the margins of crustal plates, where oceanic plates are being subducted under the continental margin (see Figure 2) or adjacent to spreading ridges (Muffler and White, 1972). Geothermal fields that are presently being exploited or developed include those in three settings:

1. Along spreading ridges (i.e., Baja California),
2. Above subduction zones (Figure 2), and
3. In zones or belts that represent former or fossil subduction zones.

In all of these settings, it has been deduced that the thermal anomalies are related to molten rock that has moved up into the crust. Economically significant concentrations of geothermal energy occur where elevated temperatures (40°C to 380°C) are found in permeable rocks at shallow depths or less than 3 km (Muffler and White, 1972).

Potentially useful thermal anomalies may occur in relatively dry rocks, but the most important resources are those

FIGURE 2. Hypothetical structure section from the Bering Sea Basin to the Gulf of Alaska, illustrating the sea floor spreading mechanism including the subduction of the oceanic crust under the continental margin. Magma which is being generated by partial melting of the downgoing oceanic crust and sediments, is erupted at the surface by Alaskan Peninsular volcanoes. The rise of magma plumes from the mantle into the crust is accompanied by the development of geothermal anomalies.

FIGURE 3. Diagram showing a hypothetical vapor-dominated, two-phase geothermal system as driven by convecting melt at depth. Meteoric (cold) water descends along fault line to hot permeable reservoir rock where it is heated by the cooling melt. Due to lowed density, the hot water ascends along another fault system to emerge at the surface as a thermal spring. A geothermal well has been driven into the reservoir rocks. In vapor-dominated systems, boiling will begin before the water reaches the surface.
in which water occurs in the fracture and pore spaces in the host rocks. In a geothermal system, heat is transferred by water from deeper sources to reservoirs which are shallow enough to be drilled. If rock porosity is low, the movement of heated water may be constrained, and heat may be stored in the reservoir rocks beneath the less porous layers (Figure 3).

Just a few years ago, most of the steam and/or water that was erupted by thermal springs and/or fumaroles was thought to be primary or magmatic water. More recently, however, based on oxygen and hydrogen isotope studies and other evidence, we have learned that less than five percent of this water is of magmatic origin and that about 95 percent is recirculated groundwater (Figure 3).

GEOTHERMAL SYSTEMS

Geothermal systems, as discussed by White, Muffler and Truesdell (1971), have been sub-divided into two types:

(1) Hot water systems, and
(2) Vapor dominated (dry steam systems)

Hot water systems appear to be about 20 times as common as the vapor dominated type, based on discoveries made up to this time (White, 1970).

In hot water systems, only a small part of the volume is steam, and the water and steam are separated mechanically before the steam is routed to the turbine system. If heat exchange systems utilizing low boiling point fluids such as freon or isobutane are proved feasible, this will increase the number of hot water systems which can be used for the generation of electricity. Producing geothermal fields of this type include the New Zealand fields and more recent discoveries in Mexico and the Salton Sea.

The vapor dominated systems produce superheated steam with subordinate amounts of CO₂ and H₂S. Only three commercial vapor dominated systems are in production today, including those at Lardello, Italy (since 1904); the Geysers, California; and a field at Matsukawa, Japan.

DEVELOPMENT AND UTILIZATION

Geothermal energy has been applied to various needs including:

(1) the generation of electricity,
(2) space heating,
(3) gardening, farming and greenhouse applications,
(4) melting of snow on roads and runways, and
(5) paper manufacturing

Proposed and possible applications also include:

(1) extraction of valuable heavy metals and salts from hot brines (Figure 4),
(2) desalinization of geothermal waters (Figure 4), and
(3) refrigeration

WORLDWIDE GEOTHERMAL ENERGY POTENTIAL

Muffler and White have estimated that geothermal energy is unlikely to supply more than about 10 percent of the world power demand, but that geothermal power will be of great importance to underdeveloped countries, and to regions which have limited sources of energy.

Although geothermal power is environmentally attractive, because there are fewer atmospheric pollutants as compared to those generated by the fossil fuels, effluent from geothermal power generation systems can pollute stream ground water systems; and federal regulations require that such effluents must be reinjected into a deep reservoir. If the dissolved components can be removed to

FIGURE 4. Multipurpose geothermal system, as designed by the UN and the Government of Chile. From "Geothermal Power" by Joseph Barnea. Copyright © January 1972 by Scientific American, Inc. All rights reserved.
produce potable water, the economics are improved. Some of the dissolved elements are economically important, and a system which could incorporate all of these processes would offer maximum utility (see Figure 4).

PROSPECTING FOR GEOTHERMAL RESOURCES

Heat Flow

Although high heat flow and geothermal gradient measurements are the most characteristic signatures of important geothermal anomalies, subsurface thermal data are often difficult to obtain if deep drill holes are not available. Localities producing heat flow values exceeding three microcalories/cm²/sec., however, would deserve additional study if detected.

There is a strong correlation between the location of productive and potentially productive geothermal systems and volcanic vents and calderas of late Tertiary or Quaternary age. Presently active volcanic provinces, such as the Alaska Peninsula–Aleutian volcanic belt, are of particular interest.

Thermal Springs

The temperature of thermal springs, fumaroles and mud volcanoes can provide valuable data on minimum subsurface temperatures. The mere presence of a thermal spring does not guarantee the presence of an economically important subsurface geothermal system. However, two geochemical parameters of thermal spring waters appear to be related to subsurface reservoir temperatures, including the silica content and the sodium/potassium ratio (Fournier and Truesdell, 1970). Thermal springs which have a high dissolved SiO₂content, and/or those which deposit silicious sinter at the surface, are probably related to high temperature subsurface reservoirs. Geysers are also a favorable indication of high temperatures at depth.

Geophysical Methods

Several geophysical techniques have produced encouraging results, including resistivity, gravity, magnetometer and infrared surveys. Some geothermal reservoirs produce seismic noise in the form of microearthquake swarms, and seismic surveys of thermal springs and other targets are now an essential part of the geophysical assessments of geothermal systems.

ALASKA’S GEOTHERMAL POTENTIAL

Although an increasing amount of research is being done on Alaskan volcanoes, very little is known about the geothermal framework of Alaska. The present state of published knowledge on thermal springs, for example, is not much greater than that summarized in U.S. Geological Survey Paper No. 418, “Mineral Springs of Alaska” (Waring, 1917).

It is not surprising that there are many thermal springs in the Alaskan Peninsula–Aleutian volcanic belt. The thermal springs of northern and southeastern Alaska, however, are distributed throughout a wider range of geologic and tectonic settings and the controls are as yet poorly understood. Based on present information, however, Alaskan thermal springs appear to occur in four geologic settings:

1. On the margins of — or within — granitic plutons of Cretaceous or early Tertiary age (30-90 million years).
2. Along fault lines,
3. Near Quaternary or Recent volcanic fields or eruptive centers, and
4. Areas of abnormally high heat flow.

ALASKAN GEOTHERMAL GRADIENTS AND HEAT FLOW

We know very little about the thermal gradient at Alaskan localities other than those located in the petroleum provinces, and there are only a few reliable heat flow measurements reported for Alaska (Lachenbruch and Marshall, 1969; Lachenbruch, personal communication).

According to Lachenbruch there are at present only five reliable heat flow measurements from Alaskan localities, although down and bottom hole temperature data are available for many holes which have been drilled in Alaskan petroleum provinces. Heat flow values calculated from data taken from drill holes near Cape Thompson, Barrow and Umiat (Lachenbruch and Marshall, 1969) were not far from the world average, and low to average values (1.3 microcalories/cm²/sec.) have been reported by Sass and Munroe (1970) for the Amchitka deep drill holes.

Heat flow data have been taken from other drill holes in the Cook Inlet and Prudhoe Bay areas, but analyses of these data are still in process (Lachenbruch, personal communication). Preliminary data from a deep test hole near Eielson Air Force Base (Fairbanks district), however, indicates that the heat flow is anomalously high at this locality (Lachenbruch, personal communication). Although it is not known at this time whether the anomaly is more than 1.5 times that of the world wide average of 1.5 microcalories/cm²/sec., the nearby location of Chena and Circle Hot Springs, and several thermal springs in the Salcha River drainage indicates that the Yukon Tanana Uplands deserve additional study.

ALASKAN THERMAL SPRINGS

Studies of the geochemistry, geophysical characteristics and geologic (tectonic) setting of thermal springs appear to be a logical initial step in the assessment of the geothermal energy potential of Alaska considering the present rarity of information on heat flow and geothermal gradients. Figure 5 shows the location of thermal springs that we have in our files, and the relative temperature of waters which issue from these springs (where known).

The map indicates that the most significant concentrations of springs with the highest temperatures are located in the Aleutian Archipelago and southeastern Alaska. According to the sodium/potassium (Na/K) temperature curves derived by Ellis (1970) and White (1970), reservoir temperatures of some of the southeastern Alaska thermal springs could be 300°C or higher, which suggests that this province deserves further attention.

Even though exploitable Alaskan geothermal systems will probably be discovered during the next decade, geothermally generated electricity will not be competitive with that generated by mine-mouth, hydroelectric and natural gas power plants for delivery to major population centers.

If freon and isobutane generators attain the desired efficiency, hot water (rather than vapor-dominated) systems could be utilized for the generation of electricity for villages in the more remote areas.

Heat is a precious commodity in the arctic and sub-arctic, and hot water from thermal springs or subsurface reservoirs could also be applied to other needs such
produced a proposed 1-year national program (Hickel, 1972) for the exploration and development of geothermal resources in the United States. If this proposed program is approved and funded by the Congress of the United States, geothermal exploration and development will be greatly accelerated, and Alaska will certainly be among those states which will receive priority attention.

REFERENCES


NORTHERN CONSTRUCTION:
SITING & FOUNDATIONS

By Eb Rice

(INTRODUCTIOn)

A hundred years ago the inhabitants of the North included mostly Eskimos, Indians, Lapps and various Siberians. Their dwellings were admirably adapted to their ways of life; and some of these structures exhibited ingenuity and command of basic scientific fundamentals that deserve study and emulation even today. Now, however, as “southern people” move into the northlands, and as northern people seek to avail themselves of the culture of the 70°F environment, the design of dwellings will need to incorporate special parameters.

Stefansson, during the 1920’s, moaned the fact that, in the American north, beaches once abundantly supplied with useful driftwood had become barren. Old-style houses, semi-buried and warmable by the heat of the occupants and their cooking lamps, were being abandoned for fuel-hungry frame dwellings like those of the newly-come traders, missionaries, and government men. To people experiencing a transition from nomadic life to a settled existence near church, school and store, mining the beaches for fuel was but a small price to pay for a house that could be lived in all year round—one whose floor would not turn to mud with the coming of spring, and one which could have real windows. No matter that firewood was becoming scarce. No matter that the new houses cooled swiftly and bitterly when the fires died. No matter that drafts were frequent and biting: this was the way of the affluent newcomer, and what he could endure, all could endure for the sake of status, style, and year-round occupancy. So people, native and newcomer, contributed to exist in uncomfortable, costly, inadequate dwellings. Neither newcomer nor native seemed to be aware that the temperate-zone dwelling was not always adapted to the Arctic. Indeed, as a fervent pioneer once said in an attempt to persuade me of the futility of striving for comfort and economy, “When you hire out to come to Alaska, you hire out to be a ‘tough man’...” It was unworthy, he figured, for a dweller in the last frontier to be thinking of comfort. And as for economy, one would be amazed at how much fuel he could save if he never removed his furs and Mukluks.... Stefansson probably was giving much the same message: if one lived in the old ways, toughly, there would be plenty of driftwood for all.

But frontier-toughness is in for a change. The northern resident demands and gets the comforts normal to the temperate-zone: the flush toilet, the heated bath, the centrally heated house, running water, and even the attached garage. This is thought to be merely our due. If people live like this “outside,” the feeling is, we should live no less well in the North.

Trouble is, these comforts and conveniences were developed for temperate places during many decades. To reproduce them in the northland without knowledgeable modification sometimes results in total failure, and always results in extra, unnecessarily high costs, now and forever.... I say “unnecessarily high costs” because careful attention to the particular of the northern environment can and must reduce to a minimum the inevitably high costs of building modern dwellings in the North. And northerners are properly becoming impatient with the inadequacy and costliness of the hasty and careless adaption of the temperate-zone house to the frigid North.

SITING: SLEEP, SNOWDRIFTS & SUN WORSHIPPERS

Choose the Site Wisely

Special care is needed in siting the arctic dwelling for a number of reasons. For example, in warmer regions the sun rises high overhead on every cloudless day; in the polar regions the sun is never high, and in winter it may not even rise at all. A site that fails to make maximum use of the horizontal southern sun is therefore one to be shunned. This is true in the sub-arctic as well. Even there, the difference between south-facing slopes and other terrain is pronounced. The variety and health of vegetation on sun-facing slopes attest to the favorable climate to be found there. In the Fairbanks area—typical of the “zone of discontinuous permafrost”—slopes facing south are usually without permafrost. Other slopes, together with poorly-drained flat ground, are often underlain by ice-rich ground. Such sites are “possible” building sites, to be sure. But for reasons of psychology (one can see the sun in the south) as well as for terrain, the south slope is much to be preferred and cheaper, too, in the long run.

Of course, a site is selected in the North, as elsewhere, to be conveniently close to water, to transportation, or to a place of work. But once these constraints are satisfied, a dwelling should be placed on ground that will not become a quagmire when thawed. Roads may be needed, and so may waste water drainage areas and recreational space. A “view” is desirable.

There are a few other controls that should be considered in the North, as well. Wind in the treeless tundra is a force to be reckoned with, and shelter from it is much to be desired. But constant arctic winds can deposit an enormous amount of snow, quite capable of filling completely a sheltered cove. Moral: either move to the wooded taiga where

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drifting is minor, or locate on exposed plains or ridge tops. Flood plains can be used, if care is taken (proper arctic foundations tend to be more or less flood-proof), but mountainous terrain may have avalanche areas which are strictly to be avoided (Figure 1).

**Which Way Should a Dwelling Face?**

Woodsmen traditionally placed their tents so that the door faced east—the rising sun was expected not only to waken the occupants early, but also to erase the night’s chill. Religious structures were also oriented with their altars to the east (and thus their main entrances to the west). Mosques are supposed to face the Kaaba in Mecca. Most dwellings, if given ample land, are placed facing the “view,” or at least facing downhill. What about the Arctic house? Does it matter which way it should face?

This topic should perhaps remain a matter of personal preference, as well as a matter of semantics about what constitutes the “face” of a building. There are, however, some pertinent parameters. The first sun in the spring, for instance, appears briefly at the southern horizon. It is amazing with how much eagerness the daily lengthening of the sun’s path is watched. No one who has lived through the arctic winter will discount the desirability of having windows on the south, with perhaps a sheltered outdoor area as well, to accommodate springtime sun worshippers. Conversely, newcomers tend to want few openings on the north side of a dwelling for they prefer to sleep undisturbed by the horizontal rays of the summer’s midnight sun. My own preference is to place the side with the best window toward the view (south), down slope (south), and capable of admitting the noontime sun (south). But I like windows facing all the other directions, too.

**Shovel, Shovel, Toil & Trouble**

Snow drifting can be important, for snow drifts are not merely marvellous sculptural elements: drifts can become frustrating or even disastrous at an arctic site. In the high arctic, winds blow continuously over the treeless plains, and winter lasts for many months. Snow drifts are not limited, therefore, by the availability of snow or by the wind of a single storm: snow can accumulate in virtually unlimited quantities; and if one has to dig his roadway or outbuilding out of a drift early in the autumn, the project may continue every day, all day, until late spring. It is therefore vital to locate roads, entryways and storage away from the downwind side of any building that obstructs the wind’s free

![Possible snowdrift line](image1)

**Figure 1**

Beware the “cozy” site....

![Prevailing winds and small buildings](image2)

**Figure 2**

Snow Drifts Make a Difference—This Site Plan Will Not Function
flow. And the building should, if possible, be aligned with its narrowest face toward the prevailing wind. Even vehicle parking must be carefully arranged so as to discourage drifting (Figure 2).

SO YOU’RE ACTUALLY PLANNING TO BUILD IN THE ARCTIC? *

Foundations Unlimited

There’s a chance that your arctic site is underlain by clean sand, gravel, or bedrock. If so, you are lucky indeed: even when frozen, such materials do not heave appreciably during freezing, nor settle when thawed. Cases are known where massive ice occurs in gravels and sands, of course, but they are rare enough to qualify as exceptions—and the exceptions may be handled the same way as ice-rich ground is.

For it is the presence of high-ice-content ground that is the chief source of grief in the construction of structural footings. If the soil is free of massive ice, it can be thawed without settling, and you may use the same types of footings common at lower latitudes: piling, foundation walls, slab-on-grade, or spread footings. No special arctic restraints will be needed. In fact, with such materials even the control of heat flow, which is so important for most arctic foundations, is unnecessary. And the “skirting” of buildings, which is anathema in ordinary arctic construction, actually has some advantages when the ground is free of massive ice.

The Exposed Bottom

Corbusier has suggested that large buildings be elevated on massive columns (pilotis) so that the bottoms can be seen by the passers-by. This, he claimed, gives a better feeling for their volume, so that the structure can fulfill properly his dictum that a house is “a machine for living.” The prehistoric Swiss lake-dwellers elevated their structures on piling above the waters, partly for reasons of defense, partly for convenience. Tropical peoples in many areas elevated their houses on posts, too. Mostly this was for defense against rising flood-waters, but possibly also to quell somewhat the need to share the dwellings with livestock, insects, or other casual tropic fauna. **

However useful or aesthetic it may be to elevate structures above the ground in other climates, in the Arctic, where the ground is so often fat with ice, it can be vitally necessary. To place a heated structure against the ground is to thaw that ground—and when ice-rich ground thaws, no structure on it is likely to survive.

The very essence of structural survival is to prevent the buildings’ heat from reaching the ground, and to make certain that the foundations are permanently immobilized in the frozen soil. This means separation of the heat source (the house) from the ground. Let us take this opportunity to dispel the idea that insulation alone will suffice: it will not. Insulation, whatever its virtues in other contexts, can never stop thaw penetration; it can only delay the inevitable thaw. To repeat: total separation of ground from heat source is vital. Insulation alone cannot substitute for separation. Much as we may abhor the idea of allowing winter to pass freely beneath our floors, there are no inexpensive alternatives, nor are there likely to be. (True, any good arctic engineer can devise a way to extract heat without elevating the structure, but he must be good indeed if his solution is to

Fig. 3

The Elevated Structure
(Drifting & Thawing Can Be Exciting)

*Or sub-Arctic. “Arctic” is where permafrost is continuous (See: “Permafrost, Its Care and Feeding,” The Northern Engineer Vol. 4, No. 2, Winter, 1972). In the sub-Arctic you have a good chance to find a permafrost-free site, in which case, your problems are minor.

**Elevated houses also are easy to keep cool. It is doubtful that this virtue will have a strong appeal in the Arctic.
be competitive.) Why do we “expose the bottom?” Let me count the ways....

First, a structure elevated high enough to allow the unimpeded intrusion of winter between itself and the ground will remain stable, for its foundation can be easily contrived to remain frozen in place. Second, an elevated structure can be installed with an absolute minimum of disturbance to a site: no alteration of drainage patterns, no massive excavation, no necessity for destruction of organic ground cover need occur (although I recommend a gravel pad over the area for fire and mud control). Third, the elevated structure is the only enclosure, other than a buried one, that will not promote severe snow drifting in the vicinity.

To these three main reasons for elevating the structure, we may add the following: the elevated structure is, or can be, flood proof. It is cheap and easy. Its simplicities commend it for construction by inexperienced builders under difficult conditions. If, somehow, it should fail, the structure can be simply and easily restored to rights. And piles, posts, and piers of a suitable type for foundations are comparatively easy to transport—even by air—to most arctic locations (Figure 3).

Unluckily, an exposed bottom can get cold. Maladroit designs have resulted in floors so uncomfortably cool as to encourage occupants to “skirt” structures with some kind of sheathing to protect the “crawl space” beneath the building from winter’s cold. Such skirting can be used, carefully, for structures in the high arctic, where the ground temperature is quite low. But skirting can be disastrous in areas of marginally warm permafrost, as at Fort Yukon, Bethel, or Glennallen. In these areas, the frozen ground is only a degree or so colder than the thaw point; and there is very little reserve to accommodate heat inputs in addition to the summer flow. So a thaw bulb forms which ultimately may include the foundation. Dramatic failures have occurred to foundations which were initially well designed and constructed, but which were skirted by the occupants to improve comfort and utility. ***

To summarize: despite the cold hazard to the exposed bottom of a building on a foundation of piles, posts, piers or pilotis, there are many virtues that recommend it for arctic construction. Among these are two salient ones: (1) the heat segregation inherent in elevated construction protects against the leakage of heat from the structure into vulnerable, ice-rich ground, and (2) pile foundations promote the unimpeded flow of arctic winds, so that serious snow drifting is discouraged. Together with simplicity, flood proofness, economy, snowdrift control, and environmental suitability, these two make the thermal isolation of a dwelling by elevation a nearly unbeatable technique for construction over icy terrain. **** (See Figure 4.)

Are There Alternatives?

There are alternatives to the elevated structure but not, unfortunately, to cold bottoms. No warm surface can be juxtaposed to icy ground without causing the ice to melt, even if separated by generous layers of insulation. Where loads are heavy and perhaps concentrated, as in aircraft hangars and heavy-equipment repair shops, elevated floors are not so practical. In such cases engineers have devised ways of keeping a floor’s underside suitably cold while still carrying the heavy loads directly to the (frozen) subgrade.

In Thule, Greenland, for example, the design engineers provided a heated hangar for large aircraft. It is of more-or-less conventional slab-on-grade construction, but the slab is special. The concrete floor is underlain by strong foam-type insulation. The insulation rests on another concrete slab on a thick gravel pad. The key to structural security of the design lies in this under-pad of gravel. It is filled

***I regard this as an architectural or engineering failure: if the design leaves occupants so uncomfortable that they are impelled actually to do something, the failure is no less serious than if the foundation design had been inherently faulty.

****If you’ve wondered why there are so many footnotes in this part, contemplate this: no engineer would be likely to recommend an exposed bottom (with piles) in the Arctic, unless he had an extra *.
For marine construction they are ubiquitous: most piers are built on piling because it is comparatively cheap and quick, and because pile construction minimally obstructs the passage of waves and currents. For arctic work, piling is popular because it is the simplest way of providing thermal isolation of a heated structure, and also because it is strong and permits easy passage of drifting snow or flood water. (Figure 6).

Piling is placed in many ways: “pile-driving” is popular for wood, steel, or concrete piles in soft ground. What is not commonly realized is that steel piling (both open-end pipe piles and H-piles) can be successfully driven into fine-grained or peaty permafrost. Piles driven into ice-cemented gravel, however, occasionally come to grief (Figure 7). Vibratory pile hammers are showing considerable promise in this area, although double-acting steam, air, or diesel powered hammers also work well, if extra large.

Commonly, piles of wood or concrete have been placed in holes melted into the frozen ground by steam, hot water, or electricity. (They cannot be driven into frozen ground.) Ideally, the hole should be thawed swiftly so that its width is but little more than the thickness of the pile. The pile may then be driven into the hole with conventional pile-driving equipment. Possibly more piling has been placed in this way than in any other fashion in the Arctic. And yet, it is not the best way: depressing failures have occurred because structures were placed on such piles be-

![Fig. 5](image-url) **A Cold-Bottomed Slab**

with large culvert pipes, laid side by side, and so arranged that, in winter, cold air will flow through to cool and protect the underlying ice from melting. In summer, the pipes are kept closed to minimize the heat flow into the subgrade during the short summer. In several Alaskan installations a similar technique is used: heat which finds its way through the insulation under a floor is intercepted by a lacework of mechanically refrigerated tubes. The heat is dissipated harmlessly above ground. In a similar fashion, one-way heat tubes and their modifications show considerable promise in using “natural cold” to protect the underlying permafrost from thawing (Figure 5).

**PILING**

**Placing the Piles**

Piles are posts or poles placed in the ground to serve as structural supports. In tropic and temperate-zone construction they are often used but rarely visible, located as they usually are beneath the lowest columns of a bridge or building.
fore they had time to freeze back. It is obvious, upon reflection, that a column of hot muddy water, filled or not with a pile, is a heated pocket destined to enlarge prior to finally freezing. If only surface-freezing has taken place, as often happens in the Arctic, a sturdy looking, solid-feeling pile may be built upon, in augers, if equipped with very sharp teeth, will penetrate frozen silts, sands, peat and ice quite swiftly. (No cheap and easy way of penetrating ice-cemented gravel or bouldery ground is known to me, and in such ground the driving of piles into thawed holes will probably remain the best way for some time to come.)

Some engineers recommend backfilling piling with a slurry made of sand, silt, and water. Some argue that the proportions and quality of sand and silt are important: they write elaborate specifications governing the mixing and placing of such backfill. Doubtless, where a builder’s crew cannot be trusted to compact properly the annulus around the pile, the slurry method may have merit. But I would favor, in that case, a backfill of free-running sand or gravel. This is easier, requires no special equipment, and is much cheaper. It is just as good, or better, and what’s more, dry fill rarely adds appreciable heat to the ground.

**FIGURE 7. Avoid driving piles into ice-cemented gravel.**

Immobilizing the Pile or Pole

In the high Arctic, the piles can be short, and they act as end-bearing piles. Their depth of burial must be sufficiently far below the depth of maximum thaw that they will give adequate lateral support (for wind or earthquake) during the thawing season. No further precautions need be taken, as a rule, for in such regions the active layer is thin and the permafrost is cold and strong. Decay of wood is slow and rarely critical in the high Arctic.

In the sub-Arctic, though, things can be different. The active layer may be thick—up to five meters—and the permafrost is warm, weak and willing to thaw. The task of designing a foundation in such locations is formidable. Decay may be a problem, lateral loads may become significant, and, worst of all, “heaving” may be so severe as to warrant elaborate and expensive countermeasures.

In such places a pile foundation is the preferred type: in fact it is difficult to think of a reasonable alternative. In the selection of a foundation, the designer first assures himself that it will handle the expected loads. Then, especially in the sub-Arctic, he must consider the other problems:

**Will it Heave, Rot, Melt, Settle, or Lean?**

One way to make certain that a foundation does not do any of these evil things is to keep the piles frozen in place, as they would be in the high Arctic. This can be done through extraction of heat throughout the summer, or by so thoroughly overcooling the ground in the winter that there is insufficient time in the summer to complete the thawing of the foundation area. There are several ways to accomplish this, all of which can be expensive. But sometimes a permanently frozen condition of the foundation is the surest solution, and often it is cheapest among the alternatives. Methods of achieving a permafrost-stabilized foundation range from mere snow removal and shading, through provision for massive heat extraction in winter, to elaborate refrigeration systems. In general, heat...
extraction in winter through the use of automatic thermal valves (the Long "Thermo-valve," the Thermodynamics "Frost-Filter," or the MacDonnell-Douglas "Heat Pipe," for instance) is possible. A somewhat less sophisticated, but still effective, way of using winter's cold to maintain summer permafrost is Rice's "Brute Force" system—a simple arrangement of pumps, pipes and heat exchangers which is operated in winter and shut down in summer (Figure 8).

Where a permanently-frozen footing is impractical, other means of stabilizing piles must be used. Permanently thawed footings involve no special problems in areas where there is no permafrost. But oftentimes foundations in the sub-Arctic can neither conveniently be kept frozen nor thawed: there will be an active layer and this spells trouble. With the periodic freezing of material near the foundation there can be serious yearly deformation due to frost heave. This causes a phenomenon known as "frost-jacking" of piles, which is an insidious process which causes piles to heave upward during the cold season, with no countervailing tendency to return to the original level when thawed (Figure 9).

The mechanism is simple enough, yet not widely understood. Figure 9a shows the freezing front beginning to penetrate the frost-susceptible ("heavable") siltless soil. Ice lenses are forming, forcing the frozen layer upward. The pile, which is frozen solidly to the heaving layer, goes up with it. This process goes on, and the pile continues to rise so long as ice layers continue to form. In Figure 9b the heaving is complete, and in Figure 9c summer has come, thawing the upper layers. Excess water rises to the surface and is lost, and the thawed soil settles back as the thaw penetrates. By the time the thaw penetrates to the bottom of the active layer, the heaved soil has reconsolidated, and it grips the pile anew (Figure 9d). But the pile is now elevated somewhat, for until the last few inches of frost were melted, it was held in its raised position by a frozen grip.

This jacking process is the chief source of deformation of pile footings. Fortunately, something can be done about it (Figure 10). If some kind of mechanical anchor is attached below the active layer, resistance to heaving can be enormously increased. Or if some method is employed to make the pile too slippery for the frozen ground to hold, the heaving forces can be reduced. So there are really five things that can contribute to safety against pile jacking:

1. Never let the surrounding soil freeze, or
2. Never let it thaw. Or,
3. Anchor the pile against uplift, and
4. Break the bond in the active layer, or
5. Place piling only in non-frost-susceptible soil

If it's a wooden pile, of course it should be placed big end down.

****Siltless soil is usually non-frost-susceptible, and non-troublesome.

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Sometimes, piling is impractical. Perhaps there is no equipment available to drill holes. Possibly piling is too bulky to ship with the transport available (for example, to a remote hunting lodge served by small airplanes only). Or perhaps the ground is unsuited to a foundation of piling. In such cases, where separation of structure and ground is needed, post-and-pad construction can be used. In this kind of foundation, pads (usually of timber) are placed on, or in the top few inches of, the soil. Posts are erected on the pads, and the building is constructed on the posts as if they were piles embedded in the world. Figure 11 shows how this might be accomplished.

Are There Problems?

If post-and-pad footings are used over "bad" ground, where heave or settlement can be expected, then of course, the supported structure will heave or settle. This will rarely be uniform, so the building will also wrack. The key to successful use of such a footing is therefore (1) to select "good" ground—that is, bedrock or iceless sand or gravel, or (2) to provide the means and personnel to monitor the level of the building's floor and adjust it as needed (which is to say, often).

This will require underfloor access for jacking equipment, together with shims, wedges, or turnbuckles to adjust the structure to its shifting foundation. I suggest that architects and engineers, in choosing such a foundation, do so with caution—one is entrusting the integrity of his structure to the whims of a capricious Nature, and still more to the skill, sobriety, or availability of some future workman.

The Site's Right....

When the problems of psychology, view, radiation, drainage, drifting, flooding, convenience, and utility have been reconciled, and the designer is ready to begin his plans, and such features as roads, water supply, and waste disposal have been agreed upon, it is time to think of selecting a foundation type.

How Firm a Foundation?

In the Arctic and sub-Arctic one can be certain that a solid foundation is possible if underlying permafrost stays frozen. This usually means that the structure should be isolated from the ground by piles, piers, posts, poles, or pilotis to prevent heat input to the foundation soils. Once this decision is made, subsequent decisions must be made about how to make sure a cold bottom does not cause a cold floor, for a cold floor may be hazardous to your toes, and, ultimately, to your structures.

Next Time

In the third installment of this series on building in the North, we will attempt the inside story on insulation, and on windows, walls, doors and floors.

Vol. 5, No. 1
ICE CROSSINGS

by Edwin M. Rhoads

Historically, bodies of water have been at once important avenues of communication and serious obstacles to overland movement. It is not surprising that the art of building bridges extends back thousands of years. Even more ancient is the use of ice as a natural means of crossing water obstacles. In today’s world of sophisticated modes of transportation, advantage is still being taken of nature’s deep freeze to facilitate the movement of people and cargo. A number of techniques have been developed through experience, and the application of science and technology, for improving upon the natural freezing process to increase the capacity and duration of ice crossings.

ICE AS A BRIDGE MATERIAL

The oldest and simplest method of preparing ice crossings is to let nature take its course. Crossing sites are selected with an eye to approaches and reasonably quiet water. Often transportation routes in northern countries for both man and wild life are patterned after the habitual ice crossing sites used in winter. From experience, the beginning and end of the ice season is pretty well known, and after preliminary testing for adequacy of the ice strength, the crossings are used until the advent of spring. Animals are quite wary about their footing, but man, being less sensitive to his surroundings, often plunges through.

The physical and mechanical properties of ice and the influence of climatic factors on its formation and duration have been studied by scientists of northern countries as a matter of practical necessity. When meteorological conditions are known, prediction of the growth of the ice cover over bodies of water can be made with some degree of accuracy by mathematical expressions such as that developed by Stefan in 1890.

The equation was derived from the physical principles of heat transfer and expresses the increase in thickness of the ice in relation to the atmospheric temperature regime below the freezing point (Jumikis, 1966). The latter is commonly expressed in degree-hours or degree-days below freezing.

Stefan's equation: \( H = \alpha \sqrt{\theta} \)

where

- \( h \) is the ice thickness in inches
- \( \theta \) is the number of degree-days below freezing (°F)
- \( \alpha \) is a coefficient representing the combined effects of local conditions such as snow cover, river conditions, and water properties. Average values are shown in Table 1.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical maximum for ice not covered with snow</td>
<td>0.95-0.90</td>
</tr>
<tr>
<td>Arctic sea ice (first approximation)</td>
<td>0.80-0.75</td>
</tr>
<tr>
<td>Medium-sized lakes with moderate snow cover</td>
<td>0.80-0.70</td>
</tr>
<tr>
<td>Bays with brackish water</td>
<td>0.70-0.65</td>
</tr>
<tr>
<td>Rivers with moderate flow</td>
<td>0.65-0.58</td>
</tr>
</tbody>
</table>

Stefan's equation and others of similar nature are approximations only and do not take into consideration the many factors influencing the complex thermal processes involved in the formation of ice. Therefore, accurate ice surveys are essential.

Ice is a polycrystalline material which exists on earth very close to its melting point. It is visco-elastic in nature, and varies greatly in its mechanical properties, especially with relatively minor changes in internal temperature as contrasted with other construction materials (Barnes, 1928). The behavior of ice has intrigued scientists for centuries, and while much study remains to be done, considerable practical knowledge has evolved. The tactical value of ice has been exploited by commanders from ancient times, and military engineers have developed crude but adequate “rules of thumb” for weight and spacing of loads on ice. Application of mechanical theory supported by field and laboratory tests resulted in significant advances in the knowledge of ice as structural material (Assur, 1966; Leggett, 1958; Kingery, 1962; Nevel, 1967; Weeks and Assur, 1969; Gold, 1971; extensive bibliography contained in these references).

The Russians developed considerable expertise during the years of World War II (Lagutin, ed., 1946) as an outgrowth of extensive use of ice as highways and as foundations for railroad tracks. In the forest regions of Canada, Scandinavia and Russia, lumbering is practiced in winter specifically to exploit ice and frozen ground as a base for transport and stockpiling of heavy loads (Duff; 1958; Ager, 1961; Korunov, 1956).

When ice provides a principle means of supporting transportation, it is highly desirable to use it for the longest possible time between freeze-up and break-up. This involves attaining the required ice strength as early as possible in the

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season, and frequently extending it as long as possible in the spring (Wolff, 1940).

The onset of freezing of rivers and lakes is generally accompanied by snow fall, and the newly formed ice cover is under a blanket of snow. The ice sags and frequently cracks under the additional weight and upwelling water saturates the snow, which freezes into a porous ice, “snow ice,” of lesser strength than the clear “black ice” formed from water (Figure 1). Snow is an efficient insulation material and as it continues to accumulate, extraction of heat from the water body to the atmosphere is retarded. Consequently, the build-up of the ice cover is slowed, as indicated empirically by the coefficient $\alpha$ for a snow-covered lake in Table 1 above.

CLEARING SNOW FROM ICE CROSSINGS

The simplest way of getting more heat transfer is to remove the snow. As soon as the ice will support a light weight tractor or oversnow vehicle equipped with a blade or pulling drag (six inches or so), the snow is cleared off. As the ice becomes thicker, larger snow removing equipment may be used. A layer of compacted snow, two to three inches, is left on the ice surface to protect it from chipping. This is particularly necessary at extremely low temperatures, as ice becomes quite brittle (Rose and Silversides, 1958).

Except for the “snow ice” described above and that accumulated from freezing rain, ice forms at the bottom of the ice layer. Therefore, as it increases in thickness, the rate of heat extraction is retarded and the ice accumulation gradually slows down. Even with the snow removed, there is a limit to the increase in ice thickness, depending on the length and severity of the freezing period.

To illustrate using Stefan’s equation (eq. 1) and Table 1, assume a lake where the annual freezing index is 3600 degree-days ($^\circ$F) and a moderate snow cover ($\alpha = 0.75$).

$\frac{h}{0.75\sqrt{3600}} = 45$ inches

With snow removed, $\alpha = 0.95$, $h = 1.55\sqrt{3600} = 57$ inches.

Theoretical rates of ice growth under the above conditions are shown in Figure 2.

Preparation of crossings by simply blading off the snow is economical. It is frequently done on convenience or short-term crossings such as the Chena River crossing at Pike’s Landing, Fairbanks, to provide additional safety for the users (Figure 3).
BUILDING UP THICKNESS OF ICE CROSSINGS

Flooding the initial surface with water, and letting it freeze in layers permits a more rapid build-up and a greater ultimate thickness (Figure 4). Well known in the lower states as a method of constructing skating rinks, it is a standard technique in the Canadian and Scandinavian logging industry (Ager, 1961; Rose and Silversides, 1958). In both areas logs are transported over snow or ice roads, and stacked on ice landings on a lake or river to await the spring thaw. The landings and necessary ice bridges are prepared in late fall or early winter to transport loads up to 50 tons and to stack cordwood at a loading density of 1100 tons per acre. Because of the short winter hauling season (60 to 75 days in eastern Canada), it is essential to have the ice landings available as soon as possible. The snow is compacted by men on snowshoes as soon as it will bear them, then the area is dragged using a horse or light oversnow vehicle. For bridges, a strip 150 to 200 feet wide is prepared. Pumps of 30,000 to 40,000 gallons per hour capacity are used to flood the cleared areas. Generally lifts of two to three inches per day are built up in this manner, normally up to a total of 36 inches, considered adequate for the above-mentioned loadings. Improved pumps of higher capacity and less weight, based on the principle of the Archimedes screw, are being used now (Rose and Silversides, 1958) and even outboard motors are very effective for spreading water. A 10 horsepower outboard motor mounted on a small sled splashing water from a rectangular hole cut by a chain saw can spread up to 130,000 gph (Hughes, 1960). Two pumps and one power auger or chain saw can flood a large sized bridge site daily with ease.

USE OF SUPPLEMENTAL MATERIALS

Yet another way to improve on nature's engineering is by the use of reinforcing and insulating materials. Freezing log stringers and cross members in place, filling intervening spaces with brush and flooding the structure with water is a common practice. Excellent railroads have been constructed on ice this way. In many parts of Sweden, Russia and northern Canada, reinforced bridges of this type are built routinely (Wolff, 1940; Korunov, 1956; Rose and Silversides, 1958). Even south of the subarctic zone, safe ice crossings are possible with judicious assistance given to the available freezing index. A reinforced ice bridge was successfully emplaced over the Imjin River in South Korea in January, 1963 (Carnes, 1964). The bridge was 485 feet in length, with a 25 foot roadway. A four inch matting of rice straw laid between two rows of four to six inch logs formed the basis of the bridge beam. After flooding the rice straw, successive layers of brush were frozen in, flooding about two inches at a time until about nine inches of reinforced ice had been built up. The total ice thickness eventually reached 20 inches. A roadway of two by 12 inch timbers cleated together completed the structure (Figure 5).
bridge remained in operation for about five weeks when operations were terminated by a warm spell toward the end of February. The maximum load sustained by the bridge was a light tank M41A1 weighing 20 tons. According to ice strength tables published by the Department of the Army, this tank requires 25½ inches of unreinforced ice for safe river crossings (Dept. of the Army, 1971).

During the winters of 1968-69 and 1969-70, the Alaska Department of Highways constructed a reinforced ice bridge across the Yukon River in the vicinity of Stevens Village to support the transport of heavy equipment and supplies north to the Prudhoe Bay oilfield (Figure 6). These bridges (2000 feet long with a 40 foot wide roadway) were built using four longitudinal rows of logs as stringers, with brush packed between them and flooded with water in successive layers. The roadway was corduroyed with smaller logs, and a layer of compacted snow maintained on the surface (Figure 7). The design total thickness of river ice and the built-up section was five feet, calculated to support gross loads up to 100 tons. The maximum load to cross the bridge was a double trailer rig carrying two Caterpillar D9 crawler-tractors, a Caterpillar Traxcavator loader, and a 10,000 gallon tank. Total gross weight was 200 tons, but the crossing was made without difficulty. Each year less than 30 days of construction time were required to complete the bridges; however, the date of completion is dependent on the extent of continuous cold weather. According to Bruce Robinson, Alaska Department of Highways, the reinforced design was selected by the Department of Highways over straight flooding to provide an extra margin of safety when the river level drops. The drop in water level leaves air voids near the shores and causes cracking as the ice sags.

When it is desired to use an ice bridge up to the last possible moment in the spring, the ice surface may be protected from atmospheric and solar heating by a layer of insulation. In Sweden, it was common practice to use ice bridges right up until ferries were able to operate, thereby minimizing the disruption in transportation usually associated with break-up (Wofff, 1940). A four to six inch layer of sawdust or wood shavings makes this possible (Figure 8). Normally, the insulation is laid down in late winter, when the average daily temperature begins to rise.

**COMPARISON OF TYPES OF ICE CROSSINGS**

To compare the several techniques discussed above for application to a specific situation in Alaska, the site of the proposed Trans-Alaska 48 inch pipeline crossing over the Yukon River 20 miles west of Stevens Village will be used as an example. The length of the crossing is 1800 feet, and the maximum gross load crossing the river is assumed to be 100 tons. A design ice thickness of 60 inches was selected for this load, derived from tables developed by the U.S. Cold Regions Research and Engineering Laboratory for ice airfields (Assur, 1956 and Dept. of the Air Force,
The climatological regime for our model was derived from existing National Weather Service records of average daily temperatures in the vicinity of the site or at comparable locations on the Yukon River for the winter of 1969-70. An ice crossing was established in February, 1970, by clearing the snow. Figure 9 is a graph of the degree-days of freezing on a square root scale and the recorded ice thickness build up. It was observed that the accumulation of naturally frozen ice under cover of the seasonal snowfall reached a maximum of 34 inches, therefore preparation of a crossing site by increasing the ice thickness was necessary. An assumed growth rate of the natural ice cover was established by laying a straight line from \( h = 0 \) at the beginning of freeze-up. Note that the slope \( \alpha = 0.49 \) correlates reasonably well to the value of \( \alpha \) in Table 1 for rivers with moderate flow (\( \alpha = .58 \) to .65).

The most economical approach is to remove the snow cover as early in the season as possible beginning with light tracked vehicles. In order to estimate the probable rate of bare ice growth, a line parallel to the straight line fitted to the recorded average thicknesses along the 1970 ice crossing was laid out in Figure 9 from the point where the natural ice was six inches thick. We read then that the crossing would not reach the design...
thickness until around the beginning of March, and would be usable for heavy loads until near the end of the freezing season, a period of roughly eight weeks. The total cost would be on the order of $1000.

To make use of the crossing earlier, building up ice on the surface is required. The easiest way of doing this, as previously described, is by repeated flooding. After clearing the surface and drilling holes about 200 feet apart along the centerline, a crew of three to four men with two 30,000 gph pumps could flood the crossing site daily with three inches of water for a width of 200 feet. Beginning with six inches of ice on 10 October and allowing 20 days for preparation, the crossing could be ready for traffic by 1 November at a cost of around $3000. A useful period of nearly six months can be anticipated.

The third type of construction, a reinforced bridge, is the most costly in terms of time, equipment, materials, and labor. Although construction time would not be much longer than that for the flooded crossing, materials must be assembled, and the use of construction equipment must await an adequate initial thickness of around 12 to 14 inches for light truck-mounted equipment. By clearing with light tracked vehicles initially, as described above, the power equipment could begin operations by around 20 October. Based on the Highway Department experience, a crew of 20 men could complete the bridge in about 25 days, at a cost in the neighborhood of $25,000. Traffic could move from mid November until around the beginning of May. If necessary, the traffic period could be extended by applying a layer of sawdust, wood chips or other insulation before any thawing occurs, as in the Swedish practice described earlier. The reinforced bridge has an added margin of safety in the event of unexpected cracking such as that encountered when the water level lowers. The log stringers and fibrous material along the crack zone might make the difference between falling through or not. Certainly the overload factor was clearly demonstrated on the State Highway bridge.

In summary, the expedient procedures for improving ice crossings described herein are practical and used extensively in northern countries. The simple snow-cleared crossing has the advantage of low cost, but is limited in capacity and duration of use. The flooded crossing is the most efficient in terms of initial cost relative to traffic capacity. The reinforced bridge is the most costly, but can be used later in the spring if properly insulated, and offers a possible margin of safety over unreinforced ice.

This brief discussion by no means considers all possibilities for the preparation of ice crossings. For example, the addition of fibrous materials within the ice has demonstrated in the laboratory a considerable increase in ice strength (Coble and Kingery, in Kingery, 1963). Fiberglass-resin mixing and spraying equipment developed for preparing expedient landing fields in South Vietnam might be adopted for spraying a mixture of fiberglass and water. The choice of methods used, as the case with any other engineering decision, will depend on the requirement, the economics, the conditions of the particular situation, and the resourcefulness of the project engineer.

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TRANSPORTATION OF ALASKA’S NORTH SLOPE COAL

by Paul R. Clark


Some of which is coking coal. This coal may be in an advantageous geographical position to one of the world’s largest importers of coking coal, Japan. This study was undertaken to determine the economics of transporting coal from these coal fields to Japan.

Figure 1 shows the location of the northern coal fields. Barnes (1967) estimated the coal resources of the region to total 120,197 million tons under less than 3000 feet of overburden, of which 19,292 million tons is bituminous coal in beds of significant coking qualities, as well as low moisture, ash and sulfur content.

MARKET

At the present time, Japan is the most favorable market for coking coal from Alaska (Japanese Government regulations restrict the importation of steam coal). Alaskan coal has a geographical advantage over many of Japan’s other coking coal suppliers; this advantage could result in a favorable competitive position through lower shipping costs.

In 1971, 34.4 percent of U.S. coal exports were shipped to Japan, all of which originated from the east coast of the U.S., 9500 miles from Japan. In re-

On the North Slope of Alaska, there is approximately 120 billion tons of subbituminous and bituminous coal, more than 14 inches thick and 100,905 million tons is subbituminous coal in beds of more than two and one half feet thick.

Analysis of the bituminous coal from the Kukpawruk River and Cape Beaufort areas has revealed that these coals have

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Siberia coal field at a cost of 175-185 million dollars (International Coal Trade, May 1972). Japan conveyed its intention of importing up to 10 million tons per year from this field in the late 1980's provided the quality meets its requirements.

Carbonization tests performed to date on the North Slope coal indicate that it is a blending coal, not a premium coking coal and would therefore sell at the medium to low coking coal prices.

COAL TRANSPORTATION METHODS

Railroads

Railroads have been constructed and operated successfully in northern areas for many years. Recently a transportation study was performed to evaluate the cost of a railroad from Nenana, Alaska on the existing Alaska Railroad, to Deadhorse on the North Slope of Alaska (Tudor, Kelly, Shannon, 1972).

In the lower 48 states, most large coal producers ship their coal to a port or market by unit trains. The unit train technique involves the dedication of a train or number of trains exclusively to the haulage of the bulk material, from one source to one destination, and with a predetermined loading, unloading and travel time. The use of the unit train technique normally results in minimal transportation costs through maximum utilization of equipment for haulage.

Slurry Pipeline

The movement of a fine, suspended material through a pipeline is not a new concept, although its application over long distances has only developed in recent years. One of the most noted applications to coal is the 273 mile long, 18 inch diameter, Black Mesa pipeline which transports approximately five million tons of coal annually between Arizona and Nevada.

A slurry pipeline has only one source and one destination. Each application is a separate case and normally cannot be used interchangeably with other materials.

The cold northern climate poses some unique problems to slurry pipeline construction and operation: the scarcity of water in northern, particularly arctic, areas in the winter may require consideration of seasonal operation, a smaller water supply line from a large water source, or recirculation of water. Normally pipelines are buried except over river crossings or when traversing a mountainous terrain. Burying a pipeline in permafrost may cause complications. Heat is generated from the abrasion of the slurry along the pipe and pump walls. Although this heat generation is not great, it will have to be accounted for.

A year round pipeline system would have to be insulated and/or heated. Facilities would be required to permit rapid drainage of the pipeline if a breakdown occurred in low temperatures. No long distance commercial slurry pipelines exist in areas where freezing of the line is a problem.

Roads and Trucks

Compared to other modes of bulk transport, trucking is considered to be one of the most flexible since the transportation system can be expanded simply by adding more trucks. This flexibility advantage is offset somewhat by inherently high operating and maintenance costs over other bulk transportation methods.

There are two major classes of trucks for the movement of bulk materials: on-the-highway trucks and off-the-highway trucks. Off-the-highway trucks have capacities up to 250 tons and are normally used for short hauls in open pit mining operations or on large construction projects. On-the-highway trucks can be of two types: those operating on public roads and those operating on private roads. Trucks operating on private roads are not normally subject to restrictions except those imposed by the condition of the road on which they operate. Trucks operating on public roads are subject to length, width and weight restrictions. As a result of these restrictions, truck payloads usually range up to 25 or 30 tons.

Belt Conveyors

Until recently, belt conveyors were not considered for long distance transportation because the strength of the cotton carcass limited the length of the belt to short distances. New developments such as the nylon belt, steel cord belt and the cable belt have increased belt tension ratings, which have permitted increases in the length of single flight belt conveyors.

Conveyors are widely accepted as transportation vehicles for two main reasons: ease of operation and low operation and maintenance costs. Similar to pipelines, long distance conveyor systems are inflexible to increased tonnage since they are designed for a specific tonnage, source and destination.

The primary consideration in the construction of a belt conveyor system is belt alignment. A misaligned belt will result in excessive belt wear and possible spillage. Alignment will be a more serious problem in northern areas because of land shifts caused by frost action. Belt conveyors have operated successfully below -45 degrees F and belts can be designed to operate in temperatures as low as -67 degrees F. Conveyors which are operated in cold climates are shut down only for short periods of time. When material is not being transported, the conveyor continues to run but at a creep speed substantially lower than the normal operating speed.

Shipping

The ice free season on the northwestern coast of Alaska averages three months at Point Hope to about two months at Barrow. For the movement of large amounts of coal from the North Slope of Alaska, stockpiling and handling at both Japanese ports and the northwestern coast of Alaska would be minimal if year round shipping could be achieved. However, the problems involved with year round shipping in this area of Alaska may become paramount over the alternative extra handling problems. To date, there has been no successful navigation north of the Bering Strait in winter, even by icebreakers. Alternatives to year round shipping include shipment of all the coal to Japan during the ice free season, shipment of the coal to an ice free transshipment point during the ice free season for furtherance to Japan for the remainder of the year, and extension of the shipping season.
In the transportation systems analyses, 100,000 ton dwt. ships (draft of 50 feet) were used for the computation of shipping costs. This size of ship was selected as a trade-off between economy of scale and the vessel draft. The draft of the ship is an important consideration due to the shallow waters along the northwestern coast of Alaska.

Ocean freight rates for coal to Japan are approximately $4.00 per ton from the U.S. east coast and $2.75 per ton from Vancouver, British Columbia.

**Barging**

Tug and barge combinations for the movement of bulk materials have traditionally been confined to inland waterways and coastal areas. It has only been in the last few years that ocean barge developments have become significant.

The use of a trans-ocean tug-barge system for the movement of coal from northern Alaska has a number of advantages over self-propelled ships: tugs require a smaller crew than ships; a tug-barge can operate in much shallower waters than a ship; and further, there is no tug port time except to change barges. However, tug-barge combinations have a lower cruising speed than ships and are restricted to very light ice conditions.

**Harbors**

Natural, deep water, ice free harbors exist in the southern areas of Alaska, but these harbors are at least 600 miles from the northern coal fields. On the tip of Cape Darby on Golovnin Bay, water depths of 60 feet exist close to shore. This site is approximately 380 miles from the northern coal fields. Also on the Seward Peninsula is the natural harbor of Port Clarence, which is between 40 and 45 feet deep. Port Clarence has good potential for harbor development, but will require dredging if large ships are to be used. Its usefulness to the northern coal deposits is again limited by the distance between the coal and the harbor. The next natural harbor past Port Clarence is at Herschel Island in the Canadian Arctic.

A potential site for the construction of an artificial harbor close to the coal is at the mouth of Ogortoruk Creek, south of Cape Thompson. At this site, the shoreline is fairly flat and the sixty foot water depth is closer to shore (three miles) than at most points on the northwestern coast. A nuclear device was considered for the excavation of an artificial harbor at this location (Project Chariot). The ecological consequences of this detonation were determined to be long lasting, and the projected movement of materials through this harbor was not sufficient to warrant the expenditures required for its construction at that time.

The information available on the seabottom of the northwestern coast near Cape Thompson indicates that bedrock is at or near the surface of the seafloor. The cost of removing sediments from the seafloor is up to $2.50 per cubic yard, while the cost of blasting and removing rock from the seafloor can be as high as $25.00 per cubic yard (Koisch, 1971). An excavation close to shore and a channel to this excavation large enough for large ore carriers would require the removal of approximately 10 million cubic yards of material. It is doubtful that the exploitation of the coal deposits alone could carry the economic burden of the construction of an artificial harbor by conventional methods.

This does not necessarily rule out shiploading in this area. Other methods which may be alternatives to an artificial harbor are structural steel, concrete or earth filled piers to deep water; an artificial island in deep water to act as base for smaller, lighter craft from shore; a slurry pipeline from shore to a moored vessel in deep water; and the use of lighter craft to a ship moored in deep water. The two most practical designs appear to be a rock and gravel filled pier, and slurry loading. These are the only two designs used in the cost analyses.

**TRANSPORTATION SYSTEMS**

Cost analyses were performed on five separate systems used for transporting coal from the North Slope of Alaska to Japan (See Figure 2). These analyses were confined to single use transportation. The establishment of a new overland transportation system and harbor facility with the specific goal of the movement of coal would benefit other resource developments, but no attempt was made in this study to evaluate the magnitude of these benefits.

**System I** consists of a railway which connects a mining area on the eastern portion of the coal deposits to the port of Seward on the Pacific coast of Alaska. The system requires the construction of a 492 mile railroad from the existing Alaska Railroad at Nenana to the coal deposits, and the construction of coal handling facilities at Seward. Unit trains transport the coal directly from the northern coal fields to Seward without any handling or excess waiting time between the source and destination. Coal is unloaded at Seward, stockpiled, then loaded onto 100,000 ton deadweight ore carriers for year round conveyance to Japan.

**System II** proposes the use of the road that is to be constructed from Fairbanks to Prudhoe Bay. The coal deposits are reached by traveling on this road and a secondary spur road to the coal deposits. These two roads supply a linkage to the Alaska Railroad where the coal is loaded into railway cars and shipped to Seward for furtherance to Japan. The trucks used in this system have a capacity of 25 tons.

**System III** involves the movement of coal by an overland system to a harbor near Cape Thompson on the Chukchi Sea.

During the ice free season, the stockpiled coal at this port is shipped simultaneously to Japan and to an ice free transshipment port at Dutch Harbor in the Aleutian Islands. The purpose of the simultaneous shipment is to maintain a consistent delivery schedule to Japan. The coal shipped to Dutch Harbor is stockpiled until the ice begins to form at the Chukchi Sea port. At this time, the coal stockpiled at Dutch Harbor is shipped to Japan.

Three types of overland systems were considered in **System III**: railroad, slurry pipeline and belt conveyors. Two types of shiploading techniques were also considered: dry loading and slurry loading. In the analysis performed for slurry pipelines, the costs of a secondary smaller pipeline was added to the total cost.
Because of the scarcity of an inland supply of water in this region, feed water would either have to be recirculated or transported from a large lake or the ocean in order to operate a slurry pipeline year round.

In order to use slurry loading for ship loading, two ponds would have to be constructed on shore, one for the actual loading of the coal to the 100,000 ton dwt ship and the second as a settling pond for the fine, suspended material decanted from the ship.

During the ice free season, the coal is transported to Japan and simultaneously to a transshipment point at Dutch Harbor. The coal stockpiled at Dutch Harbor would then be transported to Japan by ocean barges when the Point Lay area is non-navigable due to ice conditions.

System V is similar to System IV except 100,000 ton dwt ships have replaced the barges. A slurry loading system loads the ships anchored eight to 10 miles offshore.

CONCLUSIONS

The results derived from the analysis of System I indicate that it would not be economically feasible to construct and operate a railroad from the North Slope to Fairbanks if the coal deposit must support the entire construction and operation. The economics may be entirely different if the additional benefits to other users were considered.

System II, the transportation of coal by truck from the coal fields to Fairbanks, would be prohibitively expensive even if the coal did not have to support any of the main road construction and maintenance.

The cost of moving the coal to the northwestern coast of Alaska (Systems III, IV, and V) appears to be competitive with the transportation costs of existing coal suppliers to Japan, particularly if these coal deposits are on or near the coast. As the overland distance to the coal deposits increases, the costs become greater and the coal becomes less competitive.

Future Research

There are many aspects of coal transportation in northern Alaska which require further research. These include marine terminals and shiploading techniques, arctic slurry pipeline operation, extension of the shipping season, and probably most important, the delineation of favorable coal mining areas.

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(A complete bibliography can be found in the M.S. thesis or M.I.R.L. Report No. 30).

REFERENCES

In spite of what is known about vapor barriers and roof ventilation, moisture stains on the ceiling of a roof are still a common maintenance problem in the winter climates of Canada, Alaska, the Great Lakes and North Atlantic States. Water vapor produced in a building has a tendency to migrate from a warm to a cooler area. Water vapor will move through any air leaks in the floor, wall, and ceiling and will eventually travel to the roof cavity (Dickens, et al., 1966). During sub-zero temperatures, the moisture may collect as ice in the roof cavity and does not present a problem until it melts in the spring or other warm periods. Leaks in the ceiling can be aggravating as water can stain painted surfaces and soften and buckle wallboard. Sometimes the water unexpectedly dribbles out of a lighting fixture and may even ruin the finish on a piece of furniture. Lack of ventilation at the eaves results in a “warm” roof cavity (Graee). This causes formation of ice dams and the backing of water over the flashing into the ceiling, which may be misinterpreted as a condensation problem (Figure 1). Methods of solving these problems are discussed in more detail below.

The complaints of individual homeowners over condensation problems at the ceiling received very little serious attention on the part of the architect, the finance agency approving the plans, the building code officials, and the builders until condensation problems began to occur in 600 electrically heated homes in a large tract housing development in Canada. Apparently the reactions of the tenants were concerted and vehement as the Canadian Central Mortgage and Housing Corporation issued a special Builders Bulletin suggesting more careful sealing of the vapor barrier in the roof (Builders Bulletin No. 220, 1972). Although this bulletin was directed primarily to the builders of electrically heated homes, similar problems occur in Alaskan homes where a hot water boiler is installed in the garage and is isolated from the main part of the house by a fire wall. When the heating plant is located in the main portion of the house, it draws air from the house and exhausts it up the chimney; this is an aid in the reduction of excess humidity levels within the home.

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SCUTTLE OPENINGS

The inconspicuous scuttle opening located on the ceiling of a closet or wall of a split level house is one of the primary sources of vapor and air leaks into a cold roof cavity. No scuttle openings or stairways into a cold attic should be permitted unless insulated and fitted with vapor resistant gaskets and appropriate latches. A scuttle opening should not be installed in the ceiling of an attached garage. Ideally, the access openings into an uninsulated attic should be installed in the end wall of the gables as is done in the Scandinavian countries.

VAPOR BARRIERS

To minimize condensation problems, the entire ceiling should be sealed with a continuous sheet of 4-mil polyethylene (Visqueen) vapor barrier prior to installation of interior partitions. Interior load-bearing partitions, installed before the ceiling vapor barrier is placed, should have a 16-inch strip of polyethylene laid on the top of the plate prior to their placement. The plate of a double plumbing wall or double sound-proofed partition should be fitted with a 16-inch strip of polyethylene. All lapped splices should be sealed against solid blocking placed between the framing members.

If it separates a split-level home, the upper portion of a wall adjacent to a cold roof cavity should be vapor-proofed and insulated as if it were a fully exposed wall. Suitable blocking should be installed between the studs for sealing the vapor barrier and isolating the lower “warm” portion of the wall from the upper “cold” portion.

The vapor barrier lap extending down from the ceiling should always be placed under the wall vapor barrier so that any condensation is diverted into the wall cavity rather than allowing it to stain ceiling or wall surfaces.

All holes drilled in a wall plate at the ceiling for electrical wiring, and other minor openings, should be sealed with a non-hardening caulking compound to prevent water vapor from migrating into the roof cavity. Openings around plumbing vent stacks and chimneys should be carefully sealed with suitable metal collars and a non-hardening caulking compound. Care must be taken to seal the plate of double plumbing walls.

ELECTRICAL WIRING

A typical one-story three-bedroom house with a crawl space may have as many as 64 electrical outlets consisting of 14 outlets for ceiling lighting fixtures and ventilation fans, 18 switch outlets in the walls, and 14 convenience outlets in the walls. Even though many of the switch and convenience outlets are on interior walls, the wiring extends on into the roof cavity. At least 14 branch circuits from the electrical distribution panel spread through the framing like a spider web (Figure 2). The holes drilled in the studs, plate, and sole may result in a tortuous path for migration of moisture, but it eventually leads to the roof cavity. Usually no attempt is made in Alaska to seal the openings in the plate against the migration of water vapor and air.

The “chimney” action of air infiltration through windows, doors, and electrical outlets in the walls forces the moisture and heat into the attic through holes in the ceiling vapor barrier (Tamura, et al., 1963). This becomes apparent during prolonged periods of sub-zero temperatures by the appearance of cold drafts and frost at electrical outlets on the wall and the formation of frost in the roof cavity or attic.

In the Scandinavian countries, the electrical wiring is installed after the insulation and vapor barrier have been properly placed. In the United States and Canada, the electrical wiring and rough plumbing is placed first, followed by the placement of insulation and vapor barrier as shown in Figures 3 and 4. In Scandinavia either 2 x 3 or 2 x 4 nailers are placed over the “warm” side of the vapor barrier, perpendicular to the roof.
or wall framing members. This provides chases for the installation of the electrical outlets and the extension of electrical circuits without the need for puncturing the vapor barrier. After the insulation, vapor barrier, electrical wiring and plumbing have been inspected and approved, the sheet rock, paneling or other interior finish may be applied.

The added cost of nailers may be offset by a four-foot spacing of roof trusses. Also allowing the "rough" carpenter to completely frame, insulate, and vapor proof the structure while on the job without his having to return after the electrician and plumber have completed their work—except to patch holes in the vapor barrier—cuts costs as well. Further, the rough carpentry, insulation, vapor barrier, electrical wiring, and rough plumbing can be inspected and approved at one time before any sheet rock is applied. Temporary heat can be used by the electrician and plumber with no hazard of damaging the siding due to condensation stains or ice formation. Nailers placed perpendicularly increase the interior surface temperatures of the ceiling, which will minimize condensation stains of sheet rock nail heads.

PLUMBING

Holes drilled in the plate and sole for the plumbing are another source of vapor and air leaks into the roof cavity (Figure 2). A double plumbing wall with a split plate is a particular hazard as it has even resulted in the freezing of plumbing on interior partitions. Prior to erection, the top of the plate should be covered with a 16-inch strip of polyethylene that can be sealed with the ceiling vapor barrier of rooms on each side of the wall. Any openings cut in the plate for plumbing vent stacks should be neatly sealed with a metal collar and non-hardening caulking compound.

A double plumbing wall constructed on an outside wall should be carefully built to avoid condensation and freezing problems. The exterior wall should be insulated and vapor proofed before setting the interior wall. The vapor barrier of the exterior wall should extend over the plate of the inner plumbing wall so that no moisture or air can leak into the roof cavity.

The plumber must be extremely careful when sweating copper water and waste fittings to avoid burning the vapor barrier and the insulation. Perhaps the carpenter should install a sheet of fire resistant cement asbestos board between the insulated wall and the plumbing wall to protect the vapor barrier and insulation against fire and puncturing during the installation of the rough plumbing.

CHIMNEYS

Openings around the chimney can be a source of vapor and heat leaks into the roof cavity. Light weight uninsulated metal gas vents can result in excessive heat formation in a poorly vented roof cavity. This causes snow on the roof to melt and flow to the eaves and to refreeze as ice dams and icicles. Gas furnaces should be equipped with an approved all-fuel insulated metal chimney. The chimney must be tightly vapor (air) sealed at the ceiling with a metal collar and non-hardening caulking compound.

ROOF CONSTRUCTION

The "cold" roof concept was originally conceived in the effort to prevent the formation of ice dams along the eaves and the backing-up of water through flashing on to the ceiling (Finne, 1963). Most everyone knows that a one inch ventilation slot is installed in the soffit along the eaves of the roof. Unfortunately very few individuals realize that the ventilation slot no longer performs as intended because thicker applications of insulation restrict the flow of air from the slot intakes (Figure 5). To compound the problem, the heat flowing through air leaks in the vapor barrier at the scuttle openings, electrical outlets, plumbing vent stacks, etc., often exceeds the thermal conduction through the insulation. As a consequence, the roof cavity becomes sufficiently warm to melt the snow over the insulation so that the melted snow migrates to the eaves and refreezes as ice dams over the colder portion of the eaves. If a roof is not flashed properly, the water may leak under the asphalt shingles at the eaves or at the valley. In a flat roof, the water may leak over the flashing at the parapet walls, chimneys, etc.
Although gable trusses constructed of 2 x 4 and 2 x 6 chords can be safely designed to resist Alaskan snow loads, special design considerations are necessary at the eaves to avoid restriction of the air flow at the eaves and a resultant "warm" roof (Carlson, July 1971). The 2 x 4 and 2 x 6 chords only allow three and one half and five and one half inches of space, respectively, between the top of the plate and the bottom of the roof deck (Figure 5). A minimum of six inches of fiberglass insulation is recommended for Alaska; this does not leave sufficient ventilation space over the insulation even though a one inch slot is provided in the soffit. For electrically heated homes, nine and one half inches of fiberglass insulation is suggested and this aggravates the problem even further.

The author purchased a home in Fairbanks with roof trusses constructed of 2 x 4 chords and six inches of fiberglass insulation in the ceiling. The icicles at the eaves by mid-November nearly hung to the ground. A carpenter was called on the project and he crawled up into the attic and pressed insulation down at the eaves with a long piece of 2 x 2 lumber. This allowed air to flow over the insulation to form a "cool" roof as originally intended. After a month or so, the icicles began to reform, as the insulation apparently had begun to swell up and restrict the air flow. This resulted in a "warm" roof again.

Once the error in roof design has been created on the drawing board and constructed on the building site, a satisfactory solution is nearly impossible to attain. Some builders have inserted fiber tubes over the insulation at the eaves which appear to be satisfactory in the warmer climates but are not recommended for interior Alaska. Other builders have either tapered or pulled back the insulation at the eaves, which is entirely unsatisfactory for prolonged periods of sub-zero temperatures, particularly at higher humidity levels. In the latter situation, serious moisture and mildew stains have been observed at the plate and under the lower chord, 10 to 15 inches from the outside wall. Attempting to correct ventilation problems at the eaves is difficult at best because of the laborious task of crawling between chords and diagonals. This is particularly annoying with low pitch trusses where one may be allergic to fiberglass.

The Scandinavians have modified the gable truss designs by increasing the height over the bearing wall 15 to 18 inches to accommodate ten inch applications of fiberglass. The upper chord has two slopes to simplify stress analysis of full triangles. A short rafter is scabbed over the lower portion of the truss to provide a uniform slope over the entire roof surface. The author suggests a simpler technique of cantilevering the truss two feet over the wall, which will provide 18 inches of space between the top of the plate and the bottom of the roof deck (Figure 3). The cantilevered truss involves more complex stress analysis to account for internal redundant forces, but these problems can be easily solved by the structural engineer. The heel of the truss must be supported by 2-foot long plywood gussets on both sides and two inch blocking between the upper and lower chords over the bearing wall.

Eave ventilation of a stick-built rafter roof is often restricted by the conventional method of notching the rafter into the plate, particularly when utilizing thicker applications of insulation (Figure 5). To increase the height of the rafter at the eaves, the rafter may be set on a ledger notched into the top of the joists (Figure 6). The joist should extend over the wall sufficiently to provide adequate nailing surface to restrain horizontal thrusts of the rafter due to snow loads on the rafter.

The cause of moisture problems in single sloping "flat" roofs or double sloping "cathedral" roofs is more difficult to determine as it is usually not possible to look into the roof cavity without cutting a hole in either the ceiling or the roofing, which most people hesitate to do. People have even gone to the useless expense of installing new roofing, only to discover the "leak" still persists. As with a gable roof, air leaks through the vapor barrier at such places as outlets for electrical fixtures, holes drilled in the wall plate and sole for electrical wiring and plumbing vent stacks, cracks of split plumbing walls, and chimneys are common sources of vapor and heat migration into the roof cavity. Recessed beams between the living and dining areas often completely restrict ventilation over the insulation. This results in excessive accumulation of frost in the roof cavity, which later melts and leaks back onto the ceiling and stains painted surfaces.

All too often the rafters of a flat, shed or cathedral roof are selected on the
basis of local minimum code requirements, hence sufficient space is not always provided for adequate ventilation over the insulation (Figure 7). The situation is further aggravated by installing recessed beams to support the roof between living and dining areas, as mentioned earlier. With three and one half inches of fiberglass, this presents no particular problem; however, with the six inches minimum thickness of insulation for Alaska, and the one and one half inches recommended for electrically heated homes, eave-to-eave or gable-to-gable ventilation may be totally cut off. As with the gable roof, the ventilation over insulation at the eaves may be restricted by the former practice of placing blocking on the plate. The blocking was sometimes used to support the edge of the sheet rock on the ceiling. Fortunately this practice is gradually being abandoned as the ceiling sheet rock is being supported by the sheet rock on the walls.

Flat roofs are very popular in Scandinavia. Ice dams at the eaves of flat roofs may be minimized by sealing heat (air) leaks through the ceiling and providing adequate ventilation. To provide adequate ventilation over the insulation to maintain a “cold” roof, 16 to 24 inch deep span trussed joists or lumber-plywood “I-Beam” joists are used (Figure 4). In the United States and Canada, 2’ x 8” to 2’ x 12” lumber joists spanning 12 to 16 feet are used which require interior bearing walls. The shallower depth joists have a tendency to minimize ventilation over the insulation and this results in a “warm” roof. To minimize costs, the Scandinavians place all roof trusses for homes on four-foot spacing. The insulation is placed between the trusses, followed by the vapor barrier. Then 2 x 3 or 2 x 4 nailers, 16 inches on center, are secured perpendicular to the trusses. The nailers serve as a chase for the extension of electrical circuits with minimum rupturing of the vapor barrier. The ceiling finish is installed after the insulation, vapor barrier, and other concealed work has been inspected and approved.

The plank-and-beam has created condensation maintenance problems in Alaska due to lack of insulation and the failure to seal the cracks between the insulation. If adequate foam plastic insulation is not provided, condensation may form between the deck and the insulation (Carlson, Summer 1972). Although rigid foam plastic insulation is an excellent vapor barrier, the joints must be carefully sealed with a compatible adhesive to avoid migration of water vapor. Ice blisters may form under the roofing and melt during warmer weather causing mildew stains on the roof deck. The formation of condensation can be so heavy at times that moisture has been known to stain walls and cause carpets to mildew.

The “upside down” roof, developed
by Dow Chemical Company, hopefully will eliminate the problem of ice dams at the eaves as well as prevent the freezing of roofs drains (Sturman, December 1970). Foam plastic insulation is laid on the top of the roofing, as shown in Figure 8, instead of the conventional method of laying it below the roofing. In this situation the roofing also serves as the vapor barrier. The snow melting on the roof deck can flow down between the planks of rigid foam insulation into a warm temperature zone where it remains unfrozen and flows to the roof drains. To prevent refreezing the roof drains are also covered with rigid foam plastic insulation. The drain pipes are installed within the warm portion of the structure so that they will not freeze as with conventional down spouts. The insulation is weighted down with one and one half inch concrete patio blocks to prevent the wind from carrying the insulation off. This type of construction is ideal for patios over garages or other heated areas.

**INSPECTION**

The inspection of the vapor barrier, insulation, electrical wiring, and rough plumbing should be a critical phase in construction and no further work should be permitted to proceed until inspected and approved by the buyer or his authorized representative—either the architect, the building inspector, finance agency, and/or a disinterested builder.

The use of clear polyethylene vapor papers are signed with the finance agent.

**SUMMARY**

Condensation problems on the ceiling as well as on other surfaces and ice dams at the eaves can virtually be eliminated by the careful and diligent sealing of all potential air, heat, and vapor leaks in the roof cavity and other exposed surfaces. No scuttle or other access openings should be permitted in a cold roof or attic. All openings drilled in the wall plate for electrical wiring and plumbing vent stacks should be properly sealed. Recessed lighting fixtures cut into the ceiling of a cold roof cavity should not be prohibited. Ideally all electrical wiring should be installed on the "warm" side of the vapor barrier by the use of nailers (furring strips) or surface-mounted raceways or cable. The vapor barrier should be continuous and should be extended over the top of all interior partitions. Air intakes, in addition to windows, should be provided for the control of incoming fresh air and relief of excess vapor during prolonged periods of sub-zero temperatures. Finally, no finish ceiling or wall covering should be installed until the vapor barrier, insulation, and other concealed work has been inspected and approved by the prospective owner or his authorized representative.

**REFERENCES**

Anno., Measures to Control Condensation, Canadian Central Mortgage and Housing Corporation, Builders’ Bulletin No. 220; Ottawa, Canada, 1972.


Græe, Trygve, (Luftlekkaisier Og Sno­melting Pa Tak) Air Leaks and Snow melting on Roofs, Institute of Agricultural Structures, Agricultural College of Norway, Reprint 132; As, Norway.


SYMPOSIA & CONFERENCES

24TH ALASKAN SCIENCE CONFERENCE
University of Alaska, Fairbanks, Alaska, August 15—17, 1973
First Announcement

CLIMATE OF THE ARCTIC

* PHYSICAL CAUSES
* BIOLOGICAL EFFECTS
* CONSEQUENCES TO MAN

Conference Chairman—Dr. Gunter E. Weller
President, Alaska Division AAAS
Geophysical Institute, University of Alaska

MAIN THEMES of the 1973 AAAS Conference will Include—

* The Climate Now
* Climates of the Past
* Future Climates
* International Climatology

MANY DISCIPLINES can contribute to solving problems of the Arctic—Meteorology, physics, chemistry, oceanography, mathematics, geology, geography, glaciology, astronomy, history, anthropology, botany, zoology, physiology, economics, psychology, sociology, art and architecture, engineering and agriculture. Authors wishing to contribute papers should write to—

Director
Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701
Telephone (907) 479-7282

SECOND INTERNATIONAL CONFERENCE ON PERMAFROST

The second “International Conference on Permafrost” will be held from July 16—28, 1973, in Yakutsk, USSR. For information on this conference, residents in the United States should write:

Dr. T. L. Pewe
Chairman, Department of Geology
Arizona State University
Tempe, Arizona 85281;

Canadians should write to:

Mr. R. J. E. Brown
Northern Research, Geotechnical Section
National Research Council
Ottowa, Ontario K1A 0R6;

Information from the USSR can be obtained from:

Dr. P. I. Melnikov
Chairman, Organizing Committee
International Permafrost Conference
c/o Institute of Permafrost Studies
11/4 Fersman Street
Moscow v 312, USSR

SYMPOSIUM ON WASTEWATER TREATMENT IN COLD CLIMATES

A Symposium on “Wastewater Treatment in Cold Climates” will be held on the Saskatoon Campus of the University of Saskatchewan on August 22–24, 1973. The program will include discussions covering the following topics:

a) Problems and Solutions for Cold Climates
b) Operation of Stabilization Ponds
c) Aeration Under Low Temperature Conditions
d) Biological Treatment for Organic and Nutrient Removal
e) Physico-Chemical Treatment
f) Disinfection
g) Disposal of Liquids and Sludges

For further information on the Symposium contact:

Dr. Eric Davis
Department of Civil Engineering
University of Saskatchewan
Saskatoon, Saskatchewan
Canada S79 0W0

ALSO . . .

A session on “Cold Climate Wastewater Treatment,” a joint congress sponsored by the American Institute of Chemical Engineers and the Canadian Society for Chemical Engineering, will be held in Vancouver, British Columbia on September 9–12, 1973.

RESEARCH REPORTS

The following research reports are now available to the public from the University of Alaska’s Institute of Water Resources, Dr. Robert F. Carlson, Director:


BioProcesses of the Oxidation Ditch When Subjected to a Subarctic Climate, K.R. Ranganathan and R. Sage Murphy, IWR-27.


The Effects of Suspended Silts and Clays on Self-Purification in Natural Waters: Protein Absorption, Ann P. Murray, IWR-23.

An Analysis of the Demands for Water From the Private Sector in a Subarctic Urban Area, Robert P. Haring, IWR-22.

These reports are distributed without charge. However, if a report is out-of-print, the Institute of Water Resources will Xerox a copy of the report at a fee of 14 cents per page.

Direct your inquiries to:
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