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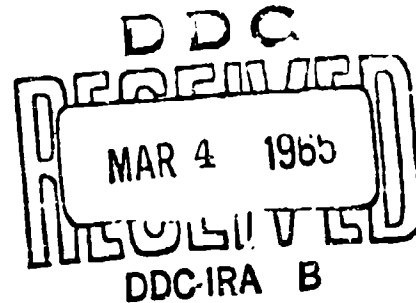
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REVIEW OF RESEARCH ON MILITARY
PROBLEMS IN COLD REGIONS

TECHNICAL DOCUMENTARY REPORT AAL-TDR-64-28

December 1964



ARCTIC AEROMEDICAL LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
FORT WAINWRIGHT, ALASKA

and

ARCTIC TEST CENTER
TEST AND EVALUATION COMMAND
ARMY MATERIEL COMMAND
FORT WAINWRIGHT, ALASKA

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SYMPOSIUM

REVIEW OF RESEARCH ON MILITARY
PROBLEMS IN COLD REGIONS

Presented at

FIFTEENTH ALASKAN SCIENCE CONFERENCE
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
College, Alaska

31 Augus. - 4 September 1964

Organized and Edited by

CHARLES R. KOLB
Research and Development Office
Arctic Test Center
Fort Wainwright, Alaska

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Fort Wainwright, Alaska

December 1964

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Horace F. Drury

HORACE F. DRURY

Director of Research

PREFACE

Examples of failure to prepare adequately for military operations in cold regions can be found in history from the time of Hannibal to the Korean conflict. Cold, darkness, wind, snow, ice, muskeg, glaciers, vast unpopulated areas, insects, ice fog and whiteouts are well-known examples of factors which characterize the harsh unyielding arctic environment. It is depressingly true that many of the major military problems faced by our troops during the Korean winters more than 10 years ago are still with us today. A periodic reminder of this fact and an assessment of the current status of research that is nibbling at the edges of military operational problems are not only enlightening but serve as a stimulus for a more concerted effort toward resolving these problems.

The papers in this symposium will hopefully assist in providing such a stimulus. They were presented at the 15th Alaskan Science Conference, held at University of Alaska under the auspices of the Alaska Division, American Association for the Advancement of Science, from 31 August to 4 September 1964. Their purpose is to focus attention on problems which affect military operations in cold regions, to outline the major research effort being expended to solve these problems, and to point out some promising avenues of approach to future research.

It is recognized that only a fraction of the cold regions military problems and research needs can be summarized in such a small group of papers. However, the papers provide an illustrative cross-section of the many scientific and engineering disciplines which contribute toward solution of military problems in cold regions. Research specialties represented include biology, civil engineering, geography, geology, geophysics, hydrology, materials engineering, physiology and psychology.

There is a growing awareness of the need for an interdisciplinary approach to research problems. Liaisons between scientists of various disciplines and between scientists and

developmental engineers have never been better. Meetings such as the 15th Alaskan Science Conference are prime examples of the popularity and effectiveness of the interdisciplinary approach. On the other hand, liaison between the research scientist and the potential military user of his product could stand a great deal of improvement. Progress has been made in disseminating current military needs to the scientific community, but it is only a beginning. The results of scientific studies, couched in nontechnical language, should also be disseminated among the military. There is a need for a breakthrough in communications. The papers presented in this symposium should help to narrow the gap between the scientific and military communities, between scientific research and military operations.

Charles R. Kolb
Fritz M. G. Holmstrom
November 25, 1964

A MESSAGE FROM THE GENERAL CHAIRMAN,
15th ALASKAN SCIENCE CONFERENCE

The symposium, "Review of Research on Military Problems in Cold Regions," was a highlight of the 15th Alaskan Science Conference, sponsored by Alaska Division, American Association for the Advancement of Science and held at the University of Alaska from August 31 to September 4, 1964. Dr. William R. Wood, President of the University of Alaska, commented on the scientific program as, "... an outstanding program which drew an enthusiastic response from the largest group of scientists ever to assemble in Alaska." Registration at the conference was, indeed, more than double and financial income more than triple that of any previous conference.

The major factor in the success of the 15th Alaskan Science Conference was the application of the energies and abilities of Dr. Charles R. Kolb in organizing the program for Earth Sciences Section, one of six sections of the conference. Dr. Kolb and his Section Committee succeeded admirably. In fact, participation in the Earth Sciences Section alone surpassed that of any entire Alaskan Science Conference held previously. Science in Alaska and the purposes of Alaska Division, AAAS, were furthered significantly. Earth Sciences Section of the 15th Alaskan Science Conference set a standard of accomplishment for all sections of all future conferences.

Dr. Kolb's fondest activity was the organization of his "Military Problems Symposium." In this he was approbated by Lt. Col. Kermet Applewhite, Chief, U. S. Army Research and Development Office, Alaska, and Col. Stephen J. Mancuso, Commander, U. S. Army Arctic Test Center. Lt. Col. Fritz M. G. Holmstrom, Commander of the U. S. A. F. Arctic Aero-medical Laboratory, advised in the organization and served as coeditor of the proceedings. The problems reviewed and discussed are interservice and multidisciplinary; they have, in fact, relevance far beyond that of military applications. The limits of environment within which man can exist are quite narrow. The limits within which he can perform useful work are even narrower. Physiological conditioning can extend these limits only to a small (though significant) degree. Man must be insulated from a hostile environment by technological means.

Then he must make a behavioral adaptation both to the fact of the environment (which includes a dynamic assessment of potential stress) and to the technology which insulates him from it. This symposium was concerned with identification of the arctic environment, with factors affecting military operations within the arctic environment, and with man. Always we come to man — with the promise, the problem and the hope of effective performance. We lessen the uncertainty by critical definition and assessment of all factors — physical, technological and human. This was the aim of the present symposium. Perhaps most salient is Richard Possenti's conclusion that military command is the most important military problem in an arctic environment. One cannot but suspect that this is true for all environments.

The presiding chairmen for the three sessions of the symposium contributed materially to its success. These were:

- Session I. Charles R. Kolb
Research and Development Office
Arctic Test Center
Ft. Wainwright, Alaska
- Robert R. Philippe
Research and Development Directorate
Army Materiel Command
Washington, D. C.
- Session II. Leonard S. Wilson, Chief
Environmental Sciences Division
Army Research Office
Washington, D. C.
- Session III. Col. Herbert H. Kerr
Command Surgeon
Alaskan Command
Elmendorf Air Force Base, Alaska
- Lt. Col. Fritz M. G. Holmstrom, Commander
U. S. A. F. Arctic Aeromedical Laboratory
Ft. Wainwright, Alaska

Charles J. Eagan
President, Alaska Division, AAAS

November 30, 1964

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OPENING ADDRESS

A PHILOSOPHY FOR MILITARY RESEARCH AND DEVELOPMENT IN ALASKA AND OTHER ARCTIC REGIONS

Robert R. Philippe and Lt. Col. E. F. Clark, USAR Retired
U. S. Army Research and Development Directorate
Washington, D. C.

It is a pleasure to be here this morning to open this session of papers reviewing research on military problems in cold regions. The primary purpose of this session is three-fold: first, to focus your attention on problems which affect military operations in cold climates; second, to attempt, within the short span of time allotted to each speaker, to outline the major research efforts being expended to solve these problems; and third, to point out some promising avenues of approach to future research of this nature. In organizing this symposium, no attempt was made to cover all military problems in cold regions. They are numerous and variable, and often only partially defined. Instead, the plan was to select several of the more significant problems and to explore them, as well as current research underway to discover acceptable solutions.

As the day progresses, you will note that nearly all scientific and engineering disciplines contribute, either directly or indirectly, to solutions of cold regions military problems. For instance, the physical scientist, who studies surface chemistry, crack initiation and propagation, and dislocations in materials; the geologist or engineer, who studies the physical properties of frozen soils; and the physiologist, who studies the effects of low temperatures on human metabolic processes, all contribute to these solutions and are excellent examples of the diversity of scientific talents and interdisciplinary approaches required to solve a wide spectrum of cold regions problems.

Our accomplishments in this field of endeavor have been considerable, with many of them of more than minor significance. We have probed many of the secrets of the Arctic and of the remnants of the great continental glaciers; we have constructed cities under the ice; and we have enhanced greatly the fund of human knowledge concerning these regions. However, it is not

the purpose of my few remarks this morning to extol our deeds of the past. Instead I wish to draw your attention to a need for a more meaningful philosophy for arctic research, and greater effort on our part to marry science and technology to assist the comparatively small cadre of scientists and engineers who have labored diligently in Alaska and other arctic lands.

The late Dr. Compton of MIT once said, "The experience during the war as well as the experience with the great industrial research laboratories and of some of the groups in university laboratories, have increasingly demonstrated the great power of co-ordinated group effort, where a number of scientists or engineers with different backgrounds and points of view can tackle a major scientific problem in a co-ordinated manner." Generally, this will be the theme of my remarks.

With this increasing awareness among scientists and engineers, there is a growing realization that we in the Arctic are often engaged in limited investigations instead of broad and balanced programs.

In the course of our cold regions investigations we have done much to increase the ease of arctic operations, but unfortunately there is still far too much effort, discomfort and ineffectiveness involved. We still need a magnitude of change in providing better protection from the elements, in transport of cargo and personnel, in handling and protection of supplies, and in the accomplishment of a multitude of other logistic tasks.

If we seek improvement, what best can help the cause? I believe we can point at three possible real contributors; namely, greater interest by our nation as a whole in arctic regions, a better bridge between science and technology, and maximum use of the interdisciplinary approach to problems. I should like to dwell upon each of these points briefly.

My first point is that as yet we as a nation have not developed as positive an attitude toward the Arctic as have toward the Antarctic. Although we conduct cold regions research, it would help our purposes if we would assess more fully both the complete military and the economic potential of these regions. With this, we could evolve a firm philosophy upon which to conceive policies and programs of research in the Arctic. It would follow that we could concentrate our limited resources on the solution of major problems.

Our actual investment in arctic research is small compared to what we spend in the Antarctic. Mostly we have been pioneering in the Arctic, but the need for a more systematic development is upon us. As a nation, we need a critical assessment of arctic potential to determine if the more costly phase of development is to our national interest.

My second point is that in our polar and arctic research and development efforts, we need greater play between science and technology. We know of the materiel deficiencies common to cold climate military campaigns and to wintertime arctic and subarctic military maneuvers and exercises. In many instances, science has already provided an answer, but we still need to press technology into providing workable solutions. For example, small turbine engines substituted for internal combustion engines would solve the problem of cold-soaked starting of engines. Metallurgists and other materials researchers advise us that many new metal alloys and other materials, which will retain desirable properties at very low temperatures, would solve many problems caused by low temperature embrittlement of metals and other materials. The very notable advances on research in fabrics and in physiological responses at Natick should be applied to reducing the bulk and weight a combat soldier must carry into the field, to increase mobility and conserve energy in face of physical contact with the enemy.

These are but a few of the examples where we can hasten to close the gap between science and technology. We must seek means of better communication between the researcher, the designer and the user, to exploit available knowledge to problems at hand. Perhaps, more and more, we should thrust these groups together into actual common problems in the field, where the adversity of the environment could force them to become bed-fellows. In truth, they must become members of one team, welded by need of a common and urgent objective.

This brings me to my third point, which is the need for more effective interdisciplinary approaches to problems. For example, we might study an arctic river by addressing our efforts solely to measurements of hydraulic characteristics. Yet without serious consideration of hydrological, geological, morphological, pedological and climatological factors involved, our conclusions might be so limited that they would serve little purpose in understanding the environment as a whole.

This leads us to a final important question; namely, what can we do to bring the Arctic into proper over-all perspective? I believe we can and should, within our available resources in people, do three things: First, we should engage in a concerted effort to provide the usable information necessary to enable the nation to make a wise decision concerning the arctic potential. Second, we should assist in evaluation of this potential from a national viewpoint. In this we should make available a cadre of arctic scientists and soldiers to join others in facing the assessment foursquare and on a grand basis. Third, we should direct concerted efforts to the translation of expanding scientific knowledge into well-engineered techniques and hardware systems which will make the Arctic more easily accessible to the advances of development.

NOTES ON THE PHYSICAL ENVIRONMENT OF ALASKA

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INTRODUCTION

Alaska is the largest peninsula of North America and extends between the meridians of 130° W and 173° E and between the parallels of 55° and 72° N. It is bounded on the north by the Arctic Ocean and on the south by the Pacific Ocean. On the east it is bounded by Canada and on the west by the Bering Sea, Bering Strait and Chukchi Sea.

The area of Alaska is $1,520,000 \text{ km}^2$, about 15% the size of Europe. The state contains extensive lowlands and towering glacier-clad mountains, including Mt. McKinley (6,200 m elevation), the highest peak in North America.

PHYSIOGRAPHY AND GEOLOGY

The main physiographic provinces of Alaska are outlined by major topographic units and are similar to the United States and western Canada. The four major provinces (from south to north) are: the Pacific Mountain System, the Intermontane Plateaus, the Rocky Mountain System and the Arctic Coastal Plain (Figure 1). The Pacific Mountain System extends from southeastern to south-central Alaska and through the Aleutian Islands, including the coastal mountains as well as the Alaska Range. The Intermontane Plateaus include the lowlands and rolling hills of the interior and western Alaska, between the Alaska Range on the south and the Brooks Range on the north. The Brooks Range and the northern foothills belt comprise the Rocky Mountain System. The area comprising the Arctic Coastal Plain extends north from the Rocky Mountain System to the sea. These major divisions have been divided into 12 provinces and further subdivided into 60 sections.

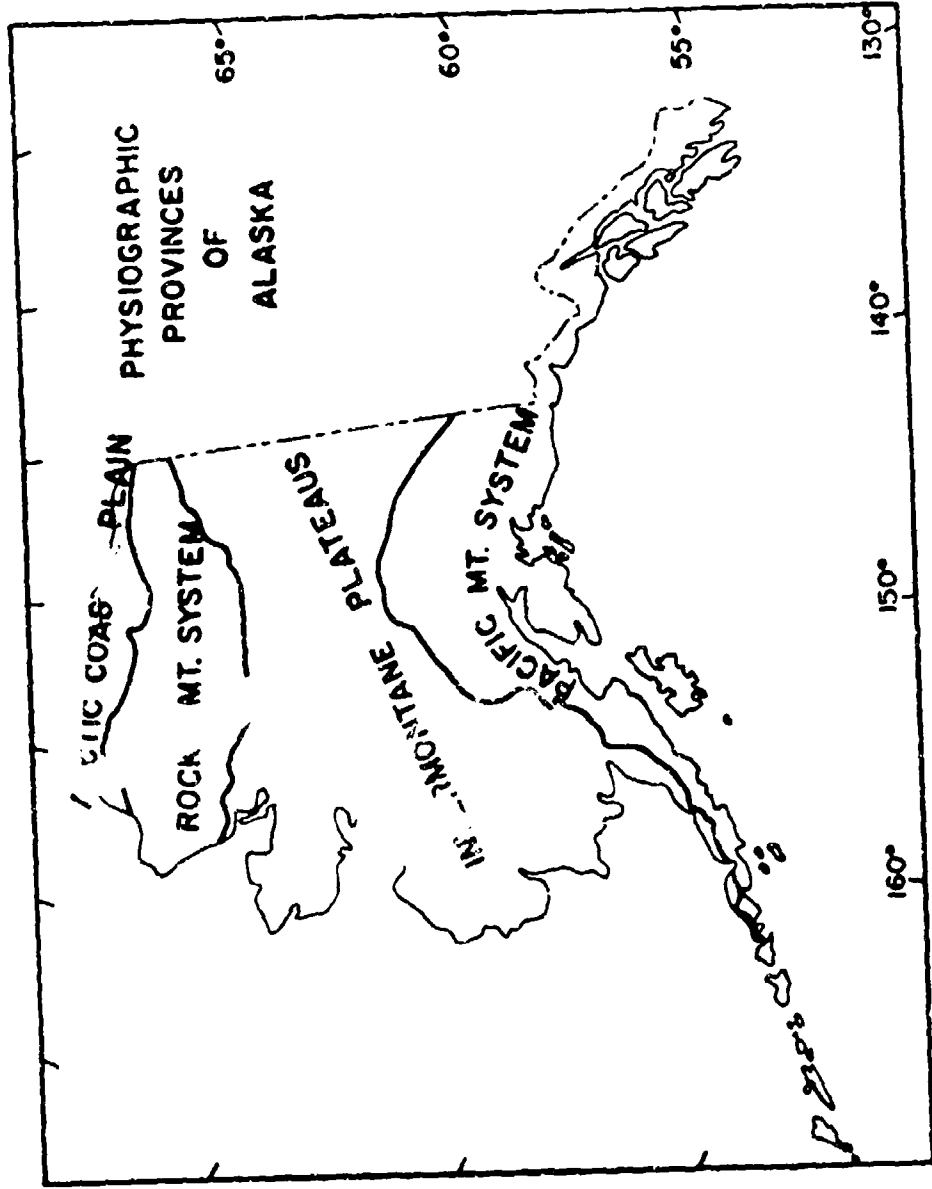


FIGURE 1
Physiographic provinces of Alaska. (After Wahrhaftig (13) in press).

The Pacific Mountain System includes the jagged coastal ranges of southeastern Alaska as well as the St. Elias Mountains, which are continuous with and geologically similar to the Chugach Mountains. The St. Elias Mountains contain the second and fourth highest mountains in North America and are, in large part, fault controlled. The Chugach Mountains are composed mainly of metamorphosed sediments and volcanic rocks.

The Wrangell Mountains are a small volcanic group, one of which, Mt. Wrangell, is still active. The Talkeetna Mountains comprise a rugged glaciated area of igneous, sedimentary and metamorphic rocks. The Pacific Mountain System also includes the Copper River basin, an intermontane depression filled with more than 30 m of unconsolidated sediments of Quaternary age. Another lowland is the Cook Inlet-Susitna Lowland, underlain in part by coal and oil-bearing beds of Tertiary age.

The largest mountain group in the Pacific Mountain System is the Alaska Range, an arcuate barrier 1000 km long. It includes large number of ice-clad peaks, many more than 4,000 m high. The range has great areas of igneous rock, many of which support the highest peaks, but in large part, the range is composed of metamorphic and sedimentary rocks, some of great antiquity. In addition to these older rocks, coal-bearing deposits of Tertiary age are widespread, especially on the north side of the central Alaska Range. These, in turn, are overlain by poorly consolidated gravel deposits of Tertiary age.

The Alaska Peninsula and the Aleutian Islands are part of the Pacific Mountain System and compose an arcuate line of volcanoes 2600 km long. Nearly 80 volcanoes are known in this belt, and more than half of them are active.

The Intermontane Plateaus physiographic province lies between the Pacific Mountain System on the south and the Brooks Range on the north. This broad area, comprising half of the state, consists mainly of gently rolling hills and broad sediment-filled tectonic basins, but a few rugged, glaciated peaks are present. The rocks of the highlands are of great antiquity and include both pre-Cambrian and Paleozoic rocks. Deposits of Mesozoic age are also widespread, especially in the west. Areas of intrusive igneous rock are present in the interior of Alaska and generally give rise to the higher peaks, most of which, however, are lower than 1800 m elevation. Volcanic rocks of Quaternary age are present mainly on the Seward Peninsula and the Yukon-Kuskokwim Delta (Figure 2).

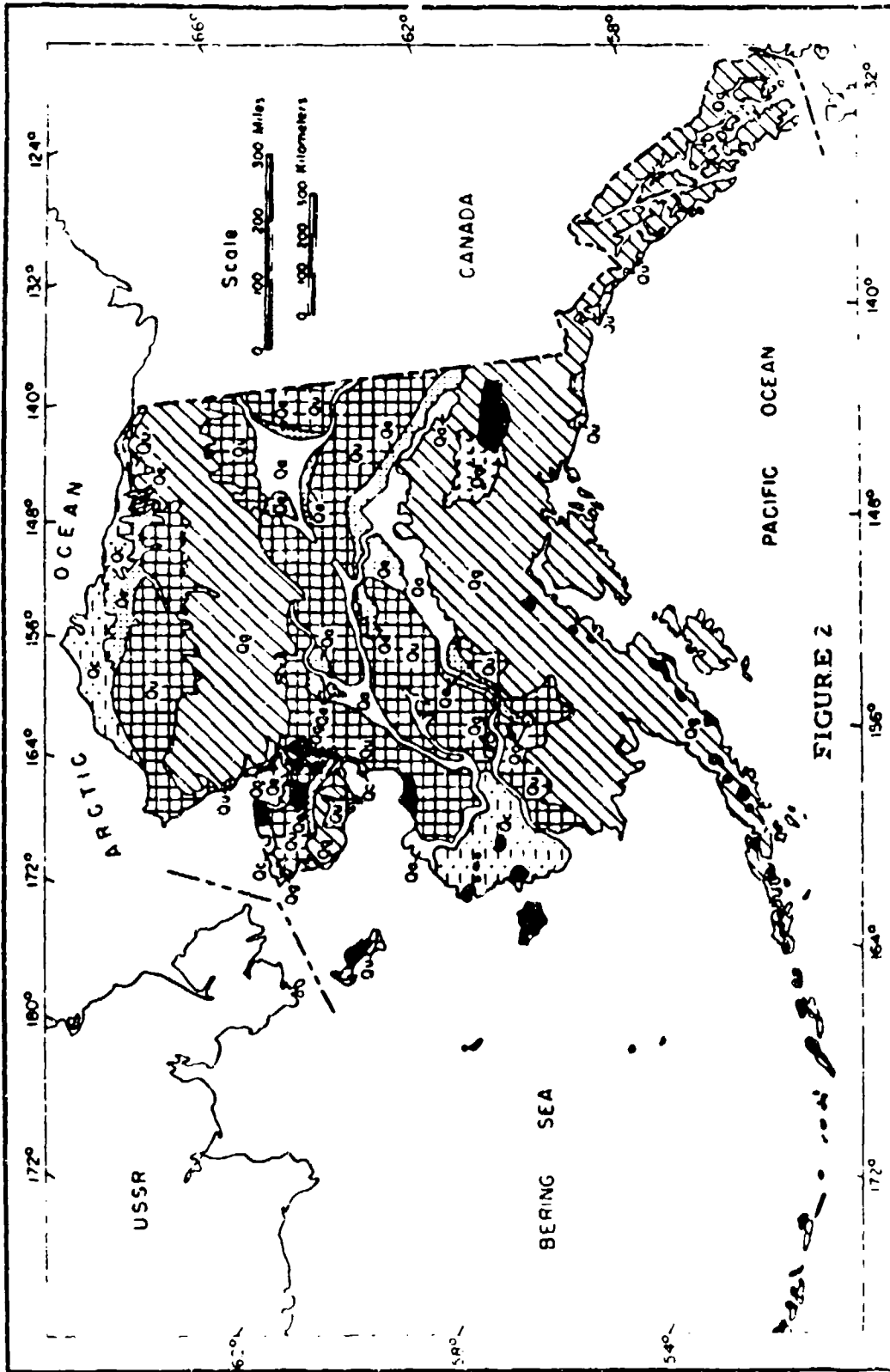


FIGURE 2

LEGEND FOR FIGURE 2

Quaternary deposits of Alaska — Sketch map of major regional groups of surficial deposits in Alaska. Qg - glacial and other deposits associated with heavily glaciated alpine mountains; Qgl - glaciolacustrine deposits of larger Pleistocene proglacial lakes; Qu - undifferentiated deposits associated with generally unglaciated uplands and lowlands of the interior and North Slope; Qa - fluvial deposits; Qe - eolian deposits; and Qc - coastal deposits of interbedded marine and terrestrial sediments. Solid black areas - deposits associated with volcanic peaks and flows of Quaternary and Tertiary age. (Modified from Karlstrom (6) figure 154.1).

The Brooks Range and the foothill belt north of the Range comprise the Rocky Mountain System in Alaska. The Range is a dissected and faulted complex anticlinorium of mostly Paleozoic and Mesozoic sediments. Local intrusions are also present. The foothill belt is composed of isolated hills, mesas and hogbacks of sedimentary rocks, reflecting anticlines and other structures.

North of the Rocky Mountain System and extending to the sea is the Arctic Coastal Plain, which is a vast plain covered with thousands of lakes and swamps. Many of the lakes are oriented about 30° west of north, perhaps by wind action. The coastal plain is underlain with rather flat-lying sedimentary rocks.

Surficial deposits cover most of Alaska and are Quaternary in age (Figure 2). Eolian deposits cover a large fraction of the low-lying parts of Alaska. The deposits include large areas of loess and reworked loess (known in Alaska as "muck"), smaller areas of stabilized sand dunes and very small areas of active dunes. Practically all of the loess was derived from glacial outwash plains, and the few areas where loess is accumulating in significant quantities today adjoin the braided flood plains of streams from active glaciers. Most of the fossil sand dunes also adjoin sandy glacial outwash plains of late Pleistocene age, but a large area of stabilized dunes in the Arctic Coastal Plain and a small area of stabilized dunes on St. Paul Island in the Pribilof Islands and in the Yukon Delta probably accumulated on the lee side of extensive sandy beaches.

Loess probably constitutes the most widespread Quaternary sediment in Alaska. It forms a blanket, ranging in thickness from 1 cm to more than 60 m, that covers almost all areas in the state that lie below altitudes of 300 to 600 m. Thick deposits of loess are most widely distributed in central and western Alaska.

Lacustrine deposits of Quaternary age are relatively limited in Alaska, and only one large area, the Copper River basin, exhibits widespread, well-developed lake deposits. The Copper River basin is an intermontane lowland about 14,000 km² in extent, bounded by the Chugach, Wrangell and Talkeetna mountains and the Alaska Range. The lowland is drained by canyons through the surrounding mountains, which still support large glaciers today and which supported much larger glaciers in the past. During Pleistocene glacial cycles, glacial ice repeatedly blocked the drainage from the lowland, producing huge lakes, into which glacial silt and clay was deposited.

It is estimated that 25% of Alaska is covered by fluvial deposits, if the overlying loess blanket on the terraces is ignored. In addition to the modern flood plains of rivers, huge areas of glacial outwash fans flank most major mountain ranges, and many large tectonic basins, such as the valleys of the Kuskokwim and Tanana Rivers, the Yukon Flats and Yukon-Koyukuk lowland, are filled with one meter to a few hundred meters of fluvial sediments of Quaternary age.

Coastal lowlands underlain by marine deposits fringe much of the perimeter of northern and western Alaska, from the Canadian boundary to the Kuskokwim River and along the northwest shore of the Alaska Peninsula.

CLIMATE

As might be expected, the climate of Alaska is quite varied; this is caused by a varied topography, different conditions of seas bounding Alaska on three sides and its great geographical extent. The northernmost point of Alaska is only 19° of latitude from the North Pole, and the southernmost tip of southeastern Alaska is near the latitude of Copenhagen, Denmark. It is not generally realized that the range in climate in Alaska is greater than that between Florida and Maine in the contiguous United States.

Several distinct climatic zones have been recognized in Alaska; early climatic subdivisions differ only slightly from those used today by the U. S. Weather Bureau (Figure 3). The nine subdivisions of today fall into four major climatic zones, zones which are closely related to the physiographic provinces outlined earlier. The southernmost climatic zone, zone of dominant maritime influence, includes southeastern Alaska, the south coast and the Aleutian Islands. The area is characterized by small temperature variations, much cloudiness and abundant precipitation, especially in southeastern Alaska. The highest recorded mean annual precipitation, 560 cm, is at Little Port Walter in southeastern Alaska. It is no wonder that this zone is one of no permafrost but has extensive glaciers. The mean annual air temperature is warmer than 0° C except in the high mountains (Figure 4), and the degree ($^{\circ}$ C) days of freezing are less than 1000 (Figure 5).

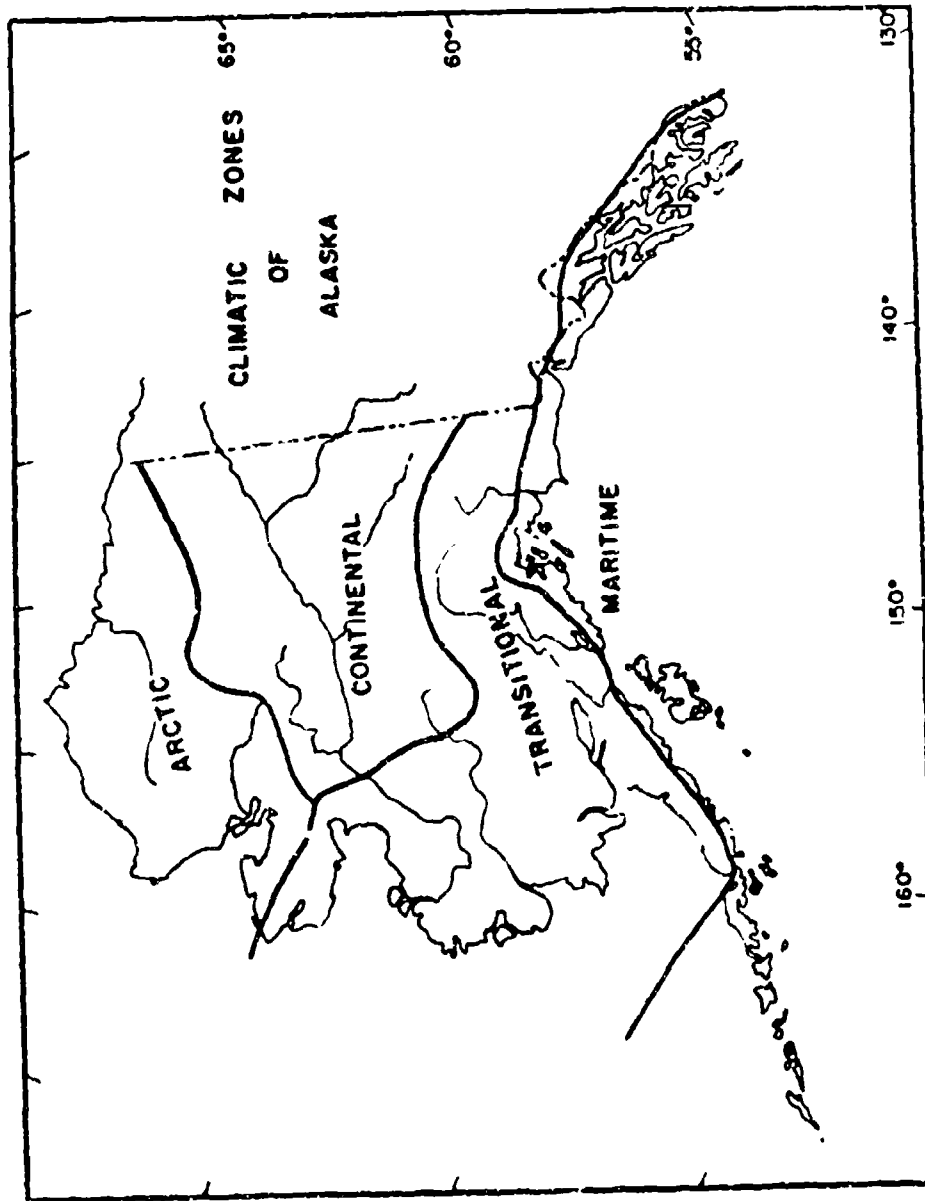


FIGURE 3
 Climatic zones of Alaska. (After Watson (14) 1959).

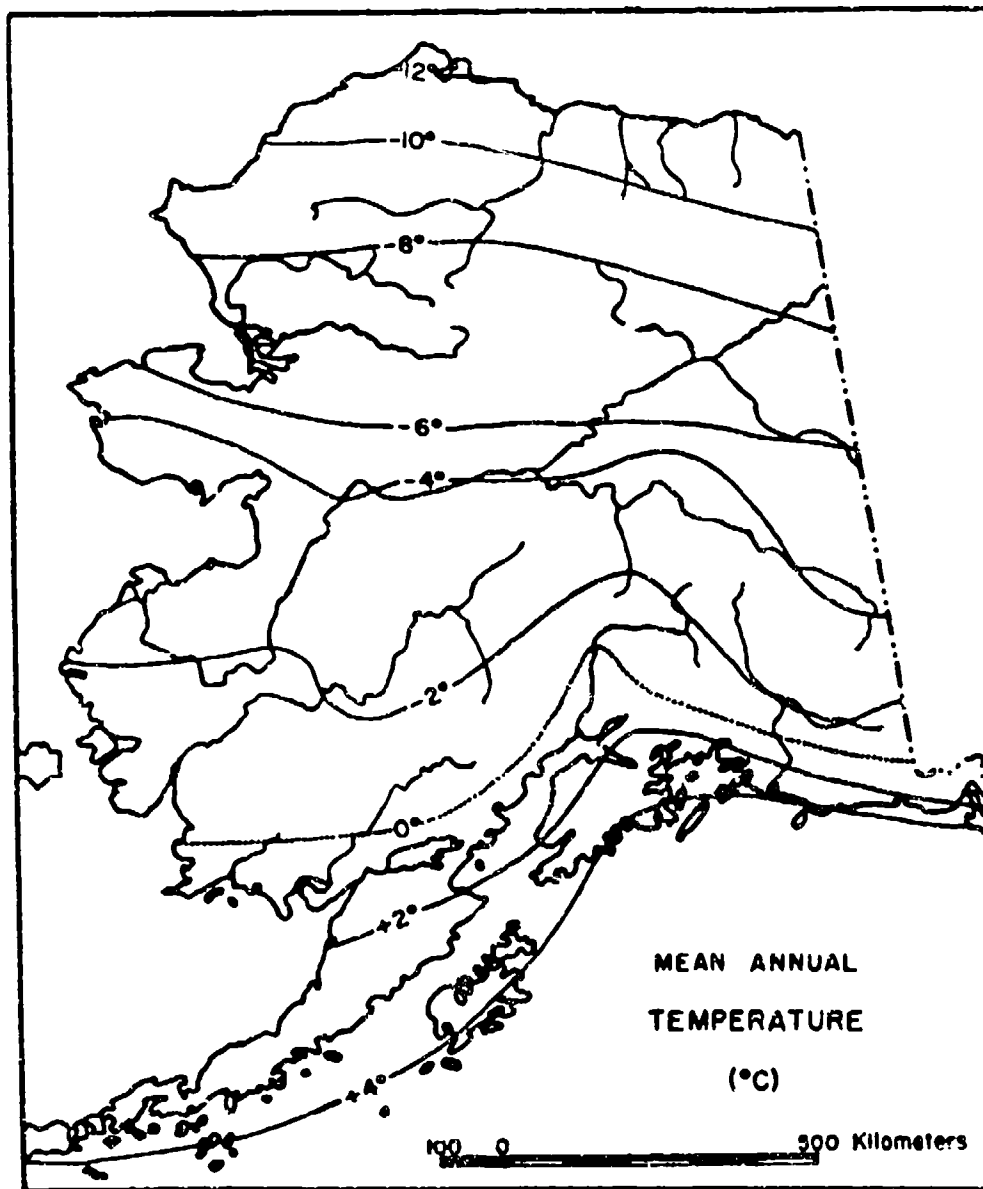


FIGURE 4

Mean annual air temperature ($^{\circ}\text{C}$) isotherms in Alaska.
 (Compiled by L. Mayo, U. S. Geological Survey. Effect of
 topography is not considered).

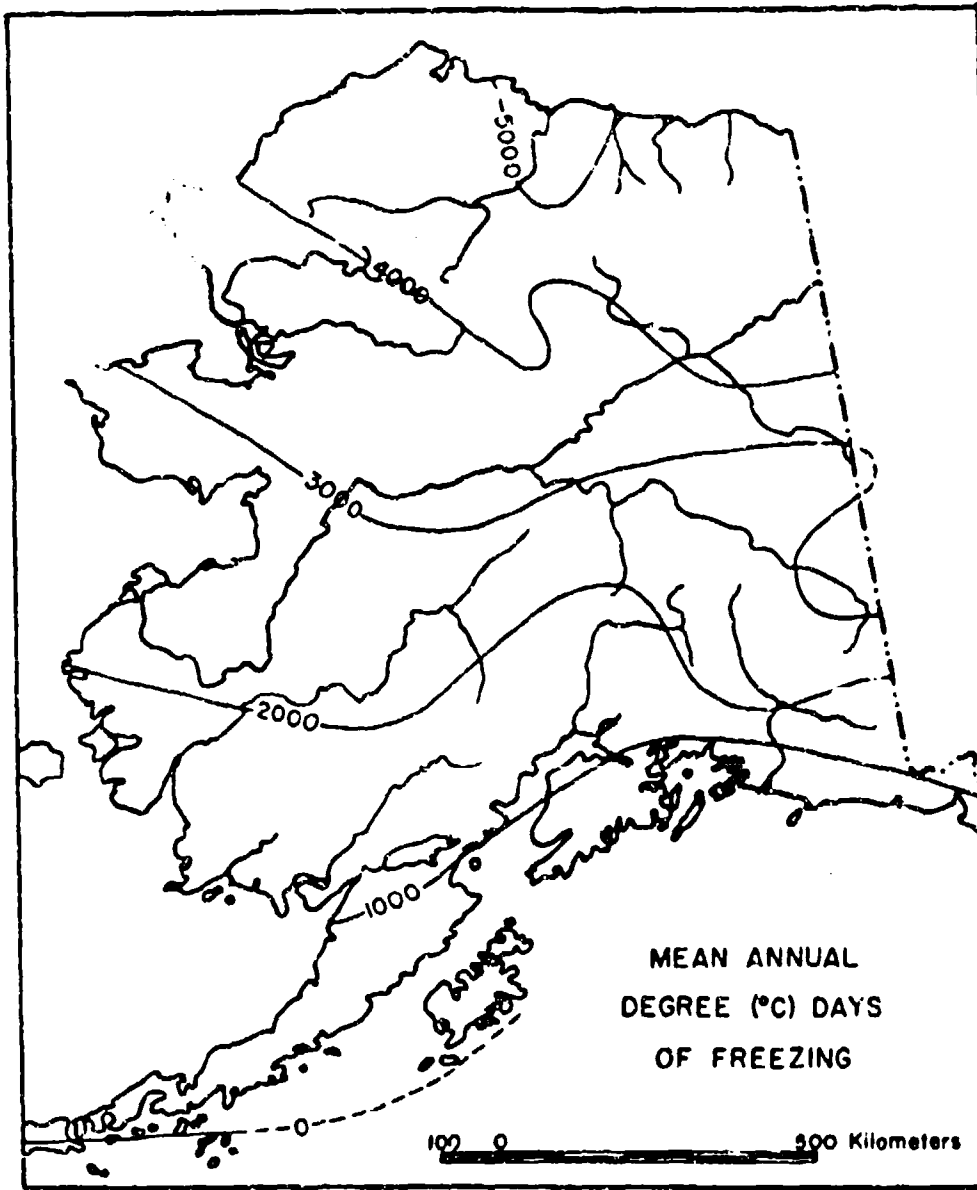


FIGURE 5

Degree ($^{\circ}\text{C}$) days of freezing in Alaska. (Compiled by L. Mayo, U. S. Geological Survey, from monthly mean temperature data. Effect of topography is not considered).

A zone of transition from maritime to continental climate lies north of the maritime zone (Figure 3). Temperature variations in this zone are more pronounced, and there is less cloudiness and precipitation than in the maritime zone. The mean annual air temperature is about 0°C in the south and as cold as -2°C in the north of this zone (Figure 4). Characteristics of continental climate are common in the northern part of the zone. The degree ($^{\circ}\text{C}$) days of freezing range from 1000 to 3000.

The dominant continental climate zone lies north of the Alaska Range, south of the Brooks Range and east of the Seward Peninsula (Figure 3). These topographic barriers tend to prevent the inland movement of air, and the area is semi-arid. This zone has great extremes of temperature, from 37.8°C to -60°C . The mean annual air temperature ranges from -2°C on the south to -6° to -8°C on the north, and the degree ($^{\circ}\text{C}$) days of freezing are from 1700 to 4000.

The Arctic climate zone lies in northern and northwestern Alaska and has the most rigorous climate of the state. It has a very low mean annual air temperature, from about -6° or -8°C on the south to -12°C at Barrow on the north (Figure 4). The mean annual degree ($^{\circ}\text{C}$) days of freezing averages from 2800 to 5400 (Figure 5).

The winters are very cold, and the summers are cloudy and cool. Both rainfall and snowfall are light — about 20 cm annual rainfall and less than 150 cm of snow annually. Snowfall is light, and accumulation is thin enough to permit great cooling of the ground, especially since much snow is blown by the winds to provide an uneven cover and packed by drifting to provide better heat transfer.

GLACIERS AND GLACIAL DEPOSITS

Alaska is the site of most glacier ice and all of the large glaciers in continental North America. The $132,000\text{ km}^2$ of glaciers in this state comprise 66% of the glacial ice on the continent. Valley glaciers, intermont glaciers and piedmont glaciers are present. The valley glaciers range in size from less than a kilometer to the larger Hubbard glacier, 120 km in length. Malaspina Glacier is famous as the classic piedmont glacier, an enormous ice mass covering an area larger than the

state of Rhode Island. Glaciers are most numerous in southern and southeastern Alaska, are well developed in the Alaska Range, but are uncommon in the Brooks Range (Figure 6).

Glaciers have covered about half of Alaska at one time or another, leaving deposits that form terrain which ranges from hummocky knob and kettle areas deposited by glacial advances of Wisconsin age to subdued rolling areas formed by much more ancient advances of glaciers. The glacial advances of Illinoian and early time were considerably more extensive than those of Wisconsin time, especially in the south and the west. During the Quaternary period, glaciers were much more extensive in southern Alaska than in northern Alaska and much more extensive on the south flanks than on the north flanks of individual mountain ranges (Figure 6). This indicates that the glaciers were nourished chiefly by air masses moving northward or northeastward from the northern Pacific Ocean.

PERMAFROST

Permafrost, or perennially frozen ground, is defined as soil or other surficial deposit, or even bedrock, which has had a temperature below freezing for two or more years. Permafrost is defined exclusively on the basis of temperature, irrespective of texture, degree of induration, water content or lithologic character. About 25% of the land area of the world is underlain by permafrost. Perennially frozen ground is present throughout most of Alaska (Figure 7), but it is more widespread and extends to greater depths in the north than in the south.

In the continuous permafrost zone of the northern part of Alaska, permafrost is almost everywhere present and extends to a depth of as much as 105 m. In this area, away from large bodies of water, the temperatures of permafrost at depths of 15 to 25 m are colder than -5°C (15 to 25 m is the maximum depth to which appreciable annual temperature fluctuations penetrate the ground). The coldest permafrost temperature recorded in Alaska is -10.6°C near Barrow.

Southward, in the discontinuous permafrost zone of Alaska, the thickness of permafrost decreases and unfrozen areas are more and more common, until near the southern boundary only occasional patches of permafrost exist. The temperature of

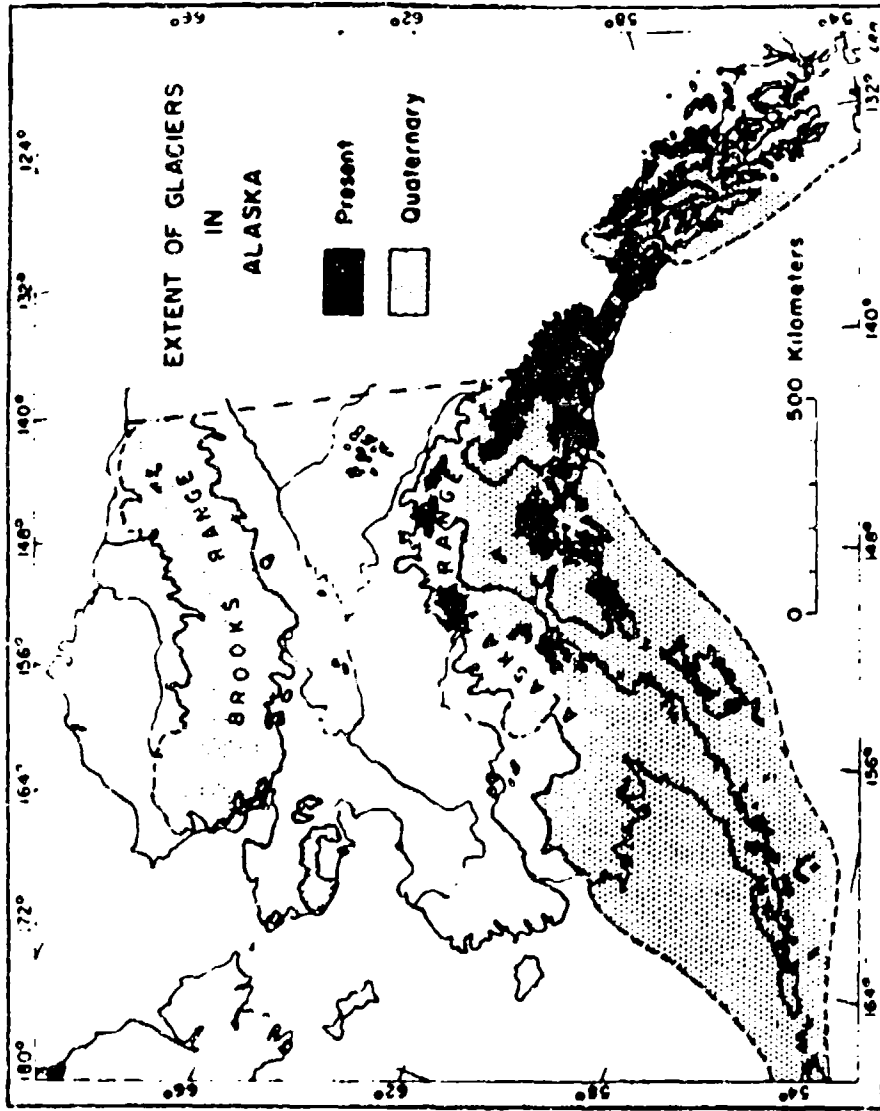


FIGURE 6

Extent of Quaternary glaciations in Alaska. (After Coulter, Hopkins, Karlstrom, Fewe, Wahrhaftig and Williams (2) in press.)

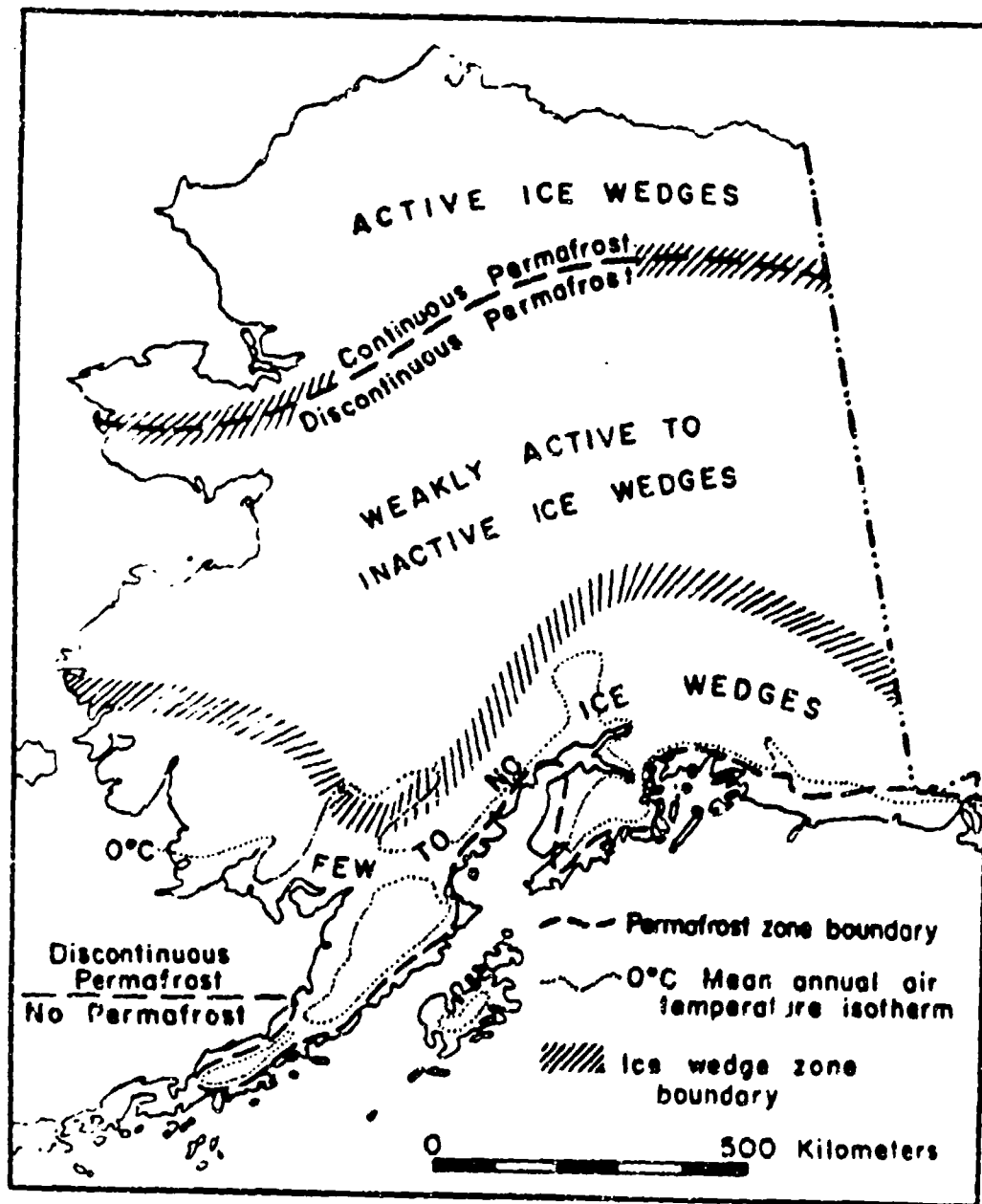


FIGURE 7

Distribution of ice wedges and permafrost in Alaska. (Compiled by Troy L. Péwé.)

permafrost at depths of 15 to 25 m in this zone ranges from -5° C in the northern part of the zone to approximately 0° farther south.

The ice content is probably the most significant feature of permafrost affecting life in the north and providing evidence concerning past climates. The most conspicuous type of ice in the perennially frozen ground is the large ice wedge or mass that has a marked foliated appearance and that forms in contraction cracks in the frozen ground. Foliated ground ice masses (ice wedges) are ubiquitous and actively growing in all types of unconsolidated material on the Arctic Coastal Plain of northern Alaska (Figure 7). They are common in central Alaska and the Seward Peninsula but are limited there to perennially frozen organic-rich silt. For the most part, the ice wedges in central Alaska are no longer actively growing. No ice wedges have been reported from the Yukon-Kuskokwim Delta or Bristol Bay area, and only one exposure is reported in the Copper River basin.

VEGETATION

The present-day vegetation of Alaska consists of three major types: the coastal spruce-hemlock forests of southeastern and southcentral Alaska, the interior white spruce-birch forest of central Alaska, and the tundra of western and northern Alaska (Figure 8).

The coastal forests extend a few tens of kilometers inland along the coast of southeastern and southern Alaska westward to Cook Inlet and northeastern Kodiak Island. In addition to the Sitka spruce and western hemlock, the coastal forest includes mountain hemlock, Alaska cedar, lodgepole pine, Douglas fir and smaller areas of alpine fir, Pacific silver fir and western red cedar.

The interior forest is distributed today through most of central Alaska north of the coastal mountains and south of the Brooks Range. In addition to white spruce and birch, other common species are black spruce, balsam poplar, aspen, larch and willow. Various species of alder grow in both forest areas as well as in tundra regions.

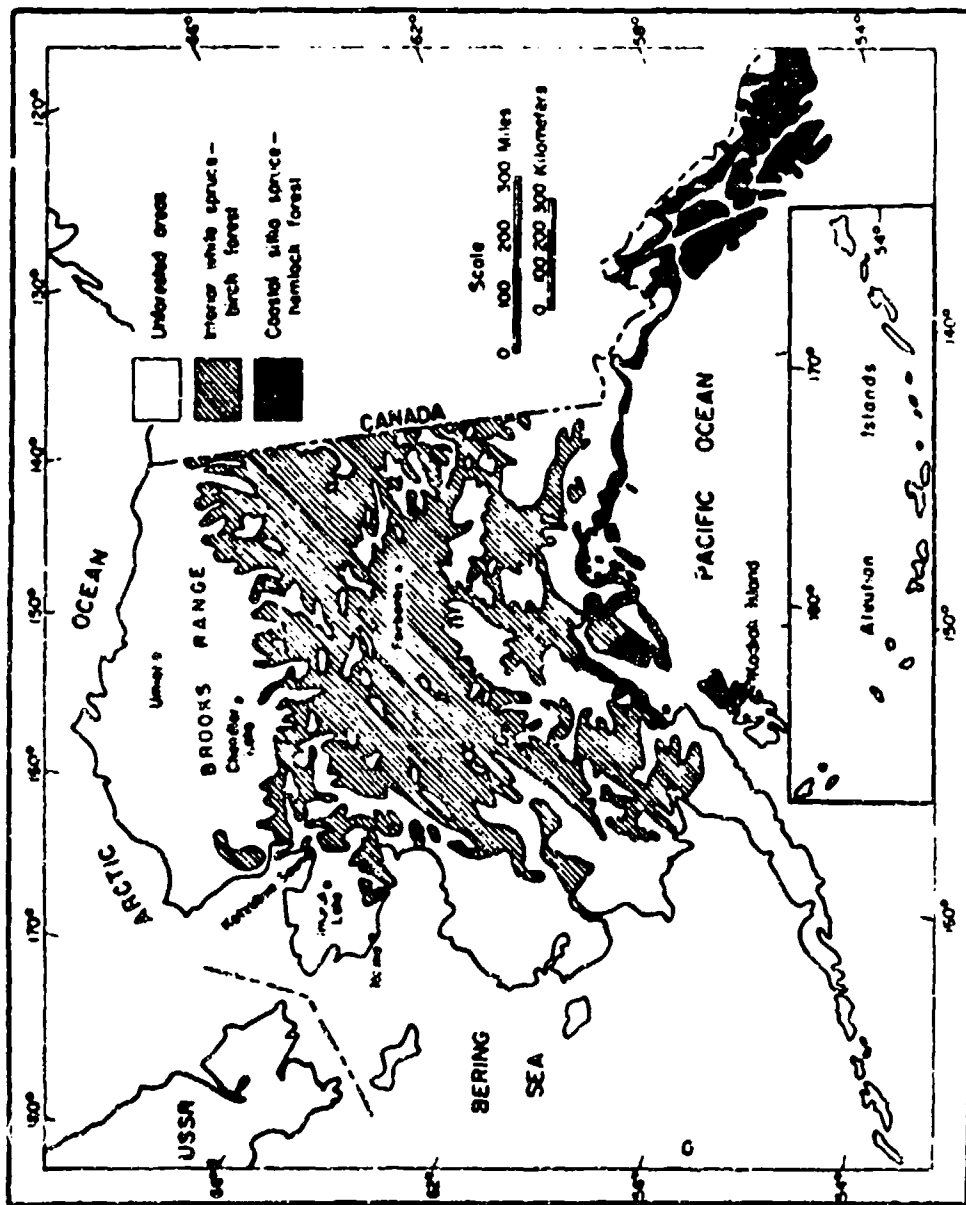


FIGURE 8
 Generalized map of major forest types and unforested areas in Alaska.
 (After Sigafos (11) 1958 and Hopkins (5) 1959.)

The tundra is found beyond the latitudinal limits of forest in central and western Alaska, in highland areas above the altitudinal limits of forest in central and western Alaska, and in highland areas above the altitudinal forest limits in southern Alaska. Tundra covers approximately 25% of Alaska and is a mosaic of many different sorts of vegetation, some of which are limited to either southern or northern tundra regions.

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MAJOR ARMY OPERATIONAL PROBLEMS IN COLD REGIONS

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The United States Army can conduct effective military operations in northern areas with the means currently available. While these operations are effective, they are far from optimum in terms of economy, efficiency or speed of response. The scientist can do much, within his individual discipline, to improve the Army's capabilities. It will be noted that many of the problems identified in this paper are also problems to other governmental and commercial agencies operating in northern areas.

The definition of northern areas used by the Army is keyed to 50° F isotherm (Figure 1). All areas lying north of the imaginary line connecting points at which the mean summer temperature during the four warmest months does not exceed 50° F are considered to be northern by this definition. Similarly, military operations at below -25° F are also considered to be conducted in the northern environment. The physiological and sociological problems encountered in the environments where these temperatures are experienced are at least equally as important as the temperature itself.

United States Army, Alaska, operating within the 49th State, is responsible for the identification and documentation of the principle, policies and concepts (doctrine), as well as associated qualitative requirements for materiel, for the conduct of operations in northern areas. Dr. Péwé, of the University of Alaska, presents elsewhere a comprehensive description of the Alaskan environment. However, it should be borne in mind that the U. S. Army is interested in all northern areas, not just Alaska.

Northern operations in vast, sparsely populated and culturally underdeveloped areas are characterized by small military formations operating independently or semi-independently. In winter, when the conditions for ground mobility are best, the extremely low temperatures pose serious problems to both the men and their equipment. In summer, when temperatures are more temperate, ground mobility is seriously curtailed by the generally saturated soils with low bearing strength which cover tremendous

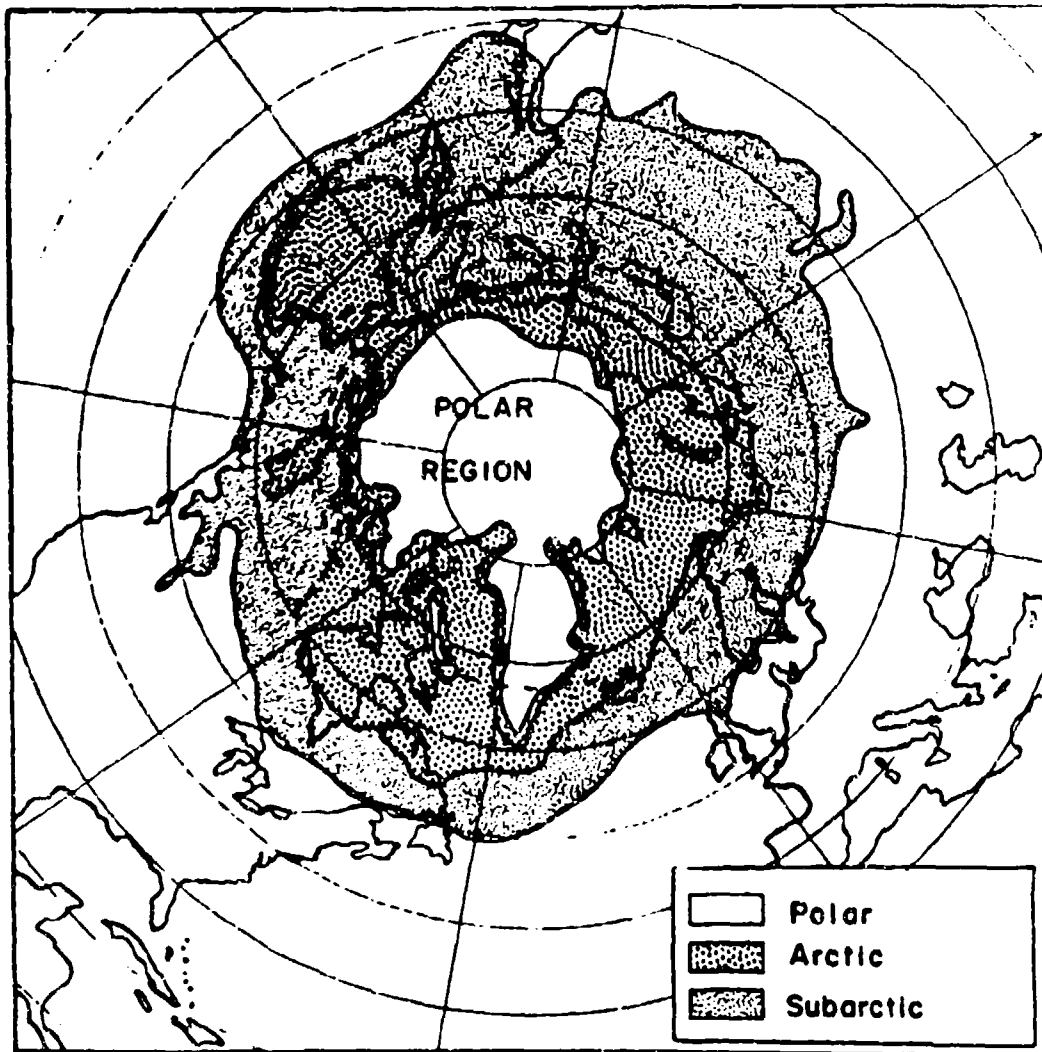


FIGURE 1

The northern area of operations includes Polar, Arctic and Sub-Arctic regions. The 50 degree isotherm is the southern boundary of the Sub-Arctic.

areas in both North America and Eurasia. Present solutions to these problems are crude and inefficient. In winter, a man must wear or carry almost 50 lbs of clothing just to keep warm. He must have his double sleeping bag near at hand to stay alive if he must sleep without shelter. Shelter itself leaves much to be desired in terms of weight, and ease of erection and striking. Necessary heaters consume tremendous quantities of fuel. Combustion products produce ice fog, which limits visibility and often reveals positions to an enemy. Vehicles and weapons designed for use in temperate, and even tropical, climates function inefficiently or not at all in extreme cold. Movement is restricted to existing roads, new roads built at tremendous expenditure of time and construction effort, or expensive, and often inadequate, air transport.

As both commercial enterprise and private individuals have amply demonstrated in Alaska, air mobility presents the most attractive capabilities for movement over areas where there are few roads. The 11th Air Assault Division, at Ft. Benning, Georgia, is currently experimenting with various types of military operations in which mobility is provided almost exclusively by Army aircraft. Many of their findings will be especially applicable to military operations in the North. Yet there are problems, over and above the fundamental one of cost.

Aircraft must perform effectively and responsively in the extreme cold of northern winter. Improved engines and lubricants are required. We cannot willingly accept the cost, in time and manpower, of our current requirement of almost two hours of preheating per aircraft when starting up at very low temperatures, or the extensive "down time" for maintenance. The gas turbine is vastly superior to the piston engine in this respect. Direct-reading navigational equipment, including terrain avoidance devices, are essential for operations which cannot be delayed by periods of low visibility, which are common in northern areas. The electromagnetic characteristics of northern areas, as well as the extremes of temperature, contribute to the difficulty of solving these problems economically.

As attractive as air mobility is, it solves only a minor part of the Army's mobility problems. In the last analysis, wars are fought between men and for the control of man's productivity. Man lives and moves on the ground. Military engagements between men will always involve some land locomotion, even if it is restricted to final assault and mop-up activities. In the foreseeable future, land locomotion requirements will be

considerably more extensive. The more favorable procurement and-operating cost to load-carrying factors of even the more sophisticated land vehicles will make them preferable to aircraft for many years. Even when employing airmobile forces, some operations are more effectively conducted on the ground, with extensive radii of operation from the base. It does not matter whether or not the base is an airhead.

To achieve a suitable ground mobility capability in the immediate future, research and development must be pointed toward cheap, simply maintainable, high performance, tracked vehicles with sufficient versatility to operate effectively on roads, where they exist, and over the low-bearing-capacity soils and snow of the North. Wheels operate effectively and cheaply when they can find footing with sinkage less than one-third of their diameter. This sinkage is frequently exceeded in the North, and only tracked vehicles can operate effectively under these conditions. Yet the tracked vehicles which negotiate extremely soft conditions most efficiently are poor performers on hard surfaces. The compromises of current armored vehicles are more effective over the soil conditions and road nets of the temperate zone than they are over the conditions of both the North and the Tropics. Further, the ponderous mass of armored vehicles limits their efficient movement by heavy aircraft, or even movement over the conventional roads and bridges that may exist in northern areas. Military units equipped with wheeled transport are severely restricted in movement. Those equipped with current tracked vehicles are more mobile, but their mobility is far from optimum.

An obsolescent, but still employed, heavy tracked cargo carrier is the M-8 Cargo Tractor. This vehicle, designed originally as a tractor for towed artillery, weighs 55,000 lbs and has a ground-pressure of 8.3 lbs per square inch. In muskeg or deep snow it must bulldoze its way, depending upon its ability to find footing at an acceptable depth beneath the surface. This requires tremendous power. Fuel consumption is excessive.

In an effort to improve its off-road mobility, U. S. Army Alaska purchased a fleet of commercial Nodwell carriers. These vehicles weigh 11,000 lbs. They carry an 11,000-lb cargo load efficiently over muskeg and are reasonably effective in deep snow. For 5 tons of airlift weight, the user gets a 5-ton lift capability in an airhead. An amphibious version of these vehicles is currently (1964) under test at the U. S. Army Arctic Test Center. But for all of these advantages, a price is paid in per-

performance on hard ground or roads. Top speed is limited to about 15 mph. And at these speeds, vibration causes severe damage, resulting in high maintenance requirements. While it is a most effective special-purpose vehicle, the Nodwell is not the solution to the more general requirements for effective military vehicles.

The most promising general-purpose tracked cargo carrier for the immediate future is the XM-54E1 6-ton Carrier. It is not the optimum vehicle, yet it illustrates the variety of characteristics which should be satisfied by any vehicle for military use. This carrier, initially developed as an ammunition carrier to accompany modern self-propelled artillery, is produced by the FMC Corporation. Its engine, drive and suspension systems are identical with the M-113 Armored Personnel Carriers used extensively in the Army today. Numerous other special-purpose vehicles have been developed using the same components. On-road movement is excellent. Fuel economy is acceptable. Off-road movement in the North is practical under many conditions, more nearly approaching the extremes than any other standard vehicle. From a supply and maintenance point of view, it is ideal, as the most vulnerable parts and systems are common to other standard vehicles, and parts are readily available. Nevertheless, it is still a compromise vehicle, which does not provide the full range of capabilities required.

One of the greater problems of mobility in the North is the means of accomplishing, in this environment, the multitude of tasks performed by the 1/4-ton truck, or jeep. Even the newer models of the jeep do not have sufficient mobility to be effective under enough of the common trafficability conditions in the North. It is interesting to note that the unofficial yardstick of mobility for light tracked carriers is the Weasel, a vehicle designed and built over 20 years ago. The Weasel was a good vehicle in terms of mobility. It was not so good in terms of weight, cost and ease of maintenance. We have been looking for a replacement for many years. At present there are three possible replacements, though none of them serve all requirements.

For general use in conventional environments, the M-114 Armored Reconnaissance Vehicle has been developed. Obviously this is a combat vehicle. We have some here in Alaska and find that they do operate over many of the surfaces which would stall the jeep. However, they are much too heavy and bulky for practical movement by air, other than in heavy transport aircraft.

For general cargo-carrying in the North, we have the M-116 Amphibious Carrier. This vehicle was built to be a replacement for the Weasel. However, the M-116 is a 1-1/2-ton carrier, whereas the Weasel had only a 1/2-ton capacity. The M-116 is a good vehicle, but is too large and heavy for airlift in Army aircraft. This prevents its practical use in short-range or small scale airmobile operations.

Now under test at the U. S. Army Arctic Test Center is the Canadian-developed XM-571. This highly mobile articulated carrier also was developed to meet the requirement originally met by the Weasel. It came closer. It has many good features, including lighter weight than the Weasel or the M-116. It can be carried in or by heavier Army aircraft, but it is larger than needed, having a 1-1/4-ton capacity. It cannot be carried, even disassembled, by the light helicopters which will be most generally available for airmobile operations. It is a fine vehicle, but whether it will pass the test of sufficient increase in capability over the current standard vehicle, the M-116, to warrant the cost of procurement is a matter still to be decided.

Even if the XM-571 is standardized, it is not the ideal small carrier for northern operations. As with so many other military requirements, we want the greatest capabilities for the least cost. We want an inexpensive tracked cargo carrier, of 1/2-ton cargo capacity, which can go almost everywhere the Infantry can go on foot. We want this vehicle to weigh less than 1500 lbs, if possible, with an absolute maximum curb weight of 2500 lbs. We would like this vehicle to float, by itself or with "water wings." It must be able to move over smooth, level terrain at a speed of at least 15 mph. We would like it to move over roads at least at 25 mph, though we would ease up on this requirement if it could easily be stacked on conventional trucks or tracked vehicles when over-road movement is required. Several commercial vehicles come closer to meeting these requirements than the M-114, M-116 and XM-571.

The Nodwell RN-10, weighing 2350 lbs, is an amphibious muskeg-crosser. It has most of the advantages, and disadvantages, of its bigger brothers. It is not a good snow vehicle, though modification of the track might correct this.

The Thiokol 1401 is a 1600-lb vehicle which is rugged and versatile. Lack of speed, power and inherent floating capabilities are its greatest weaknesses, and these may be correctable. It is not an expensive vehicle.

The Bashaw TC-2, designed and built in Anchorage, Alaska, is a light, amphibious carrier with amazing capabilities considering its weight and cost. The 1200-lb test vehicle was underpowered and slow, but it carried the required load and was simple to operate. In quantity it should be cheap enough to make throw-away maintenance of many components a practical reality.

One reason that we are interested in these light load carriers is that the modern foot soldier, armed with the necessary modern weapons and ammunition and equipped to survive the northern winter, carries a load of over 100 lbs. While some of this load must always accompany the soldier, much of it can be carried for him if the carrier can stay reasonably close to him. Many of the more versatile and effective modern weapons are heavy, in terms of man-transport, and the volume of ammunition they can use imposes serious transport problems. If we are going to rely on mobility to get troops and weapons to the general objective area where the final battle will be fought on the ground, then the loads must be as light as possible. Heavier carriers, which will transport troops as well as their loads, are not practical in such operations. Light weight and economy offset the benefits of personnel transport. Troops can still move effectively on foot, on skis or on snowshoes, but not when they carry excessive loads.

So far, the mobility of general cargo and foot troops has been emphasized, but there are other mobility problems. Heavier weapons, such as artillery, must be as mobile as the troops they support. Air transportability is, again, a significant requirement for northern operations. U. S. Army Alaska has been using the Pack 75mm Howitzer for many years after it was discarded by the rest of the Army. It has the one advantage of being transportable by light helicopters. As a weapon, it has many weaknesses. The M-102 105mm Howitzer has been developed to replace this old weapon. Armed helicopters may be the answer in some situations.

All battles in northern areas will not require air movement of all of the forces in light Army aircraft. Many operations may be carried out using roads, or easily crossed terrain, where initial entry may be by sea or heavy airlift. Here light weight is less of a problem, within limits, than effective performance. As with cargo vehicles, fighting vehicles must have higher mobility than present tanks, artillery and personnel carriers. Again, wheeled vehicles are not versatile enough to be effective.

Before leaving the problems of mobility, it should be pointed out that many of the rivers in the North represent practical routes of communication, particularly for heavy cargo loads. Most of the problems of developing practical river transport for military use are common to all environments. Much is being done to improve propulsion units to increase power and efficiency, particularly in very shallow water, while reducing noise. The hydro-jet drive is of particular interest. But one problem, particularly vexing in the glacial streams of the North, is the extreme erosive qualities of silt, which quickly wears out pumps. Development of inexpensive wear-resistant metal parts for jet pumps and venturies is needed.

There are other serious problems in the North besides mobility. Shelter is a particular problem, especially in winter. We need better shelter which is easier to transport, erect and strike than that we have now. We must reduce the variety and quantity of pins, poles, ropes, axes and mauls now needed to erect it.

Rations are a problem. The seriousness of this problem varies almost inversely with the size of the unit to be fed. Large units, with effective kitchen equipment and adequate water supply, have the fewest problems. Shelter is essential, for preparation and washing as well as for eating. The smaller units, now dependent upon the "C" ration or freeze-dried rations, have greater problems, particularly in obtaining the required water. Small units and individuals who must carry their rations with them do not have a good trail ration. The nature of operations where a trail ration is required almost precludes procurement of adequate water supplies in winter. Frequently it is tactically impossible to provide sufficient heat for preparation, making dehydrated rations impractical.

As was previously mentioned, a soldier now has about 50 lbs of clothing to keep him warm in winter. A new universal clothing system being tested may help to reduce this—to about 40 lbs. While better, this is still more weight than we desire. We are most interested in the Thermalibrium Suit, an air-conditioned uniform suitable for all climates, which will weigh not over 20 lbs, including the power-pack and fuel for 8 hours or more. The current problem area is the power source. Continuing effort in developing cheap, efficient fuel cells which use standard fuels is essential if this concept is to be achieved.

Fuel itself is a major problem in northern winter operations. Military vehicles consume vast quantities of fuel even in temperate areas. In the North these requirements increase by as much as 25%, as vehicles must be kept running longer. Great quantities of fuel are consumed to keep personnel and sensitive equipment warm. Transportation of this fuel requires more than 1/2 the total cargo capacity of support units. Much has been done to provide flexible tankage for storage and transport. Efficient Rolling Liquid Transporters have been produced. We need practical flexible pipelines, which are light in weight and easily installed, to supplement or replace vehicular transport. Standard pipelines are too bulky and expensive to support the tactical units operating over the vast areas of the North, though they are practical connections from ports to main base complexes.

Fuel problems can be further simplified, through research and development, by making fuel-consuming devices less discriminating in the type of fuel required. Reduction of the variety of fuels now needed for ground vehicles and aircraft will simplify storage and shipping problems.

Heaters are a large consumer of fuel in northern winter. Greater efficiencies, in terms of effective heat where it is needed, will further reduce fuel problems while improving effectiveness of men and equipment. Practical radiant heaters are needed to permit better use of the hands of mechanics and others who cannot perform their tasks in the open when wearing heavy gloves or mittens. Perhaps electricity, generated conventionally or by electro-chemical cells of new design, may be the most practical and flexible source of heat for many purposes.

There are many construction problems in northern areas, most of which are well identified. One type of construction, tunneling, has had little emphasis, as conventional methods are notoriously expensive and slow. Of interest in this connection are the permafrost tunneling experiments currently underway (1964) by the U. S. Army Cold Regions Research and Engineering Laboratory at its Field Station at Fox, Alaska. They are testing a tunneling machine which digs a 7-1/2 by 15 ft hole, at rates in excess of 1 ft per minute. It appears to have good potential for hard-rock tunneling, as well as excavation of softer materials. In these days of potential nuclear, chemical and biological warfare, methods of rapidly constructing underground shelters would add a new dimension to defensive warfare.

In summary, the Army's requirements in northern regions can be listed under nine basic categories, some of which have been discussed in this paper and some of which are conspicuous by their absence.

1. Continuation and extension of research on the subject of trafficability. This is not only to define the problems, but to come up with rapid and economical means of improving trafficability as an alternative to development of sophisticated cross-country vehicles.

2. Research to improve over-all mobility. Our optimum ground vehicles should have cross-country capabilities even better than those we can obtain now with the best tracked vehicles, while obtaining the efficiencies of operation on roads and the economy of maintenance now found only with wheels.

3. Development of materials, and the means to use them economically, which will overcome the shortcomings of present materials when exposed to the extremes of cold encountered in the North, and which will continue to function over the wide ranges of temperature encountered in northern winter. Seasonal or daily variations in temperature of from 60 to 80 degrees are common. A variation of 111 degrees within 48 hours was recorded at Fort Greely during Exercise "Great Bear" in 1961.

Specific problem areas include: structural materials, lubricants, tires, fabrics, electro-chemical systems and plastics.

4. Identification of human factors which inhibit operations in extremes of climate, and the means to overcome them. Physical and emotional stress and fatigue create problems even in temperate environments. These problems are amplified under the harsh conditions of northern winter, to the point that the will to learn and apply the necessary techniques of survival and operation are seriously impaired. Remember that the average soldier does not have the same motivation to overcome problems that is found in frontiersmen, prospectors, explorers and other special groups of people who regularly operate in the North.

5. Continuation of research on permafrost and the means to overcome the problems it presents. These problems affect field operations as well as permanent construction.

6. Control of ice fog. This is necessary to improve visibility during operations, reduce camouflage problems and increase our capabilities of deception.

7. Excavation in rock and permafrost. This is vital for construction of field fortifications and protected storage, as well as for the production of construction materials. The tunneling work now underway by the Cold Regions Research and Engineering Laboratory in Fairbanks could produce an entirely new capability for protective construction in the battle zone, not only in the North but everywhere. On a smaller scale, such devices might provide a practical method of producing construction aggregates in winter.

8. Increased knowledge of the capabilities, limitations and effects of explosives and demolitions (both conventional and nuclear) in northern areas. Practical improvements are needed in dealing with the effects of conventional ammunition, as well as improvement of our ability to create barriers.

9. Improvement in reconnaissance capabilities to permit rapid evaluation of routes, positions and potential barriers. The work now underway, by the U. S. Army Cold Regions Research and Engineering Laboratory, on the use of infrared rays to detect potential ice-crossing conditions on the frozen streams and lakes is part of this requirement. But the vast areas of the North present impossible conditions for effective reconnaissance with conventional ground methods.

Finally, U. S. Army Alaska is interested in everything that will improve our capabilities for northern operations. Our ultimate goal is to make these operations comparable to operations in temperate zones with an absolute minimum of adaptation of means. Research which will make it economical to build basic cold weather capabilities into all military equipment will do much to reduce the cost and complexity of the kits and special purpose equipment which are now required. We feel that only by this means will we be able to operate and fight in northern regions better than any potential enemy.

MATERIALS ENGINEERING FOR COLD REGIONS AND THE BRITTLE FRACTURE PROBLEM

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INTRODUCTION

The U. S. Army has a long historical interest in the effect of cold environments on materials used in military equipment. During World War II the Army's low temperature materiel and materials problems were pointed up in the winter tests of 1942-43 at Camp Shiloh in Northern Manitoba. Military equipment problems associated with cold regions were further underlined as a result of the very recent U. S. Army winter exercises "Great Bear" and "Timberline." The requirements for materials able to withstand unusually cold environments are still further emphasized by the inclusion of a climatic category with a lower limit air temperature of -80° F in U. S. Army Regulation AR 705-15, C1 dated 14 October 1963 ("Operation of Materiel Under Extreme Conditions of Environment"). Even without the problem of ambient climatic conditions, the advent of Army missiles and rockets powered by cryogenic fuels imposes requirements for materials which retain good mechanical properties down as low as -423° F, the temperature of liquid hydrogen.

When subjected to low temperatures, most engineering materials show a substantial loss of the useful structural properties possessed at ordinary temperatures. Although wood, ceramics and glass are virtually unaffected by extreme cold, the more important classes of engineering materials, namely metals, rubber and plastics, are indeed subject to mechanical failure. Cold regions also impose lubricant problems. Rubber materials generally lose flexibility at low temperatures and become hard and brittle, although many of the newer synthetic elastomers retain flexibility down to extremely low temperatures. Most plastics harden and embrittle, and will fracture on shock loading or impact at low temperatures. Most structural metals, particularly the steels, are subject to catastrophic brittle failure in cold environments. Since metals constitute the largest tonnage usage

of engineering materials by the military, discussion in this paper will be addressed primarily to that class of materials. Rubber, plastics and lubricants, however, will be discussed briefly first.

RUBBER

Cold regions adversely affect the serviceability of rubber components of military equipment, such as tires, inner tubes, cable, hose, bushings, seals, etc. The low temperature effects of greatest concern include changes in flexibility, changes in compression-set characteristics and the development of brittleness.

The distinct changes that may occur in rubber at low temperatures can be classified as: simple temperature effects (visco-elastic effects); first-order transitions (crystallization); second-order transitions (vitrification); and effects associated with plasticizers. Simple temperature effects are manifested by loss of resilience, increase in modulus and increase in hardness. First-order transitions are time dependent and may require periods ranging from hours to months; they are accompanied by changes in hardness, volume and coefficient of thermal expansion, in addition to increased stiffness. Second-order transitions are exhibited by all elastomers and occur quite rapidly within a narrow temperature range. Elastomeric materials ordinarily become unserviceable due to simple temperature effects well above the second-order transition temperatures. When rubber compositions are highly loaded with certain plasticizers, time effects not necessarily associated with crystallization may be evident. Low temperature flexibility may be improved by the addition of selected plasticizers; however, this is usually done at the sacrifice of other properties, such as tear and abrasion resistance, and bondability.

Although rubbers that retain rubber-like properties at very low temperatures (see Table I) are available for use in cold regions, continued research is needed on new elastomers having broad versatility. Current low temperature rubbers, for example, do not possess adequate chemical resistance for use in hoses that must handle fuels, hydrocarbon oils, hydraulic fluids and lubricants. Rubber fuel hoses stiffen and break at low temperatures because the fluids extract compounds from the rubber that impart the original low temperature qualities. A fruitful

TABLE I
RELATIVE LOW TEMPERATURE CHARACTERISTICS
OF SOME ELASTOMERS

Type	Typical Brittleness Temperature (° F)	Temperature Range for Rapid Stiffening (° F)
Neoprene	-40	+10 to -20
Butyl	-50	0 to -20
Natural Rubber	-65	-20 to -50
Styrene-Butadiene	-75	-50 to -60
Polyurethanes	below -90	-10 to -30
Silicones (General Purpose)	-90	-65
Fluorosilicones	-90	-75
Silicones (Extreme Low Temp.)	-150	-105

area of further research probably lies in synthesis of elastomers based on modified polyurethanes and fluorinated silicones.

PLASTICS

The strength of plastics increases as temperature decreases. However, the ductility of nearly all plastics decreases in cold environments. Many classes of plastics can be used successfully at temperatures down to -40° F provided they are not subject to shock loading. Polyethylene, a thermoplastic polymer, remains tough at temperatures as low as -100° F and has considerable utility for military use. At extremely low temperatures only the fluorocarbon plastics, e. g. polytetrafluoroethylene (Teflon) and polychlorotrifluoroethylene (Kel-F), retain useful ductility. The fluorocarbon plastics possess unusually good chemical inertness and other advantages, but they are costly.

Further study is needed on the fundamental factors affecting the mechanical behavior of plastics and on developing a broader range of plastics for use in cold regions. There is also need for development of high strength structural adhesives with sufficient elasticity and bond strengths for use in fabricating composite structural materials for service in cold regions.

LUBRICANTS

In cold regions serious vehicle lubrication problems are frequently encountered, although undoubtedly many difficulties can be avoided by strict adherence to lubrication orders and engine maintenance procedures. Commercially available engine lubricants and gear lubricants, covered by military specifications, are useful down to at least -65° F. Available instrument greases are useful down to at least -100° F. Solid film lubricants based on molybdenum sulfide or polytetrafluoroethylene offer excellent serviceability in certain applications and can provide lubricity down to cryogenic temperatures. Although tremendous advances have been made since World War II in development of improved low temperature lubricants, continuing

research is required, for example, on low temperature engine lubricants. Some low temperature synthetic engine lubricants, having excellent viscosity and lubricity characteristics, require further development because they may not possess good compatibility with seals and bearing materials.

BRITTLE FRACTURE OF METALS

Sudden and frequently catastrophic metal fractures in which low temperature environment has been a contributing factor have occurred in large cannon, armored structures, rifles, mortars and bridging equipment, and more recently, in motor cases, hydraulic accumulator components and support hardware of missile systems.

Early records of cannon failures showed that most gun ruptures occurred during the winter months, or in other seasons during the first round of the day when the weapon was coldest. Metallurgical factors were not fully understood in those early days, and failures were sometimes diagnosed as "overpressure," "barrel obstruction" or "premature shell explosion." The Army first recognized the important influence of low temperatures on metallurgical behavior as a result of research on notch bar impact tests on steel during World War I at the U. S. Army Materials Research Laboratories (then Watertown Arsenal Laboratories). Army research on the behavior of materials at low temperatures and the recognition of special requirements of steel, particularly for guns and armor, have accelerated since the beginning of World War II.

It is now recognized that the significant effect of cold environments on the mechanical behavior of metals is the tendency to induce brittle failure. It is also acknowledged that metals may fracture suddenly in a brittle manner even in ordinary temperature environments. Thus, to fully understand the factors affecting the behavior of engineering metals at low temperatures, it is essential to rationalize the more general phenomenon of brittle behavior, which is a subject of considerable scientific interest and has wide practical implications. Basic aspects of this complex problem are not completely understood, although progress is being made toward developing criteria for evaluating materials in terms of their tendencies to resist brittle failure. The remainder of this paper will be devoted to describing some

aspects of the brittle fracture problem, such as the concept of transition temperature, the influence of notch defects and evaluation of fracture toughness, with the purpose of conveying some appreciation of these concepts to those whose principal interests may not lie directly in the areas of metallurgy or materials engineering. A comprehensive presentation of the U. S. Army Materials Research Agency's views and current state of knowledge on materials behavior with respect to brittle fracture are contained in a recent technical monograph (4).

Transition behavior and crystallographic structure. With temperature decrease metallic materials actually become stronger, as reflected in higher measured yield strengths and ultimate tensile strengths. However, metals are also likely to develop lowered resistance to impact or shock loading and become dangerously brittle. Toughness or lack of it then becomes an overriding consideration, and an important governing factor is the so-called transition temperature range. This is the temperature below which a material behaves in a brittle manner, the mode of failure being primarily by a cleavage mechanism, and above which it behaves in a ductile manner, the mode of failure being predominantly by a shear mechanism. The transition temperature depends on a variety of metallurgical and mechanical factors; however, some qualified generalities can be made regarding the proneness of various classes of metals to ductile-brittle behavior. Metals with the face-centered cubic crystallographic structure (e. g., the austenitic stainless steels, aluminum, copper, nickel, lead, silver, gold and the platinum group metals) do not exhibit brittleness at any temperature (except when a second metallurgical phase is present). The body-centered cubic metals (e. g., most of the structural steel alloys and metals such as columbium, molybdenum, tantalum, tungsten, vanadium and chromium) display abrupt ductile-to-brittle transitions. Metals having the hexagonal close-packed structure (e. g., titanium, zirconium, magnesium, beryllium, cobalt, zinc and cadmium) characteristically exhibit low temperature behavior similar to that of the body-centered cubic metals. An important exception is that some high-purity titanium alloys display increased strength at low temperatures with little sacrifice in ductility.

Notch defects. The fact that the transition temperature of a metal is below the service or environmental temperature provides no guarantee against brittle failure. The presence of notch-type defects can exert a profound influence on susceptibility to low temperature failure of structural parts. The effects of

temperature and of notches are additive, in that the presence of notches can raise the transition temperature, and a wide variety of notch-type defects as well as geometry changes can initiate brittle fractures. These include keyways, holes, sharp fillets, threads, scratches, nicks, machining marks, corrosion pits, inclusions, tiny cracks, discontinuities, etc. The defect or notch serves to concentrate stresses so that, even though the nominal stress may be low, the local stress at the discontinuity is quite high. The high local stress of the notch initiates a crack, which under the proper conditions of temperature, metallurgical structure and section geometry can propagate rapidly, frequently at extremely high rates. Figure 1 illustrates schematically the effect of temperature on the notch strength of steel. Note that the notch strength can decrease to a very low percentage of the inherent tensile strength.

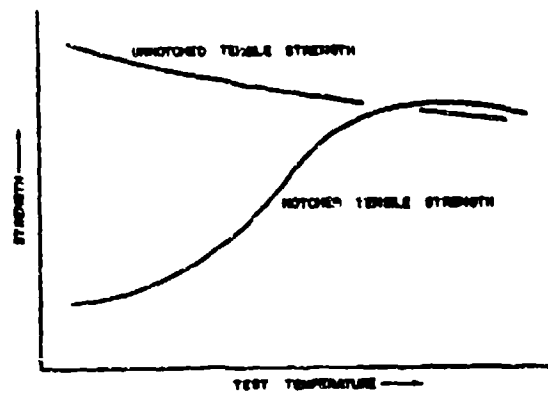


Figure 1. EFFECT OF TEMPERATURE ON TENSILE STRENGTH

Strain rate effects under conditions of complex stress states cause a marked increase in transition temperature. It may be of interest to describe how a biaxial stress results from the presence of a notch, for example a circumferential notch introduced in a simple tension bar. The metal at the bottom of the notch is under much higher longitudinal stress than the adjacent material because of the stress concentration factor, and due to Poisson's ratio it tends to contract strongly in the transverse direction. The surrounding material is under lower longitudinal stress and thus contracts much less transversely. Transverse contraction of the material immediately adjacent to the base of the notch is therefore restrained by the surrounding metal. Consequently, a transverse tensile stress is introduced on the material at the

base of the notch. Thus a biaxial stress exists at the base of the notch even though the external load is uniaxial. Biaxial tension tends to raise the transition temperature markedly and increase brittle behavior. Both effects, the effect of the notch in introducing biaxial stress and its effect on increasing strain rate, are in the same direction, with the result that the transition range in a notched part or test specimen is considerably higher than for an unnotched part. If in addition to a notch there is a high rate of loading by shock or impact, the increase in strain rate can be enormous. The strain rate in the Charpy notched bar impact test (which will be discussed later) is of the order of 1000 in/in/sec, which is ten million times greater than the strain rate in the usual static tension test. This tremendous difference in strain rate drastically increases the transition temperature of the material, and on it is superimposed the embrittling effect of the notch. Since notches and shock loads are often encountered in service, it is not surprising that a material that is tough in a static tensile test, even at low temperatures, may fail brittly in service.

In addition to the presence of the notch itself, the notch acuity and the critical length of cracks which propagate from notches are very important. The importance of notch sharpness on the strength of sheet steels can be illustrated by reference to Figures 2 and 3. The notch radius of the sheet tensile specimen shown in Figure 2 is 0.001 inch maximum, which provides a stress concentration factor (K_t) of about 18. If in a series of tests this radius is varied from infinity (an unnotched specimen) down to 0.001 inch, using specimens from two steels of the same strength level, one known to be notch tough and the other to be notch brittle, test data are obtained as typified in Figure 3. The presence of a dull notch (K_t from 1 to 6) actually strengthens both tough and brittle material. However, as the notch becomes increasingly sharper, the strength of the tough material becomes only moderately impaired, while the strength of the brittle material is severely lowered. For cold environments it is obvious that the tough material is to be preferred over the brittle one.

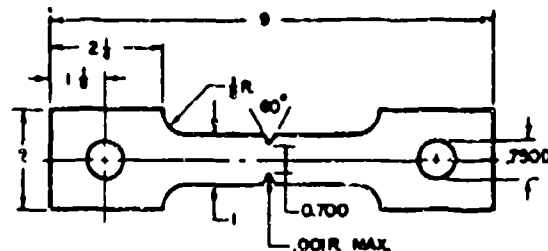


Figure 2. SHEET TENSILE SPECIMEN

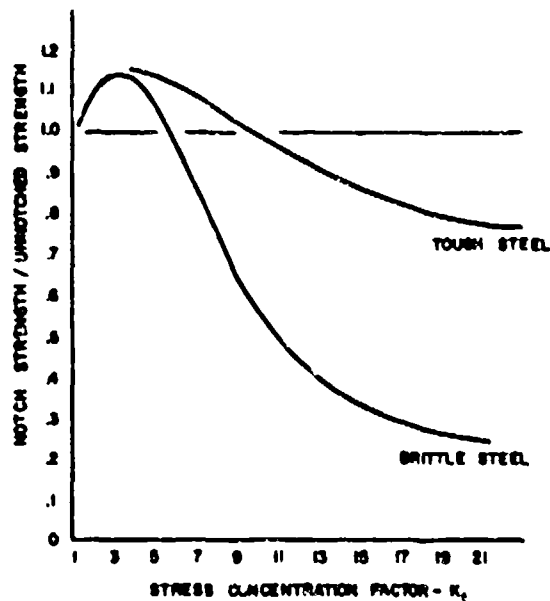


Figure 3. EFFECT OF NOTCH ON TENSILE STRENGTH

Metallurgical factors. The primary differences between tough and brittle steels derive from their microstructures. The microstructures in turn are dependent on composition, heat treatment and other processing conditions. This embraces the chemical, mechanical and thermal environments encountered during manufacture and fabrication. The inherent toughness of a material depends not only on the matrix, but also on the morphology and distribution of the phases which coexist with the matrix. In the absence of second phases, the general behavior of a metallic matrix is usually indicated by its crystallography, as pointed out earlier. Metals of the face-centered cubic system sustain only a gradual loss of toughness through a range of decreasing temperatures. Body-centered cubic metals undergo a transition from ductile to brittle behavior with decreasing temperature. Hexagonal close-packed metals generally behave similarly to the body-centered cubic metals. The exceptions to these generalizations are attributed to the degree of purity. High purity benefits the resistance to fracture by lowering, but not eliminating, the actual transition from ductile to brittle behavior. Additional phases in any of these three types of matrices exert an influence on the toughness. Thus, the inherent toughness of metallic materials is dependent on many factors.

Extensive data have been published in the literature on the effects of composition, heat treatment and work on literally

hundreds of different steels. A few steel compositional trends may be noted. In general, the so-called interstitial elements (carbon, oxygen, nitrogen and hydrogen) embrittle iron-base alloys more severely than the substitutional alloy elements. Nickel is one of the elements which exhibits the strongest effect in reducing the transition temperature behavior of low carbon alloy steels. The dramatic influence of nickel content is illustrated by the curves in Figure 4. It may be added that alloys containing above 8.5% nickel are suitable even for temperatures down to -320° F.

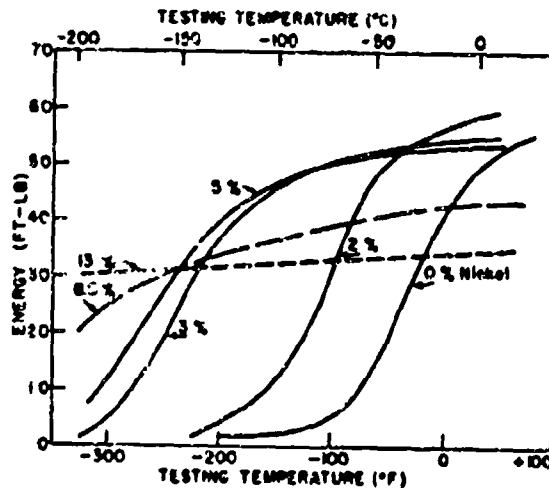


Figure 4. EFFECT OF NICKEL CONTENT ON TRANSITION BEHAVIOR OF A LOW CARBON STEEL (SAE HANDBOOK 1956)

Steels of greatest current interest to the Army are those which can be processed into sheet with engineering yield strengths well above 200,000 psi. Steels of this type, being considered, for example, in missile applications where good low temperature toughness is required, include the 18% niaging steels, the low alloy medium carbon group (such as 450 grade) and the austenitic stainless steels (such as Type 301).

Because of the high strength-density ratios that can be achieved with certain titanium alloys, this class of material also has considerable potential at low temperatures. One of the most promising alloys is titanium-5% aluminum-2% tin alloy having a so-called alpha hexagonal close-packed structure, which with adequate control of impurities, displays excellent high strength accompanied by good toughness and ductility even down to cryogenic temperatures.

Evaluating brittle fracture tendencies. Although a number of tests have been used for assessing brittle behavior of metals (such as the Izod Test, Explosion-Bulge Test, Schnadt Impact Test and many others), the most commonly used test method for determining transition temperatures and evaluating the toughness of metals is the V-notch Charpy impact test. A comparison of the low temperature behavior of different materials can also be made using notched standard round tensile specimens; however, the impact test is more widely used because of its greater simplicity.

The U. S. Army Materials Research Agency has had an identification with notch testing of steel at low temperatures which dates back several decades. Although today much remains to be learned regarding the fundamental significance of the test, use of the V-notch Charpy impact test has proven effective as a control test in specifications for materials intended for armor plates, gun tubes, breech blocks and other military items.

The Charpy impact test consists of placing a suitable notched specimen, supported on both ends, as a beam, and applying a single pendulum blow behind the notch. The energy of the pendulum is known before impact, and by determining the energy in the pendulum after impact, the energy used to break the specimen can be determined. The standard Charpy specimen is shown in Figure 5.

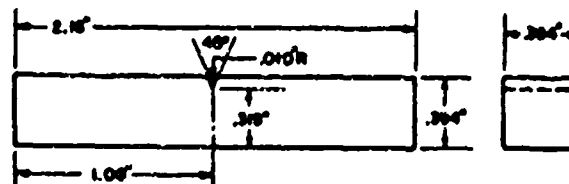


Figure 5. STANDARD V-NOTCH
CHARPY SPECIMEN

Results obtained by carrying out a series of impact tests over a range of temperatures are illustrated in Figure 6. Note that the energy decreases from a high level at the upper temperatures to a low value at low temperatures. Examination of the broken specimens shows that at temperatures where the material is tough, there has been considerable plastic deformation in the vicinity of the fracture, and the energy for this plastic deformation represents a considerable portion of the energy absorbed by the pendulum. At low temperatures, below the transition, there is little deformation in the vicinity of the fracture and low energy absorption.

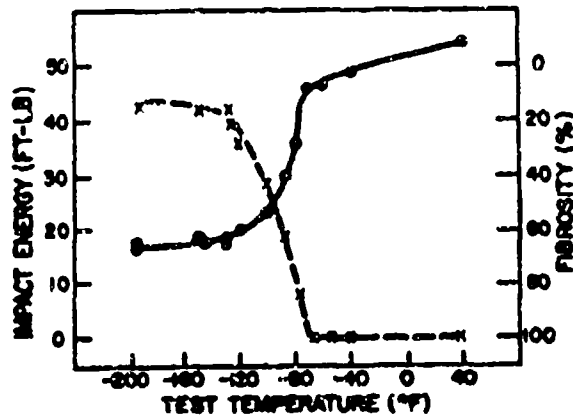


Figure 6. IMPACT TEST RESULTS

In addition to measuring the energy absorption, one can also obtain information from the appearance of the fracture surface. At low temperatures the fracture is crystalline, whereas at high temperatures the surface may appear fibrous. The percent crystallinity may be plotted versus testing temperature, and the decrease in energy absorption parallels the increase in crystallinity. For use in defining the transition temperature, either the percent crystallinity (as determined by examination of the fractured surface) or the energy absorption can be used.

The U. S. Army has been instrumental in sponsoring the adoption by industry of the Charpy impact test, through the existence of an impact requirement in specifications. While the quantitative value cannot be used directly in design, there is sufficient background to demonstrate its usefulness in predicting service behavior.

Despite its usefulness in assessing a wide variety of engineering metals, the Charpy test does have limitations. First, there is the size limitation imposed by the sheet materials coming into greater use. Another restriction is that the Charpy test becomes less sensitive for materials with strengths above 200,000 psi. High strength materials have inherently low toughness; consequently, a comparison must be made between relatively small numbers.

In the past few years, considerable interest has centered on study of fracture using notched flat tensile specimens. There are

several reasons for this. Since many new military components are made from thin wall or sheet materials, standard size Charpy impact specimens or round notch tensile specimens cannot be used, and some type of sheet specimen must be adopted. Concurrent with this increased requirement for sheet materials has been the development of the concepts of fracture mechanics which allow study of the crack propagation component of the fracture process and which entail the use of notched precracked sheet tensile specimens. The fracture mechanics approach holds considerable promise because it should provide a tool for the design engineer to more precisely predict the relative sensitivity of candidate materials to brittle failure. It also allows calculation of the maximum tolerable flaw size in components of engineering structures. The indices of fracture toughness determined by fracture mechanics are the parameter G_C , the critical crack extension force or the elastic strain energy release rate necessary to maintain a fast running fracture, and the parameter K_{IC} , the critical stress intensity or crack toughness index.

Special specimen geometries and special measurements are required to determine these parameters. Suffice to point out that edge notched or center notched sheet specimens are employed, wherein the actual crack is extremely sharp, resembling a natural crack, and is induced by controlled fatiguing in a tension-tension fatigue machine. The procedures and calculations are described in the findings of the American Society for Testing and Materials (ASTM) Committee on Fracture Testing, which issued its first report in 1960 (2) and its fifth report in March 1964 (3).

To obtain valid measurements for the fracture toughness indices, material must fracture before it undergoes general yielding, which means that the fracture mechanics parameters, although suitable for very brittle materials, are not equally reliable for the newer tougher high strength steels. For the tougher materials, the analysis of the elastic stresses requires modification to take into account the plastic action at the advancing crack tip. The ASTM consequently is not quite ready to prescribe an official recommended practice for fracture toughness testing until the fracture phenomenon is more thoroughly understood. For example, to obtain the K_{IC} parameter it is essential to measure slow crack growth prior to sudden fracture more accurately than by presently employed techniques (such as ink-staining or by estimating the shear fraction of the fractured surface). A phase of current research on fracture mechanisms at the U. S. Army Materials Research Agency includes study of this problem, and an improved method for measuring slow crack

growth has been proposed which involves determining the electrical potential difference between two points on either side of a notch as a function of crack growth (1).

Design philosophies regarding defects. Good notch toughness is essential for engineering materials for critical components intended for low temperature service. Steels, particularly the high strength sheet alloys, have varying degrees of notch toughness, and defects capable of triggering brittle fracture can be present as metallurgical defects or can be initiated during either fabrication or service. From a qualitative design standpoint, two general philosophies can be adopted regarding defects and brittle fracture susceptibility. One is to require that all components manufactured from high strength materials be constructed free from defects. The other view is that since it is virtually impossible to manufacture defect-free components from high strength materials, then high notch toughness in the material should be a prerequisite to its use in military structures. In theory, each philosophy is sound. The "no defect" philosophy assumes that solutions can be found for several very difficult production, fabrication and inspection problems. Since such problems remain to be fully solved on a practical basis, the second design philosophy is considered a much more rational one to follow within the present state of the art. Admittedly, a problem exists in specifying a test to insure adequate notch toughness so that many small defects can be tolerated in a structure without the occurrence of brittle fracture. As discussed earlier, an approach to this problem is being pursued using fracture mechanics concepts. Design based on the assurance of at least some degree of notch toughness is far better than design based on the assumption that a structure is completely devoid of defects.

SUMMARY

Most rubber and plastics materials lose flexibility and become dangerously embrittled in cold regions, although certain classes of these nonmetallic engineering materials are available which are serviceable even at extremely low temperatures.

Low temperature mechanical behavior of a metal can be correlated with its intrinsic crystallographic structure. In addition to crystal structure, factors such as chemical composition,

purity, heat treatment and processing variables influence behavior of metallic materials at low temperatures.

In cold environment, most engineering metals actually become stronger, but they lose ductility and become dangerously brittle. Thus, the major problem at low temperatures is brittle fracture. The presence of notch defects, particularly in the case of high strength alloys, plays a predominant role in contributing to sudden brittle fracture. The V-notch Charpy impact test has been used effectively as an inspection criterion for screening brittle materials for armor, cannon and other military applications. Additional research is required, however, to establish toughness criteria for thin-walled structures and for the newer ultra-high strength sheet materials. Parameters based on rational fracture mechanics concepts, although not yet adequate for specification standards, offer a promising design procedure for prevention of brittle behavior. With these tools, it should eventually be possible to select materials which are adequate for a critical structural application in a given climatic environment, or to specify a minimum acceptable value of toughness for marginal material.

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MILITARY CONSTRUCTION PROBLEMS IN ALASKA

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INTRODUCTION

Generally speaking, military construction problems in Alaska evolve around the following basic considerations: adaptation of standard design to Alaskan or arctic conditions; site access, survey, and mobilization of equipment and materials; foundation design; and limitations of a short construction season. Although the following remarks are based on construction experience in Alaska, they apply to cold regions in general. The milder areas, such as southeast Alaska, are not considered in this paper.

ADAPTATION OF STANDARD DESIGN

The use of standard design principles for housing, general-purpose buildings and other structures creates savings in design costs, construction costs and construction time. The use of standard designs by the Corps of Engineers is common in many places of the world. However, these designs are generally inadequate for the extremes of temperature and moisture encountered in many parts of Alaska. Special attention must be paid to providing greater insulation and vapor barriers in exterior wall construction. The U. S. Army Engineer District, Alaska, makes extensive use of vapor barriers in exterior wall construction, to minimize vapor entrapment within the wall and reduce deterioration of materials. In some areas in Alaska, temperatures may remain at -40 to -50° F for long periods, with an accompanying very low humidity. Normal humidity within a heated building can create considerable vapor pressures. A sudden rise in outdoor temperature after periods of low temperature leads to severe condensation on inner surfaces and frosting problems. To combat this undesirable condition, adequate ventilation of living spaces is required. This is also a variation from standard design,

which considers ventilation a necessity only for summer cooling. In Alaska, both forced air ventilation by means of fans and natural convection to the outside are utilized, depending on the conditions involved.

Other items in standard design which have to be altered in Alaskan construction include elimination of through-metal connections and metal windows. We have not found metal windows practical north of the Alaska Range because of icing. Through-metal connections transmit cold to interior surfaces, inducing condensation and frosting.

Standard design practices frequently call for flat roofs. Flat roofs were incorporated in the majority of buildings at one stage of the Alaska District's activities, primarily because of economy and simplicity of construction. Frequent failures of these roofs have led us to provide positive drainage by means of a roof slope. Since there are numerous successful flat roof installations in other states, their lack of success in many parts of Alaska is attributed to conditions peculiar to those areas. Unfavorable weather conditions and a short construction season are contributing factors. In installations using insulation as a base for built-up roofing, the vapor seal provided by the roofing traps moisture in the insulation, with consequent blistering and deterioration of the roof. Foot traffic on flat roofs frequently leads to rupture of the roof surface, inviting early failure. Bitumen with cold-flow and self-healing characteristics is essential for flat roof construction. Coal tar is the most durable bitumen for this purpose but is brittle at very cold temperatures and is not in general use in Alaska. Asphalt has not been found sufficiently durable to withstand constant ponding without deterioration. New materials to replace bitumen have shown promising results, but experience in their use is not yet extensive enough to draw any final conclusions. Certainly there is a need for the development of new materials to perform required functions under the extreme low temperature conditions frequently encountered in cold regions. We are continuing to incorporate near-flat roofs in our construction, using a minimum slope of 1/2 inch, and preferably 3 or 4 inches, to the foot.

CONSTRUCTION SITE ACCESS, SURVEY AND EXPLORATION

A glance at a map of Alaska reveals that its highway system provides access to a relatively small part of the state. The

Alaska Railroad reaches a small additional area. The perimeter is accessible by water, but in the northern areas this access is available only for a part of the year. During a portion of the year, areas along the Yukon and Kuskokwim Rivers can be served by river boats and barges. During winter, some areas can be reached by overland tractor trains. The remaining, and substantial, area is reached only by air. Many military construction sites are located in these remote areas, where the expense and difficulty of access, combined with a very short season, creates many construction problems.

Yet, much construction effort has been accomplished by the Alaska District in these areas. Detailed planning is necessary to insure that survey, design, and movement of equipment and materials are thoroughly coordinated so that maximum advantage can be taken of the construction season.

The first activity at any site for proposed new construction is survey and exploration. From the standpoint of efficiency and accuracy, survey and exploration should be accomplished during the warmer periods of the year. However, money for military construction is not appropriated by Congress until mid-year or frequently much later. By the time the money is made available through the several intervening headquarters, it is late in the year before the Alaska District has the authorization and can undertake design of specific projects. This situation poses no problems for solution by the scientist, but may seriously affect military construction in Alaska. Since design is contingent upon topographic surveys and soils and foundation exploration, these tasks frequently must be executed under any but desirable weather conditions. Design is ideally accomplished during the winter season and completed early enough to allow for advertising and awarding of contracts, procurement of equipment and materials, and movement to the site in time to take full advantage of the construction season.

FOUNDATION DESIGN

The investigation and design of foundations in areas of frozen ground must be separated into two categories, those in areas subjected to seasonal frost penetration only and those in areas characterized by both seasonal frost and permafrost.

Foundation investigations in areas of seasonal frost should be carried to a depth sufficiently beyond maximum frost penetration to assure reaching adequate subsoils. Essentially, foundation problems in Alaska in areas of seasonal frost are no different than similar conditions elsewhere. Designs for seasonal frost require footings below the depth of extreme seasonal frost or on a granular fill which extends below this depth. In general, the Alaska District uses a minimum of 6 ft below finished grade under heated structures in the Anchorage area and 10 ft in the Fairbanks area.

The design of structures on or in permafrost requires special considerations. Thaw should not penetrate the foundation area to degrade or destroy the permafrost, thus allowing differential settlement of the structure. Close attention should be paid to preserving the permafrost by insulation or refrigeration. In the former case it is important to avoid heat transfer from the structure to the foundation, by such means as the elimination of through-metal connections, which transfer heat to the soil. Degradation of permafrost can be limited in some areas by the use of a ventilated foundation. In other areas it may be necessary to use a refrigerated foundation, utilizing mechanical or natural refrigeration. Mechanical refrigeration is generally not used because of higher initial costs and difficulties of continuous operations. Pile foundations are used frequently and have been successful if adequate penetration and loading are provided to prevent frost-jacking. Refrigerated piles, using natural systems, have been used in several projects constructed by the Alaska District. They include vapor-filled types, those using circulating glycol, and types depending on natural convection of low viscosity liquids. In all cases, a greater than normal amount of cold is stored in the foundation soil during the winter, to limit more effectively the thaw that occurs during the summer.

ROAD CONSTRUCTION

Military construction involves also road and airfield construction. The problems of snow removal and ice control should be considered in the initial design of all military roads in Alaska. These problems change greatly from one locality to another because of variations in wind velocities and direction, prevailing temperatures and precipitation.

Route selection should avoid areas of heavy timber growth and steep, precipitous terrain subject to snowslides. Temporary winter routes may be located along rivers where sufficient ice thicknesses are present to support military vehicles. Areas of warm, natural springs should be avoided. Search for sources of dry unfrozen sands and gravels should be made, and these may well dictate the choice of alternate routes.

Designs to alleviate snow problems should provide for high grades, wide rights-of-way, flat slopes, careful designation of borrow pit locations, and proper widths of roadway clearing and stripping. Proper disposal should be provided for debris resulting from clearing and stripping operations.

Grades should be kept above the general elevation of the adjacent land. If all roadbed surface elevations are held to a point 2 to 3 ft higher than the land on either side of the road, practically no snow will drift onto the traveled portion of the roadway; even wet packing snow will tend to clear off such surfaces. It is not necessary to have deep, dangerous ditches adjacent to the roadway in order to accomplish this snow-free type of road. Actually, less drifting will occur if the ditches are shallow with flat slopes than if they are deep and sharp.

A narrow right-of-way is a snow hazard. Vegetation, buildings, fences and other structures built entirely on private property cause serious snow-drifting on the roadway unless the right-of-way is wide enough that these drifts run out before they reach the traveled portion of the road.

Flat back-slopes and in-slopes aid materially in the prevention of drifting. Surface winds tend to follow up and down flat slopes and keep the snow moving. In the case of steep back-slopes, the wind tends to cut horizontally across the road, and the snow is dropped in the cut. Cuts with steep back-slopes are much more apt to become blocked with snow than cuts of exactly the same depth but with flat back- and fore-slopes.

Where the in situ material is suitable for the formation of roadway embankments, side borrow should be used. The borrow pits created by this type of construction are very desirable for snow storage. If successive storms occur with little melting of the snow between them, snow fences will fill up and road ditches will become clogged with snow blown in from the adjacent terrain or plowed from the road surface. Where such a condition occurs, a good, wide borrow pit is most useful. The snow from many

more storms can be handled in such a borrow pit before conditions become critical.

Items of geometric design to be considered are good alignment and gradients. The alignment should be the best possible, considering the topography in the area. Tortuous alignment should be avoided except in the most rugged terrain. Sharp horizontal curvature should be avoided and super-elevation reduced the minimum consistent with the design speed adopted for a particular road or highway.

Steep gradients should be avoided. A maximum ruling grade of 6% should not be exceeded where ice and snow are encountered, and if possible, all adverse grades should be reduced to 4%. Steep grades affect the safety of all traffic, promoting the jack-knifing of truck-trailer units and decreasing the ability of passenger-carrying vehicles to stop.

The top 2 ft of all roadway embankments must be composed of non-frost-susceptible materials in order to provide adequate strength during the melting periods. This may be the combined thickness of pavement, base course and subbase, or in the case of an unpaved gravel road, the thickness of the surface course and the underlying base.

In permafrost areas, the normal design approach must be changed to prevent alteration of the permafrost table. This can be done by overlay methods, using embankment material as an insulator. No clearing or stripping of the existing ground cover is allowed. If trees are encountered, they are cut off near the surface of the ground and the tree stumps left in place, contrary to general construction practices.

PAVED AIRFIELD CONSTRUCTION

The design and construction of paved airfields is based on limiting frost action which will cause undesirable differential heave of the pavement surface. In non-permafrost areas this is accomplished by using a depth of granular fill that will limit or eliminate frost penetration into frost-active subgrade. Since depths of granular fill from 10 to 20 ft might be required to eliminate frost action in the subgrade, a compromise depth is used, permitting some frost heave but with a sufficient depth of

granular material to lessen the effect of subgrade heave on the surface smoothness. In permafrost areas it is desirable to eliminate all frost-susceptible subgrade, even below the depth of seasonal heave if possible, to restrict differential settlement due to the thaw of permafrost. Where such material cannot economically be removed, the depth of granular fill must be limited (particularly in areas of marginal permafrost) to reduce or prevent the settlement that will result from the degradation of the permafrost. An economical limit must be determined that will effect a reasonable balance between differential settlement due to thaw of permafrost and differential heave due to seasonal frost penetration of the subgrade.

CEMENT AND ASPHALT PAVEMENTS

The Portland cement concrete (PCC) and asphaltic cement (AC) pavements built in interior and south central Alaska present special problems due to the cold climates. The asphaltic cement pavements have a coefficient of contraction two to three times that of the base course and subbase materials, depending on the percent of asphalt used. As a result, severe contraction cracks spaced from 10 to 40 ft apart occur and must be continually repaired to prevent degradation of the pavement along the cracks. The wider the spacing between cracks, the wider the cracks. Low temperatures also reduce the flexibility of the asphalt, to the point where it acts as a weak rigid pavement. Over compressible base materials, this condition causes additional cracking of the pavement. These problems are minimized by the use of low asphalt-content mixes and the strongest possible base materials (high density gravels and crushed rock).

Portland cement concrete pavements are more susceptible to detrimental frost heave cracking because of their extreme rigidity. PCC pavement also has a greater susceptibility to spalling from the use of surface de-icing fluids. The problems of these pavements are most easily met by reducing or eliminating frost action of the subgrade and by pretreating the surface to be de-iced with linseed oil.

Airfields constructed in Alaska should be designed in terms of the surface characteristics desired of the finished pavement.

SHORT CONSTRUCTION SEASON

Frequent reference has been made in this paper to the length of the construction season in Alaska. In the lower southern areas of Alaska, the length of the construction season compares favorably with that in many areas of the other states. The usual problems of inclement weather periods (rain, snow or winds) detract from the construction season but do not necessarily shorten it. In much of the rest of Alaska, however, extremely low temperatures prevail during the winter and markedly affect the construction effort. The construction season in these areas varies, generally, from 4 to 6 months. Because of snow, ice or frost, it is May before any real construction effort can be realized, and in the more remote areas, usually June or July. For practical purposes, September and October see the end of real construction progress unless special measures are taken.

If the nature of the structure and the expense involved warrant it, an outer, temporary cover can be constructed. Within this protective cover, heated by portable heaters, construction can continue past the usual limits. By proper planning and preparation, structures such as houses or buildings can be closed in by completion of exterior walls and roof, and installation of windows and doors. Heated within by portable units, interior finishing (usually the most time-consuming) can continue throughout the winter.

The shortness of the construction season in the far northern areas is also a function of the availability of surface transportation to those remote areas. In some areas only one barge or ship visits the site during the year, requiring close coordination of movement of all supplies and equipment necessary for the construction project.

The shortness of the construction season is compensated for in a large part by the length of daylight during summer months. The use of double shifts of labor, while expensive, is common practice on projects requiring early completion. Many contractors seize upon this opportunity, particularly in remote areas, to move in, complete construction and move out in the shortest possible time.

SUMMARY

There are many problems of military construction in Alaska, particularly in remote areas north of the Alaska Range, but none are insurmountable. Within the limits of funds available, and with good design adapted to Alaskan conditions, the U. S. Army Engineer District, Alaska, is providing high quality construction. Since 1946, the year of its organization, the District has completed \$1.3 billion worth of vital military facilities for the Army, Air Force and Navy. However, the need for lighter, stronger, cheaper and more efficient construction materials is evident. There is a fruitful field for the scientist to develop improved or new materials, particularly bitumen, concrete and paint, which are among the materials most affected in cold weather operations. Hopefully, science will provide new materials which can perform the desired function and which can be placed, worked and cured under all conditions of weather. There is a need for better construction equipment, designed to operate more efficiently in all areas of the world. Finally, there is a need for improved construction techniques to provide a better product in a shorter period of time. Some of these problems will be solved by the scientists and others by the men who build.

ARCTIC AND SUBARCTIC SANITATION IN MILITARY FIELD OPERATIONS

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INTRODUCTION

Although the Arctic is no longer the formidable place it once was thought to be, certain features of sanitation connected with living in this environment leave something to be desired. Fixed installations are already furnishing such indoor comforts as wash basins, hot and cold running water and water-flush toilets. Thousands of our military men in places as far north as Thule, Greenland, enjoy the same sanitary facilities as they have back home. One hundred men live 30 ft below the surface of the Greenland Icecap at Camp Century the year around, with showers and "stateside" toilets.

Our country has been quick to adapt these conveniences to local environment wherever our troops are sent — even to the very ends of the earth. Yet we have done only those things which are of immediate necessity, and in a great many cases, we have simply dumped our carefully accumulated wastes and closed our eyes to the consequences. Millions of gallons of raw sewage are being dumped beneath the docks at Thule. Raw sewage at Camp Century is turned downward into a snow hole affecting an area 125 ft deep and 300 ft in diameter and preserved for eternity (4). Garbage and trash cover acres of ground near the Thule harbor.

While it is true that these are but relatively small incidents in the life of a vast expanse of hostile environment of wind, cold, snow and ice, we may find the effects more serious than we apparently realize. Certainly, they will not diminish as these areas become more highly populated and these practices are continued.

PRESENT MEANS FOR WASTE DISPOSAL

Many fixed installations in the Arctic provide modern sanitary facilities indoors and despoil the outdoors in more or less localized areas. In contrast, military operations in the field do without the comfortable facilities and at the same time, scatter sewage and other wastes over wide areas of the landscape. This latter practice is simply an extension of the means prescribed for temperate climates, complicated by arctic conditions.

The Department of the Army Cold Weather Manual (1) states that "unlimited space and a sparse, widely-scattered population are dominant features of most of the colder regions of the world. Such conditions permit unrestricted maneuver of troops properly trained and equipped for cold weather operations. Warfare under such circumstances is characterized by small, widely dispersed forces operating at great distances from other small units or their parent organization.

"Units must be highly mobile and have the ability to sustain themselves while carrying out independent operations over extended periods of time."

In speaking of the composition of units, the manual states: "Small units (squad, gun crew, tank crew, wire team, etc.) form the basic working group for cold weather operations. Under normal operating conditions they will work together, cook and eat together, and share the same tent or other shelter."

Although small units, on foot, may form a basic working group, the manual recognizes larger groups of strong combat patrols and long-range reconnaissance patrols equipped with personnel carriers, tanks and possibly sleds. Back-up units which also must be taken into account include headquarters, administration and supply. Housing for these units may utilize frame-type tents, and various transport equipment is furnished, including cargo sleds, wanigans and heavier and slower track-laying prime movers. Experience has already shown the vital part played by air transportation in the movement of troops, supply and evacuation, but it should be remembered that terrain, landing conditions and bad weather prevent sole reliance on aircraft.

According to the Manual, human waste disposal for all groups mentioned above is to be accomplished with slit trenches or pits dug into the earth or snow. "Cross-tree" type latrines are apparently acceptable where digging is difficult or impossible. Protection of the individual from the wind is recommended by construction of a windbreak of boughs, tarpaulins, ponchos or snow wall. Garbage and trash should be buried or burned. Abandoned latrines and garbage pits are to be covered with compacted earth or snow and clearly marked — the tactical situation permitting.

HEALTH CONSIDERATIONS

There is little doubt that sanitation measures in arctic combat have been simplified to the greatest possible extent. It is true, too, that troops on the move, especially without transport, cannot be burdened with extensive devices or equipment for waste-handling. The discomfort and inconvenience of the present measures, however, lead one to surmise that in severe arctic weather a soldier would rather engage the enemy in hand-to-hand combat than make a trip to the latrine. Certainly, it would be warmer.

Based on observations, it is the writer's belief that soldiers will restrain from defecation to the greatest possible extent in severe weather. This practice may ultimately incapacitate a soldier. The loss of one soldier in a small group may impair the mission of the group.

Of perhaps more serious concern, however, is the general contamination of an area where it is necessary to obtain drinking water locally. The concern is greater as the numbers of troops in the area are increased and as bivouac areas are used and reused.

Snow may be rather widely contaminated, depending upon the activity in and around a bivouac or a gun or observation position. Track-laying vehicles could easily scatter the contents of old latrine trenches, especially in areas of permanent snow. Demands for water from snow melt may require collection of snow from a wide area. A bulldozer is often used for this purpose. At the same time, we have reports that human wastes left near the South Pole sometime before 1917 still contain living intestinal organisms (6).

Much of the arctic country experiences a summer thaw, with the removal of most or all of the snow laid down the previous winter. Runoff from snow trench latrines will usually collect in a small nearby pond. Water or ice from such a pond may be utilized by a passing patrol. An Army research project (3) at Fort Churchill conducted in the early 1950's reveals considerable numbers of enteric pathogens in ponds and permafrost waters lying near places of excreta disposal. The Pickel Meadows studies (2) in 1953 found high coliform counts in a stream bordering a winter training area, in which snow trench latrines were used and much promiscuous defecation took place away from the latrine.

Something should be said, also, of the possibility of flies acting as vectors of disease organisms which might be present in human wastes exposed to the atmosphere. The Fort Churchill studies indicate that certain species of flies (houseflies and blow-flies) are attracted to both feces and food and that they are capable of harboring typhoid organisms for a period of time. Arctic animals such as the wolf and fox may be suspect, as well as some bird life. One can't help but shudder a bit each time seagulls are seen feeding in a sewage-polluted harbor and then flying to a nearby fresh water pond or lake to sun, wash and relieve themselves. It is not uncommon to find drinking water intakes, such as pipes, structures, etc. in lakes near the sea serving as a busy roosting place for seagulls. Water samples taken in such places by the writer have been found to be grossly contaminated.

Whether the conditions mentioned above are, in fact, dangerous to the health of combat troops remains to be seen. The Churchill studies drew no conclusions in this regard, and a final report has never been obtained on the Pickel Meadows research. If no more research is undertaken, it may never be known until a full-scale arctic war is actually underway. It would seem to be the better part of logic, however, to explore the subject more extensively and to be better prepared for an eventuality which may come to pass, namely, widespread dissemination of human excreta, with concomitant prevalence of intestinal disease. Eskimo communities have long been known for their seasonal outbreaks of enteric disease and their poor sanitary habits (5).

RESEARCH TO DATE

Research in this field has been limited, particularly with respect to the fate of fecal matter and intestinal pathogens, under the variety of conditions which obtain in the Arctic. The most important studies appear to have been carried out at Fort Churchill by the Surgeon General, Department of the Army, through the Armed Forces Epidemiological Board (3).

These studies were not adequately funded; personnel were few and facilities were sparse; so that the scope of the work was limited. Although the studies covered a period of three winters, the first two winters were spent largely in adapting test and laboratory procedures to arctic conditions. The experience gained, however, will enable other research efforts to work more efficiently and effectively.

The research at Pickel Meadows was along the same lines as at Fort Churchill, but to my knowledge, no final report has ever been prepared. This is unfortunate, because the project undoubtedly made important findings.

Without going into detail, it is believed safe to say that research into arctic waste disposal has been largely confined to fixed installations. Various means of collection, treatment and disposal have been quite thoroughly explored. As a result, many improvements have been made, but all of the problems are far from being solved. Most references in this regard are listed in the recent Navy Report (5), which includes 231 references.

At the present time there appears to be no research underway, at least as far as the military is concerned. Recent correspondence reveals concern only with fixed installations and the more exciting field of bioastronautics. This latter field may well have an application to arctic problems, however.

Research to date may be pretty well summed up in the report of the Fort Churchill studies, which concludes, "The results of these studies did not permit a firm conclusion as to whether or not surface disposal of human excreta is a safe health practice in the Arctic. "

SUGGESTED FIELDS OF RESEARCH

The state of the art in handling and disposing of wastes during the movement and deployment of troops in the Arctic is not, in the writer's opinion, sufficiently advanced to say reliably that practices now prescribed are wholly safe and adequate. Few will disagree that they are inconvenient.

With the tremendous expenditures being made in the military, it appears completely justifiable to undertake a well-financed research program, which would be barely perceptible in the total budget. Such a program might include the following:

1. A complete study of the fate of enteric pathogens and fecal material under the wide variety of arctic conditions. It is believed that most of this work should be performed in the Arctic to be truly representative of the effects of cold, wind, snow, ice, tundra, prolonged sunlight, prolonged darkness and arctic birds, animals and insects.

2. Development of a very light permanent-type material which would not add appreciably to the bulk or weight of the present existence pack. If containment of human wastes is indicated, this material could be used for individual defecations, lining and covering snow holes, and aiding in construction of a shelter or windbreak. The material might be similar to a product such as Saran Wrap.

3. Adaptation of supply containers to waste disposal use. If containment of wastes is indicated, it appears feasible to design containers to serve this purpose. It has always been a mystery to the writer why oil drums sent to the Arctic were never provided with removable but tightly resealable covers which might be replaced after the drums had been used for toilet purposes. The drums might then be sealed and stored with disinfectant until the contents are no longer objectionable. They would then be emptied and returned to toilet use. With a little ingenuity these drums, during storage, could be adapted to building construction. The 250,000 drums which are reported to have been accumulated at Point Barrow, for example, would serve as walls for a 9 ft-high warehouse approximately 15 miles long.

4. Development of chemical oxidants and disinfectants which, in small quantities, would effectively disintegrate or destroy feces and bacteria.

Further studies might appropriately be directed toward:

a. Providing built-in toilet facilities in transport and shelter equipment. This should be no problem with wanigans and cargo sleds. It might also be possible with personnel carriers. At least it seems feasible to utilize heat from combustion engines to make a toilet shelter more habitable. There appears to be no sound reason why the 10-man arctic tent and the 16-man Jamesway shelter cannot be equipped with toilet alcoves.

b. Development of a suitable flush liquid for use in toilets at semi-permanent stations. One of the major conclusions of the recent Navy Study (5) was that a non-freezing liquid, not miscible with toilet wastes, is a practicable means of flushing and transmitting feces and urine to a point of disposal without appreciable loss of the liquid.

c. Means for incinerating or pasteurizing excreta. Considerable effort has been expended on this problem with some success but not enough, apparently, to warrant its adoption by the military. It doesn't take a great deal of heat to kill intestinal organisms. It does not seem out of the realm of possibility that an individual defecation could be enclosed in a wrap of fire-resistant material in a sanitary manner, which could be placed in a Yukon stove, for example, and heated a short time before disposal.

Finally, some consideration should be given to the possibility of training arctic troops in the matter of the defecation itself. Is it too much to expect that troops might be taught to use individual receptacles? This has been done with laboratory personnel with little difficulty, especially when receptacles are properly designed and covered.

Sanitation under field conditions in the Arctic is practically the same now as it was when man first set foot there. It seems that a nation preparing to fly to the moon is capable of devising, as modern parlance puts it, "something more sophisticated."

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TRAFFICABILITY OF SNOW AND MUSKEG

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INTRODUCTION

Trafficability is the characteristic of a terrain that refers to its ability to permit the passage of a military vehicle. Whether a given terrain is trafficable or not depends not only on the specific features of the terrain, but also on the characteristics of the vehicle. The same terrain may be trafficable to one vehicle but untrafficable to another.

There are three general ways in which the Army can improve its posture in the field of off-road mobility, or trafficability: by building more mobile vehicles, by improving the condition of the terrain, and by understanding better the relations between existing vehicles and terrain.

Obviously, the most direct and decisive way of improving off-road mobility is to build better vehicles, vehicles that can cross softer ground, climb steeper slopes, pull heavier loads, negotiate tougher obstacles, run farther on a unit of fuel, and hopefully do all these things and more with no sacrifice in armor, firepower or cost. However, if we are to achieve significant improvements in off-road vehicles — real breakthroughs and not merely marginal advances — we must first develop a fundamental, basic knowledge of vehicle-terrain relations in the form of laws, equations and formulas that relate the stresses imposed by the vehicle to the strains undergone by the terrain. These relations should be theoretically sound, mathematically rigorous, and applicable to all vehicle configurations and all terrains. In other words, the relations would constitute a science of the mechanics of surface media that would serve the ground-vehicle designer in the same way that hydrodynamics serves the ship designer and aerodynamics the aircraft designer. Until this science becomes available, there is little hope that really profound improvements in off-road vehicles will occur, except possibly by chance. Interest in the development of fundamental

vehicle-surface medium relations is growing in military and commercial circles, both in this country and abroad. Some progress is being made toward the evolution of the science we so badly need, but the progress has been painfully slow, and many years may elapse before the research efforts begin to bear fruit.

Many types of terrain deny today's ground vehicles. Steep, dissected mountain ranges will block the progress of our most rugged machines; soft, swampy terrain will immobilize our lightest. A natural recourse is to seek means of altering the terrain to make it more amenable to the traffic of ground vehicles. This is the second way in which the Army can enhance its capability in the trafficability field. But here again, while there are vigorous programs in existence to develop faster and more efficient means of improving terrain, no breakthrough appears imminent. Terrain improvement today is still largely a matter of engineering effort, requiring time, personnel, materials and equipment in prohibitive amounts, especially when we consider the increased need for the off-road travel of military vehicles in this nuclear age. Truly effective methods of improving terrain from the trafficability standpoint, like significantly better vehicles, appear to be lurking somewhere in the future.

But what of the military commander in the field? He can hardly afford to wait patiently while researchers seek to unlock the secrets that will ultimately provide him with super-mobile vehicles or rapid means of leveling terrain barriers and turning quagmires into concrete highways. He needs assistance today, not tomorrow. He needs to know which of the vehicles under his command can negotiate the terrain ahead, which of the several cross-country routes available to him is the best from the mobility standpoint, and how tomorrow's rainfall will affect the suitability of these routes. He wants his answers in quick, simple terms so that he can weigh them along with the many other factors he must consider before he makes his final decision — to retreat, defend or attack.

We can give him the means of answering these questions by developing a knowledge of the capabilities of existing vehicles on existing terrain. This is the third way in which we can improve our potential in the area of mobility. We can do this by conducting the type of studies that have come to be known as "trafficability" studies. In contrast to the mobility studies which seek more basic, comprehensive relations between vehicles and media, and which are designed on the basis of available theories and conducted with scale models under carefully controlled conditions

in elaborate laboratories, the trafficability studies seek merely to determine useful empirical relations, and they employ full-size vehicles on natural terrain.

Several agencies have performed and are performing trafficability studies in snow and muskeg, the two surface media that dominate cold regions. The Cold Regions Research and Engineering Laboratory pioneered trafficability work in snow in this country many years ago, in the mountains of Colorado and later in Michigan and Greenland. The Land Locomotion Laboratory and the Transportation Research Command have studied the snow problem in Michigan and elsewhere, and the Canadian Defence Research Board has made several fine studies in both snow and muskeg in Canada. The Waterways Experiment Station (WES) for a long time concentrated its efforts on the trafficability of mineral soils but in recent years has turned its attention to snow and muskeg.

Although studies of the trafficability of snow and muskeg are far less advanced than those of mineral soils, the studies are considered sufficiently advanced to warrant some discussion. Since WES has perhaps spent more effort in the field than any other agency, the WES studies provide the main basis for this discussion. This paper will thus describe briefly the most important correlations so far found in the WES studies of the trafficability of snow and muskeg. Detailed results of the work in snow, including many facets not covered in this paper, are contained in published WES Reports 1 through 4 of the WES Technical Memorandum entitled Trafficability of Snow (2). Two reports on muskeg are currently in progress and hopefully will be published by the end of 1964.

SNOW

On the basis of examination of the results of tests conducted by WES on snow in Greenland, Canada and the United States, certain general statements regarding vehicle-snow relations may be made. Illustrations are presented where pertinent.

Measurement of Snow Strength

Because most snows compact and then shear abruptly under the load of a strength-indicating instrument, and because of the

frequent presence of thin layers of ice or compacted snow, difficulties are encountered in obtaining strength measurements with most instruments that measure strength in vertical profiles. In snow, as in other media, a large number of strength measurements should be made in order to obtain a reliable average.

Many different methods of obtaining an index or a measure of snow strength have been used in the trafficability studies. Some of the measurements obtained are cone index, rating cone index, compaction index, taper penetrometer index, vane shear strength, torque-tube shear strength, unconfined compressive strength, drop cone hardness, Canadian hardness, Rammsonde hardness, snow density, snow wetness, snow grain size and snow temperature. Equipment and techniques for obtaining these measurements are described in WES Report 3 of the Trafficability of Snow series (2). On the basis of analysis of the data relating snow properties to vehicle performance, cone index appeared to be the most useful of those studied. Moreover, cone index readings can be obtained more readily than most other readings, and the cone penetrometer is particularly suitable for measuring strength profiles. Figure 1 is a photograph of the cone penetrometer.

General Vehicle Performance

Few snow conditions tested were found to be poor enough to cause the immobilization of conventional military tracked vehicles in a few straight-line passes, and few were good enough to support the traffic of conventional military wheeled vehicles.

In Greenland snow, tracked vehicles occasionally became immobilized on natural steep slopes (if steep enough, a slope can cause the immobilization of any vehicle on any medium) and on steep slopes created by the formation of ridges and swales in repetitive-pass testing. Heavy, high-ground-pressure vehicles (such as the M48 tank with a ground pressure of 10.5 psi) occasionally had considerable difficulty maneuvering in some Greenland snow conditions. However, in no case were any of the tracked vehicles tested in Greenland immobilized within a few passes while traveling on level snow and not towing a load.

In continental snows, very deep snowdrifts occasionally were soft enough to cause immobilization of tracked vehicles while they were maneuvering, even in a few straight-line, repetitive-pass tests. However, for the most part the continental snows

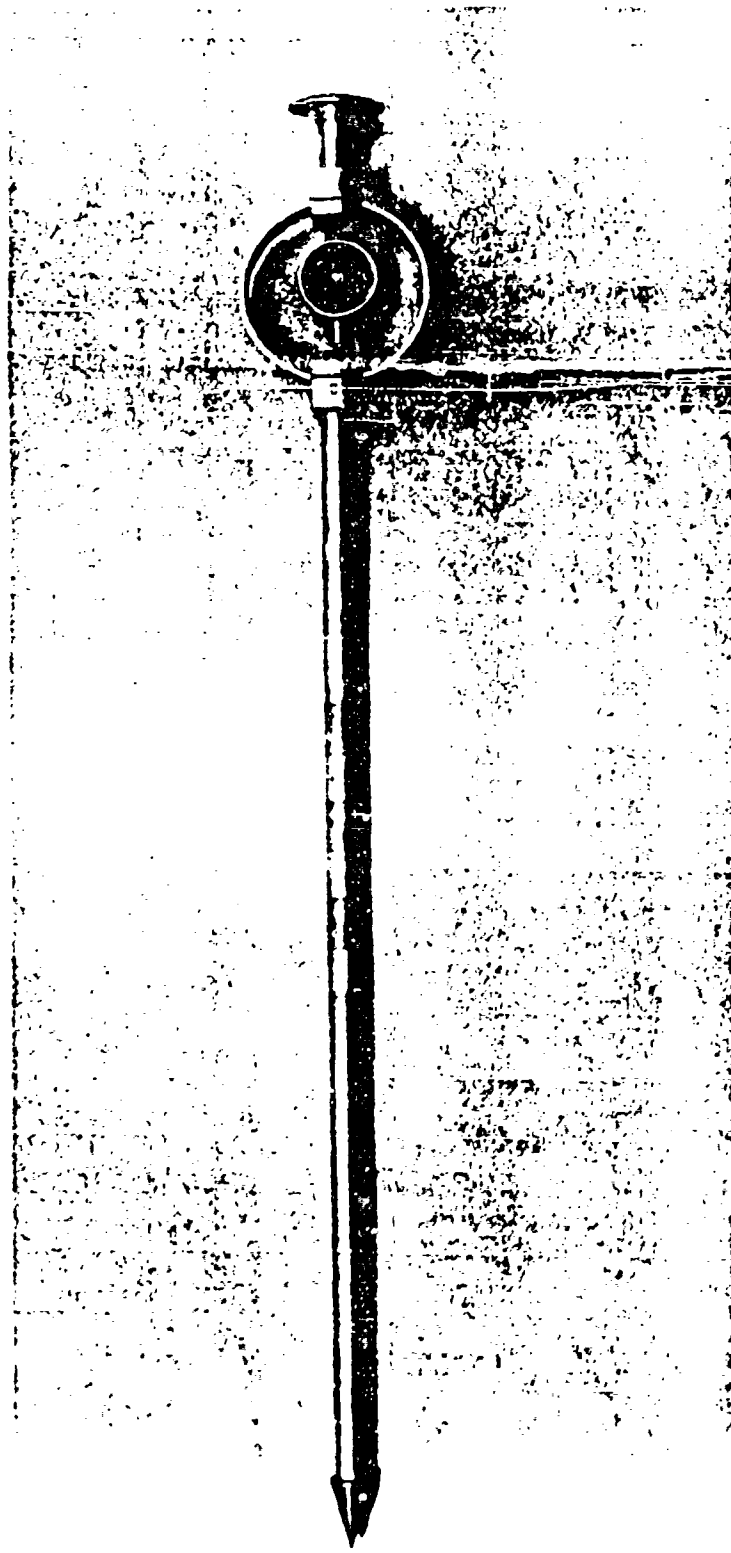


FIGURE 1

Cone penetrometer used to measure cone index

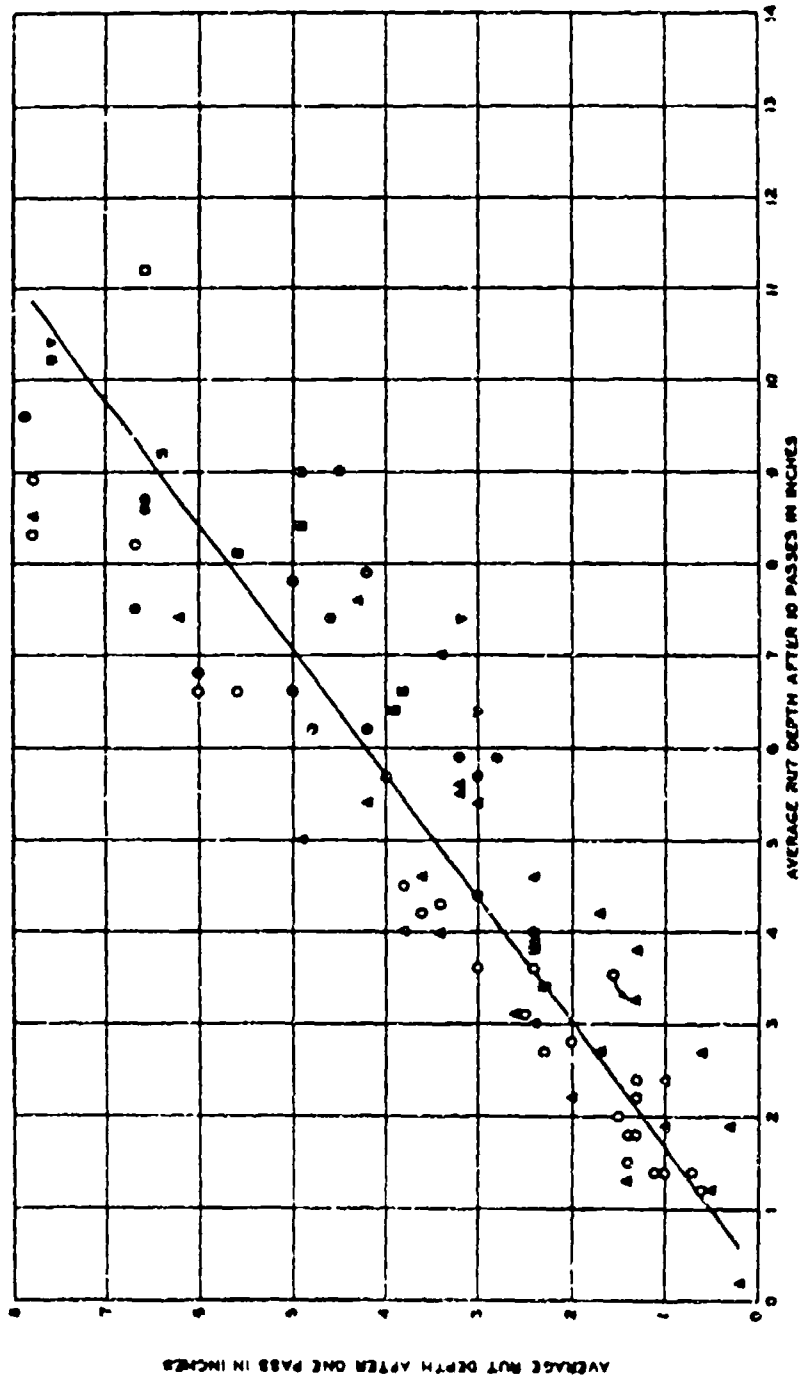
tested were sufficiently shallow that the hard soil beneath them played a part in supporting the vehicles, and very few immobilizations occurred.

Conventional wheeled vehicles occasionally negotiated a few very firm snow conditions found in Greenland. For example, a 2-1/2-ton truck with low inflation pressure was able to travel a mile, climbing 5 to 7% slopes, up the ramp at Thule Take-Off, but it could not travel in soft continental snows that were only as deep as about 1/4 the wheel diameter. Vehicles with very large wheels and low inflation pressures, such as the Marsh Buggy and the Overland Snow Train, have had some success in snow, but their performance has not been as good as that of tracked vehicles.

The first pass of a vehicle is usually the most difficult. If a vehicle can make 1 pass in a snow condition, it usually can make at least 10. However, as discussed previously, prolonged repetition of traffic may create impassable ridge-and-swale conditions. Usually, on the first pass the snow is compacted and made stronger. Generally speaking, the rut created on the first pass is about 2/3 as deep as it becomes after 10 passes. Figure 2 is a plot comparing the depth of rut after the 1st pass (Y-axis) with that after the 10th pass (X-axis). The data shown were collected in Greenland in 1957 and are reported in WES Report 3 (2).

Trafficability Correlations

The principal aim of the trafficability studies is to develop correlations between simple measurements in a medium and expressions of vehicle performance, in terms suitable for use by the military commander in the field. Generally, the first and most important correlation sought is one which will permit a distinction between "go" and "no-go" conditions for particular vehicles. In snow, the dearth of no-go conditions for tracked vehicles and of go conditions for wheeled vehicles precluded this type of correlation. However, correlations were found between measures of snow strength and the rut depth created by a vehicle, between strength and maximum drawbar pull, and in the case of sleds, between strength and the force required to tow the sleds. Strength of the continental snows tested usually varied over such a narrow range (from about 2 to 15 cone index) that it was not feasible to develop correlations between strength and vehicle performance, except in the one instance to be discussed. However, the depth of snow appeared to be a



RUT DEPTH AFTER
TEN PASSES VS RUT DEPTH
AFTER ONE PASS
GREENLAND SNOW AT VARIOUS
STRENGTHS

FIGURE 2

LEGEND

SYMBOL	VEHICLE	CONT PRESS. (PSI)
○	D6 TRACTOR	3.17
○	M28C WHEEL	1.66
△	SNO CAT 743	1.02
△	M78 OTTER	1.72
○	LGP D7 TRACTOR	2.89
○	M344 HI-SPEED TRACTOR	6.37
△	LGP D6 TRACTOR	3.59

significant parameter in estimating both rut depth and maximum tractive coefficient. The best relations were found if two general classes of snow were recognized: one, the very deep permanent icecap snow and the other, the comparatively shallow, seasonal continental snow. It was also necessary to distinguish dry, moist and wet snow. (A snowball cannot be made with dry snow; moist snow does not contain obvious liquid water, but a snowball can be made; wet snow contains obvious liquid water.) One further arbitrary criterion was found to be useful; i. e., vehicles weighing less than 10,000 lb depended on the strength in the top 6 in. in some correlations, while vehicles weighing more than 10,000 lb depended on the strength in the top 12 in.

Strength-rut depth correlations. Figure 3 illustrates the correlation between cone index and rut depth after one pass of the vehicle. Three "light" vehicles and two "heavy" vehicles are shown. Note that dry and moist snow plot together, while wet snow requires a separate curve. The data are mainly from the 1955 and 1957 tests in Greenland. Only one set of continental snow data is represented, for the M29C Weasel. These data, collected at various elevations in the mountains near Boulder, Colorado, in 1954 and reported in WES Report 4 (2), were the only data collected in continental snow that covered a wide enough range of snow strength to justify a plot. The Boulder data have been plotted separately; however, they might have been combined with the Greenland snow by drawing a curve midway between. Whether they should be combined is a question that can be settled only after more data have been collected and analyzed.

Advance knowledge of the depth of rut a vehicle will create is somewhat academic to a military commander in making trafficability decisions, but may possibly stand him in good stead if he is traversing a field of buried contact-type mines. Also, an ability to predict rut depth, even though empirical, will be of some use in more fundamental mobility studies, and may even provide some help to vehicle designers in estimating the rolling resistance of various vehicle configurations.

Strength-maximum drawbar pull correlations. Of greater utility to the military commander is an ability to estimate the drawbar capability of his vehicles in various snow conditions. Not only does this permit him to evaluate the allowable sled load (see paragraph on strength-towing force required for sleds), but it gives him a direct indication of the maximum slope his vehicles can climb. The maximum slope negotiable and the

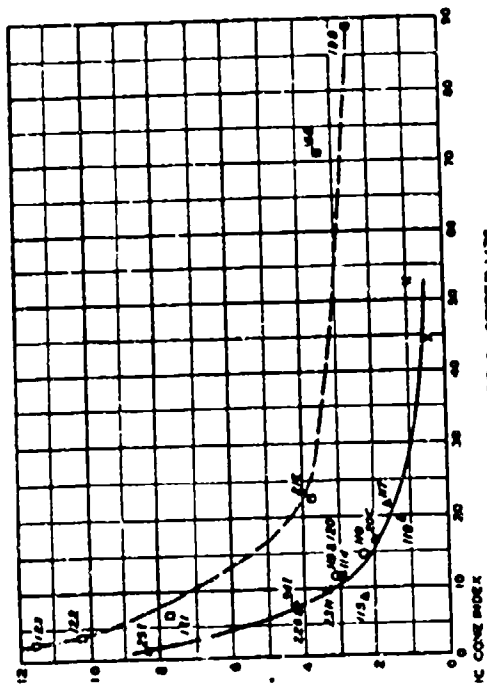


FIGURE 1 SNO-CAT 743
CONTACT PRESSURE = 102 PSI

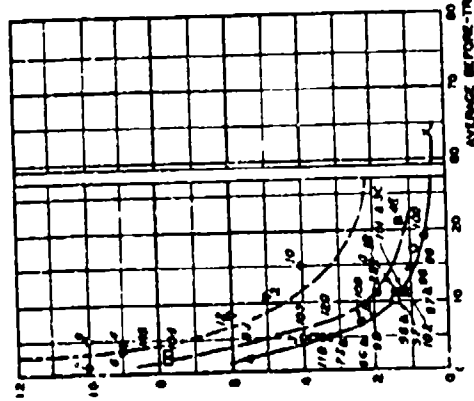


FIGURE 2 WEASEL MOOK
CONTACT PRESSURE = 1.08 PSI

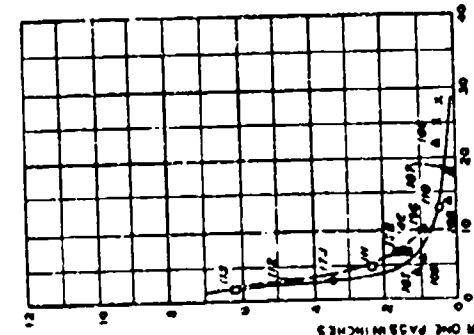


FIGURE 3 OTTERMITE
CONTACT PRESSURE = 1.12 PSI

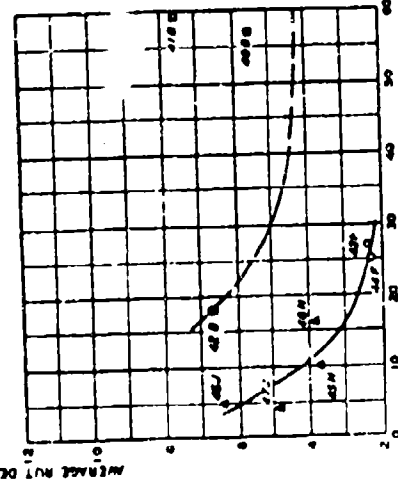


FIGURE 4 LGP-D7 TRACTOR
CONTACT PRESSURE = 2.00 PSI

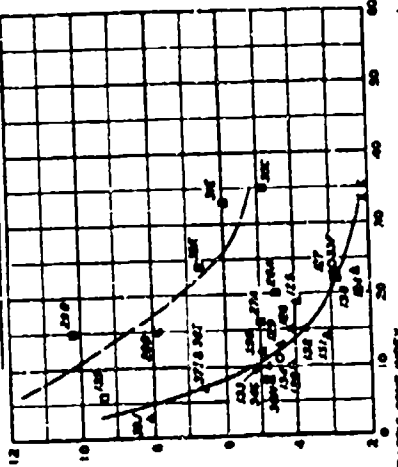


FIGURE 5 STD D8 TRACTOR (30-IN. TRACK)
CONTACT PRESSURE = 3.17 PSI

0- TO 6-INCH DEPTH

0- TO 12-INCH DEPTH

- LEGEND
- WET SNOW (W₁)
 - MOIST SNOW (W₂)
 - △ DRY SNOW (W₃)
 - NUMBERS NEAR PLOTTED POINTS REFER TO ITEM NUMBERS AND LETTERS REFER TO 1965 TEST SITES
 - OPEN SYMBOLS INDICATE FINE-CRAINED SNOW
 - CLOSED SYMBOLS INDICATE COARSE-CRAINED SNOW
 - DRY AND MOIST SNOW
 - - - WET SNOW
 - ▽ BOULDER, COLD WET SNOW (W₄)
- GREYSIAND-1953-5, 1957 GREYSIAND-1954

SELF-PROPELLED TRACKED VEHICLE TESTS
BEFORE-TRAFFIC CONE INDEX
VS RUT DEPTH AFTER ONE PASS

FIGURE 3

maximum tractive coefficient (maximum drawbar pull/weight of vehicle) are, for all practical purposes, numerically equal. The maximum tractive coefficient probably can provide the basis for estimation of the maximum speeds. However, maximum speed tests were not performed in snow, and reliable relations between maximum drawbar pull and maximum speed are not yet available.

Figure 4 shows the relations between maximum tractive coefficient and cone index for four vehicles, two light and two heavy. Because even light vehicles rutted deeply while towing a load, both classes of vehicles employ the cone index in the 0 to 12-in. depth, and further it has been necessary to separate snow into three classes on the basis of wetness. The data are for Greenland snow; no comparable data are available for continental snow.

Correlations of strength (and snow wetness) and towing force required for sleds. Sled tests were performed only in Greenland. Plots of the coefficient of kinetic friction (the force required to keep a sled moving in a straight line at a low speed/the weight of the loaded sled) versus cone index show that the kinetic friction decreases with increasing cone index, but the decrease is very light and not well defined. A somewhat more meaningful, but by no means well-defined, correlation results when snow wetness, rather than strength, is compared with the coefficient of kinetic friction. This correlation is shown in Figure 5. Figure 5 illustrates the benefits to be derived from coating steel sled runners with Kel-F and Teflon, two commercial plastics with relatively low coefficients of friction on snow. It can be seen that the coefficient of friction is reduced about 1/2 when Teflon is applied to the sleds.

Snow depth versus rut depth (continental snow). In the soft continental snows, the depth to which a vehicle sank on its first pass appeared to increase linearly with the depth of snow. Figure 6 is fairly typical of this relation. The data were collected at Camp Hale, Colorado, and are reported in WES Technical Memorandum No. 3-414, Report 4 (2).

Snow depth versus maximum tractive coefficient (continental snow). Except for the Weasel, which reached a minimum tractive coefficient in snow about 28 in. deep and deeper, tractive coefficient decreased with increasing snow depth. The Camp Hale data shown in Figure 7 are typical of this correlation. Note that the curves shown for the three other vehicles also tend to approach a minimum value of tractive coefficient in deep snow.

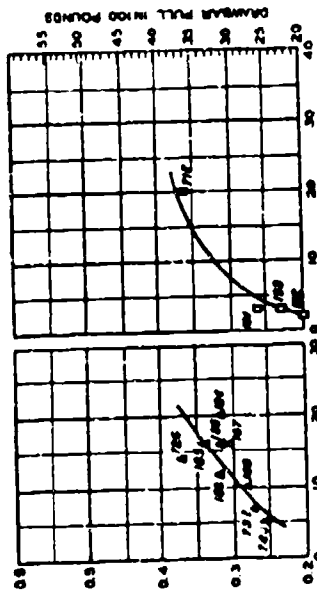


FIGURE 2. OTTER M78

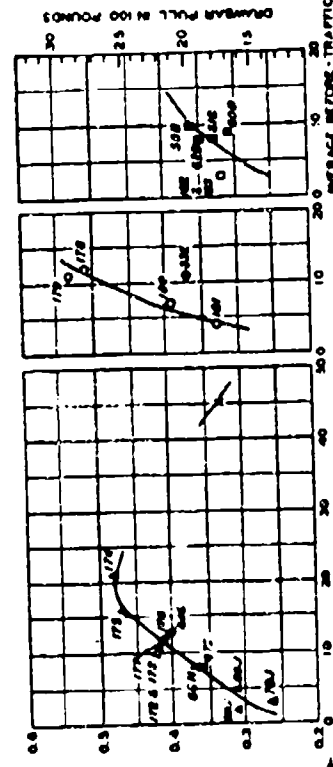


FIGURE 1. WEASEL M29C

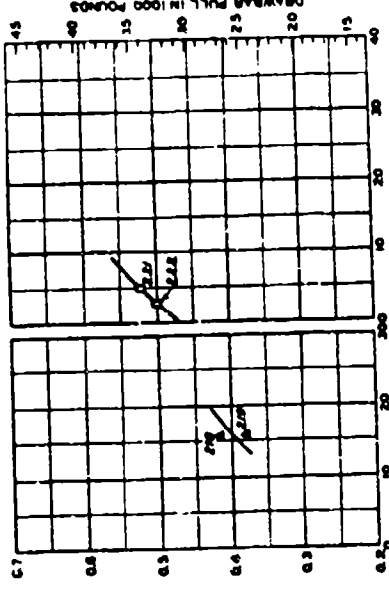


FIGURE 4. LCP-08 TRACTOR

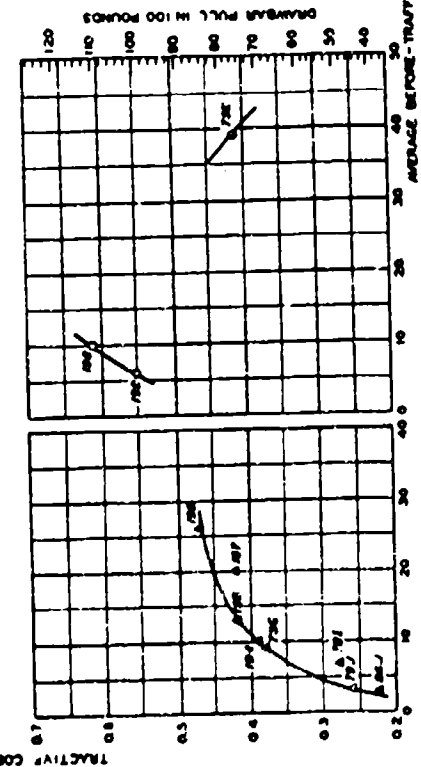


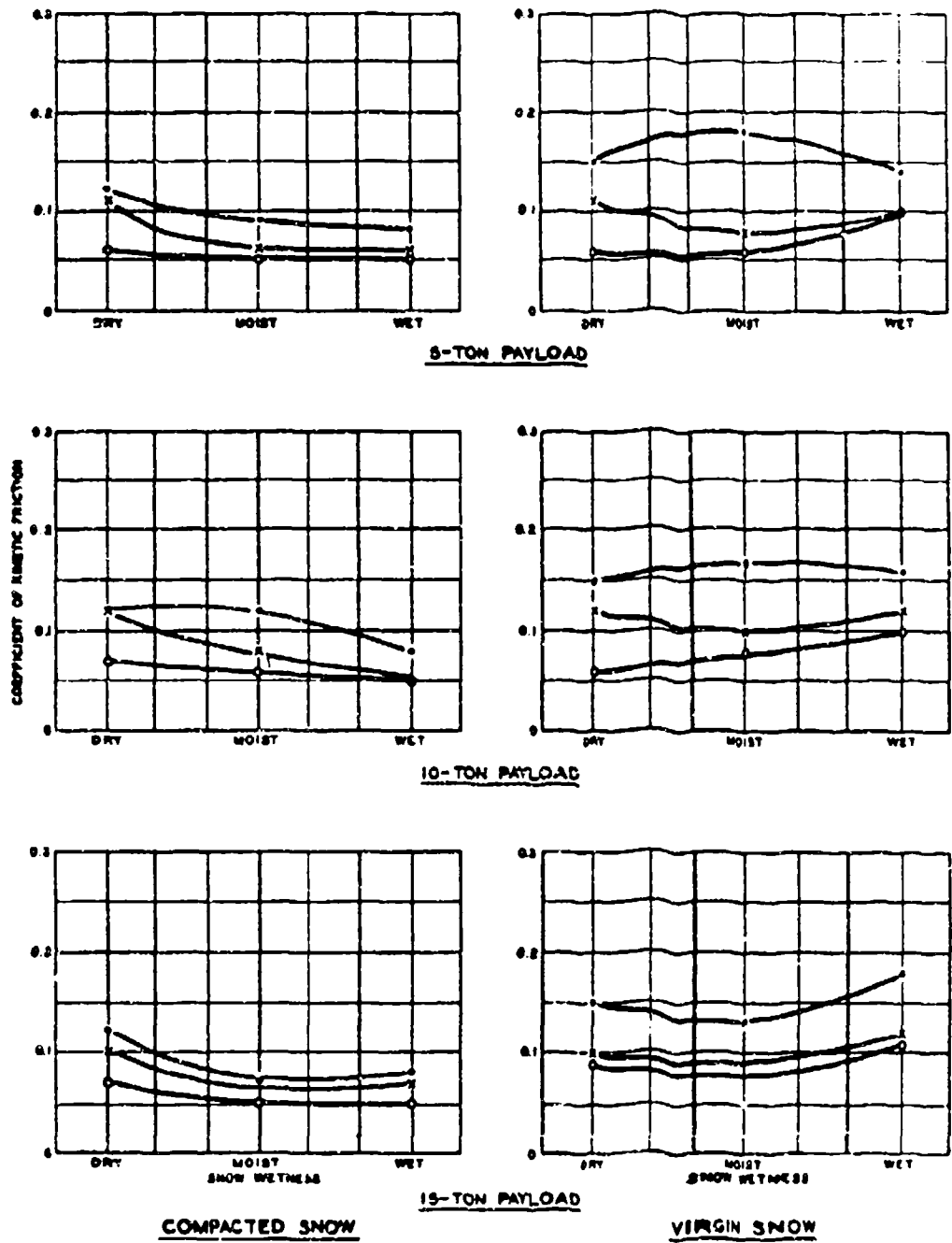
FIGURE 3. STD D8 TRACTOR (30-IN TRACKS)

LEGEND

- GREENLAND-1953 & 1957
- GREENLAND-1954
- WET SNOW (W)
- DRIEST SNOW (D)
- DRY SNOW (N)
- OPEN SYMBOLS INDICATE FINE-GRAINED SNOW
- CLOSED SYMBOLS INDICATE COARSE-GRAINED SNOW
- NUMBERS NEAR PLOTTED POINTS REFER TO TEST NUMBERS AND LETTERS REFER TO TEST SITES

TRACKED VEHICLE TOWING TESTS
 BEFORE-TRAFFIC CONE INDEX
 VS MAXIMUM DRAWBAR PULL

FIGURE 4



LEGEND
 —●— STEEL RUNNERS
 —■— REL-F RUNNERS
 —○— TEPLON RUNNERS

**EFFECTS OF SNOW WETNESS
 ON KINETIC FRICTION FOR
 VARIOUS PAYLOADS**

FIGURE 5

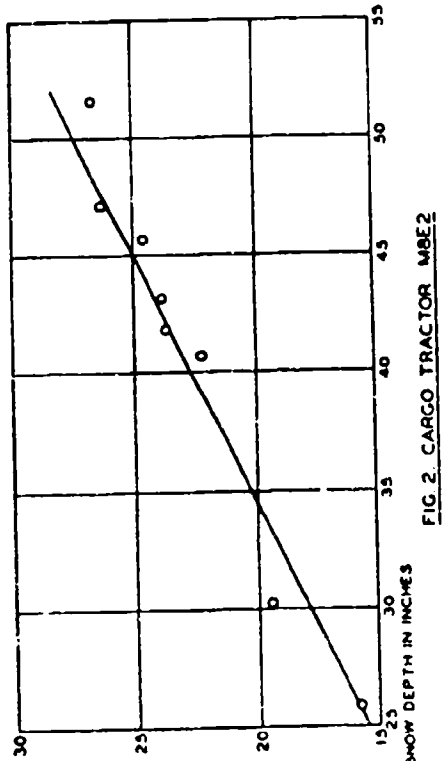


FIG. 2. CARGO TRACTOR M8E2

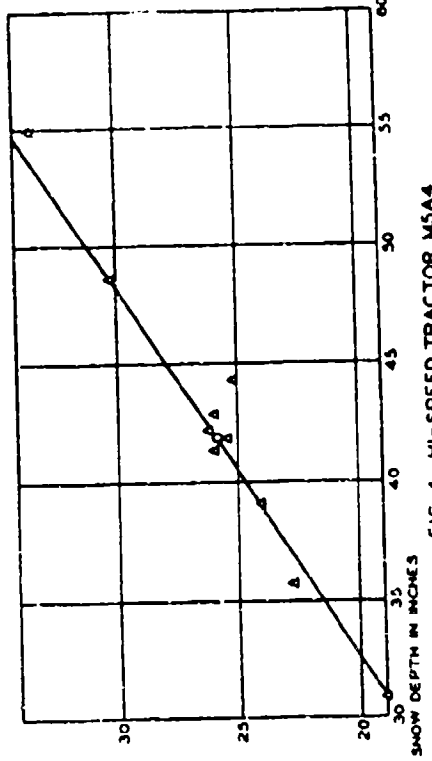


FIG. 4. HI-SPEED TRACTOR M5A4

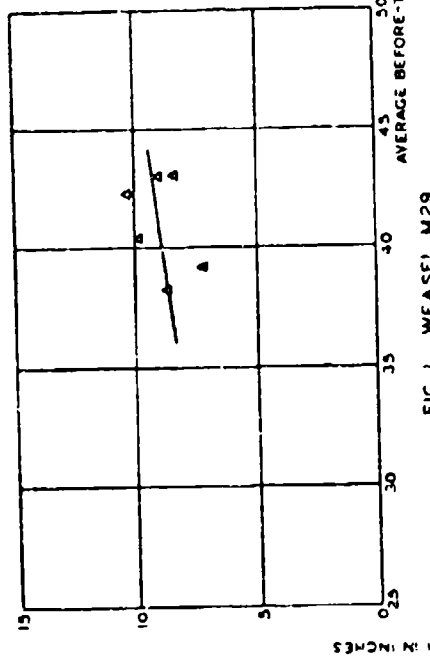


FIG. 1. WEASEL M29

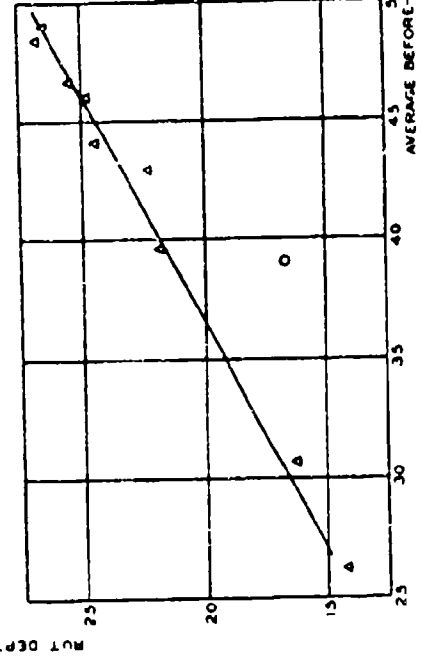


FIG. 3. PERSONNEL CARRIER M59

LEGEND

- △ DRY SNOW
- MOIST SNOW

NOTE: AVERAGE CONE INDEX WAS 8 TO 12.

SELF-PROPELLED TESTS
SNOW DEPTH VS RUT DEPTH
SECOND TEST PERIOD, CAMP HALE

FIGURE 6

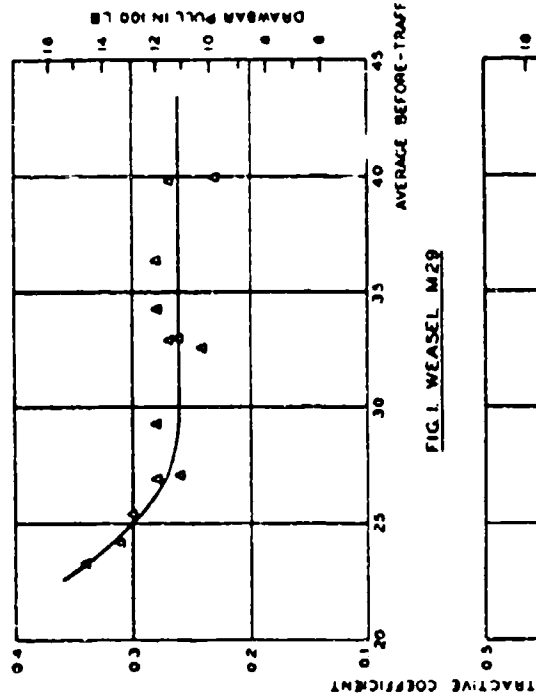


FIG. 1. WEASEL M29

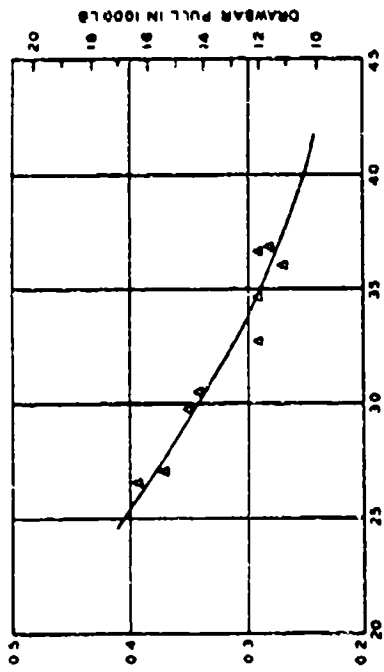


FIG. 2. CARGO TRACTOR M8E2

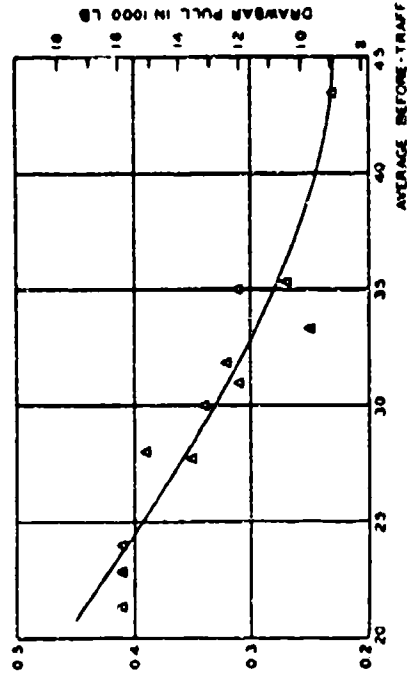


FIG. 3. PERSONNEL CARRIER M59

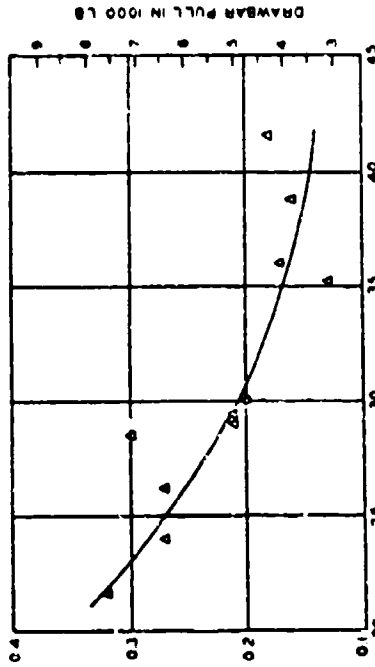


FIG. 4. M1-SPEED TRACTOR M5A4

LEGEND
 Δ DRY SNOW
 ○ AVERAGE CONE INDEX WAS 2 TO 3.

OWING TESTS

SNOW DEPTH VS MAXIMUM DRAWBAR PULL
 FIRST TEST PERIOD, CAMP HALE

FIGURE 7

MUSKEG

The level of effort expended in studies of the trafficability of muskeg has been even less than that for snow. Field programs have been conducted at Parry Sound and Fort Churchill in Canada, at Fort Wainwright, Alaska, and at Fort Custer, Michigan. The programs at Fort Churchill and Fort Custer were of only limited scope and will not be discussed. The muskeg conditions at Parry Sound and Fort Wainwright were sufficiently dissimilar to justify separate discussion.

The Radforth Classification system for muskeg has been used in the WES trafficability studies. This system "attempts to record the three dimensional problem and is based on surface vegetation which occurs above the ground, topographic features which occur along the ground, and on composition and structure of the subsurface material which occurs in the ground." (1). Obviously classification alone is not enough to assess the trafficability of muskeg, but must be supplemented by quantitative measurements of strength. Again, as it has for other media, cone index appears to be a worthwhile index of strength.

Although light wheeled vehicles, such as the Jiger and the Fisher, are known to be able to negotiate many muskeg conditions, the WES studies on muskeg have so far been restricted to tracked vehicles.

Parry Sound Program

The muskeg tested at Parry Sound, Ontario, was in confined bogs containing a wide variety of vegetal cover types, underlain by peat material that ranged from amorphous-granular, black nonfibrous peat (in the old bogs) to woody, coarse-fibrous, brownish peats (in the young bogs) and included muskeg consisting of fibrous materials mixed with roots of the living vegetation floating in water. The depth to bedrock in the Parry Sound tests was always greater than 3 ft, and all frost was absent.

Cone index versus vehicle performance. The data shown in Figure 8 for the M29C Weasel are fairly typical of those showing the effect of cone index profile on vehicle performance in terms of "go" and "no-go." A go situation is one in which the vehicle is able to make 50 or more passes, and a no-go situation is one in which the vehicle becomes immobilized before completing 50 passes. In Figure 8 it is seen that the high strengths generally

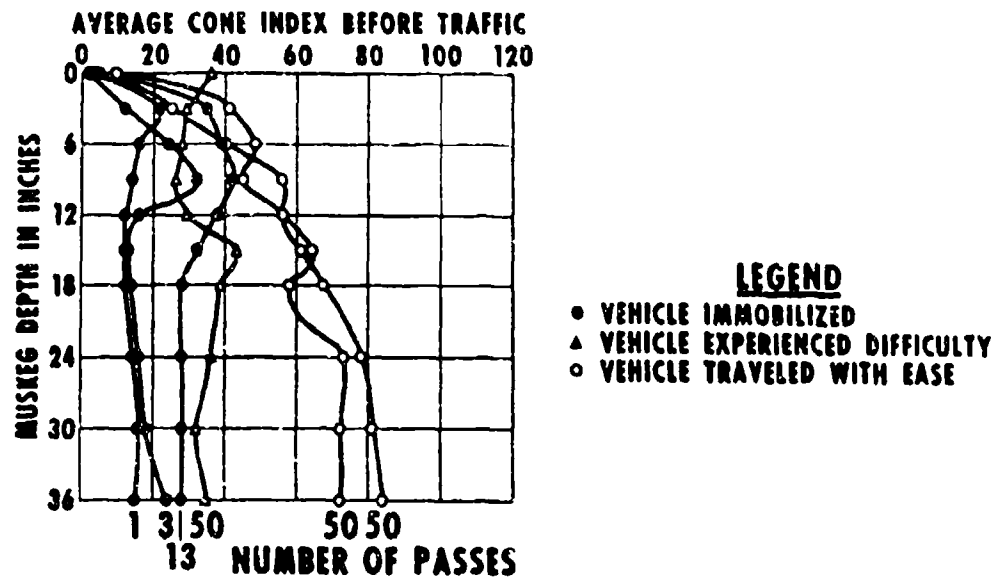


FIGURE 8

Example of effects of cone index profiles on vehicle performance: M29C Weasel (5900 lb) Confined Muskeg Tests, Parry Sound, Canada.

permit 50 passes, while the low strengths do not. Moreover, there appears to be a relation between the number of passes the vehicle was able to complete and cone index at depths below about 15 in.

Effect of vehicle weight and critical layer of muskeg on minimum cone index for go. From the military standpoint, it is more desirable to find a specific depth in a strength profile for which the measured strength would indicate go or no-go for the vehicle of interest than to have to study the entire profile. Locating this specific depth has seldom been achieved, even in sand which is probably the most straightforward soil from a trafficability standpoint. Next in desirability would be to obtain a correlation between the strength of a specific layer and vehicle performance. This has been attempted in the analysis of the data for muskeg, and the results are shown in Figure 9. The 12 vehicles tested are listed at the right, and the vehicle weights are shown on the Y-axis. "Critical layers," which have been arbitrarily established solely on the basis of weight ranges, are

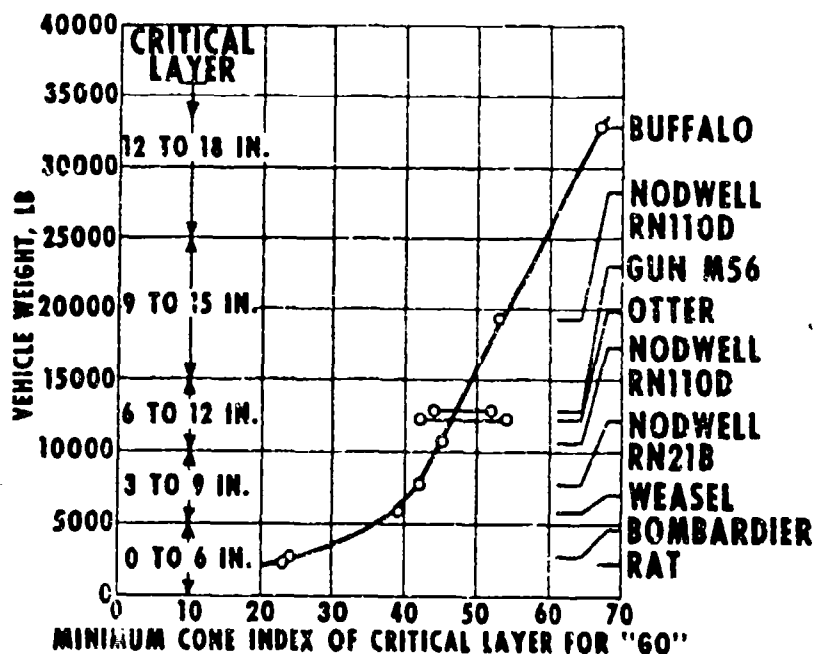


FIGURE 9

Effects of vehicle weight on cone index requirements for critical layer: Confined Muskeg Tests, Parry Sound, Canada.

indicated to the right of the weights. The minimum cone index (in the critical layer) required for the completion of 50 passes by each vehicle is plotted on the graph. The data have been idealized to some extent. The result is a fairly smooth curve, apparently indicating that vehicle weight is highly significant to vehicle performance. However, rather than viewing this presentation as a true relation of vehicle weight to minimum strength required for 50 passes, one should accept it merely as a trend that appears from the testing so far conducted. The real value of the presentation lies in the fact that specific critical layers and specific minimum cone indexes have been shown for specific vehicles, and this is information that military commanders in the field can put to good use. Even this must be qualified by the statement that the values are approximate and subject to change pending the accumulation of additional data. Exactly why the relations are as they are is obviously of basic importance if a true understanding of vehicle-muskeg relations is to be attained. However, an

attempt at this understanding, while it is in progress at WES, is beyond the scope of this paper.

Fort Wainwright Program

The tests in the Fort Wainwright area were conducted on unconfined muskeg of varying thickness. For most tests, permafrost was present within 30 to 36 in. of the surface and had a significant effect on vehicle performance. The fact served to complicate correlations between muskeg strengths and vehicle performance, since it was not feasible to separate the effect of muskeg strength from the effect of the depth to the frozen sub-surface layer. However, it was feasible to demonstrate that certain muskeg strength-depth to permafrost combinations permitted go conditions, while others did not. This is illustrated by Figure 10, for the M116 personnel carrier. Here the open symbols represent tests in which no immobilization occurred before 50 passes, and the closed symbols represent tests in which the vehicle was immobilized before completing 50 passes. As can be seen, the dashed line fairly cleanly divides the two types of symbols.

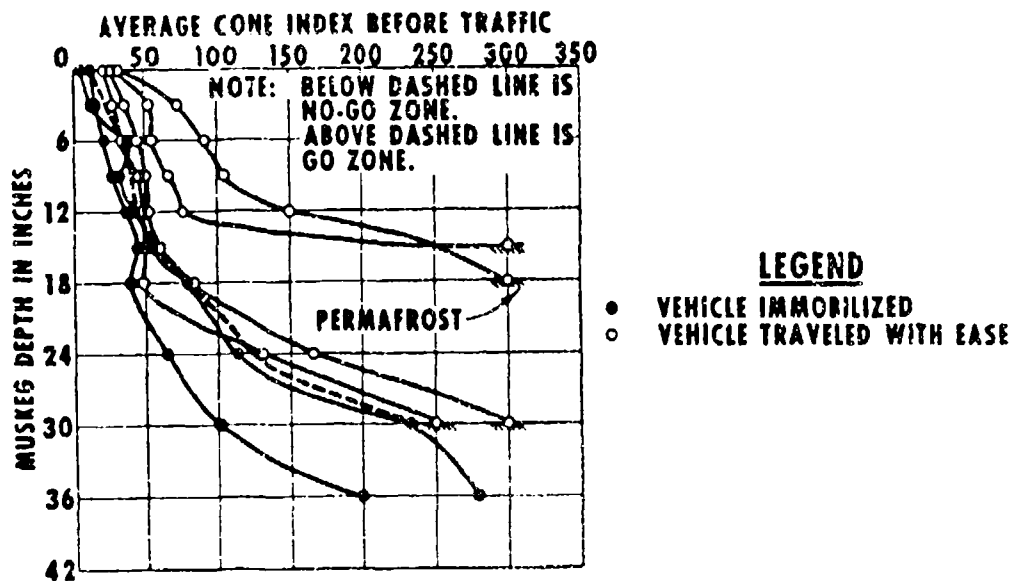


FIGURE 10

Example of effects of cone index on vehicle performance: M116 Personnel Carrier (7600 lb) Unconfined Muskeg Tests, Fort Wainwright, Alaska.

SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

Summary

On the basis of field test programs in snow and muskeg of admittedly limited extent, it has been possible to show approximate effects of measured characteristics of snow and muskeg on vehicle performance in these media. In snow, the type, wetness, depth and strength appear to be of significance, while in muskeg, the strength and depth to a frozen layer appear to be most important. The relations found are defensible only on the basis of the data from which they are derived. They should be considered tentative and subject to refinement or change when additional data are collected or when a deeper understanding of the mechanics involved has been found.

Future Research

Future research should emphasize trafficability testing; additional vehicles should be tested in wider ranges of snow and muskeg conditions. A massive, statistical approach to the problem, however scientifically unsophisticated, is bound to pay dividends. It is the only way we can put vital tools in the hands of field commanders should the need arise tomorrow.

Trafficability testing so far has emphasized the effects of the strength of the medium on the "go-no go" performance of the vehicle. We need also to increase our efforts toward a better understanding of the ability of vehicles to surmount obstacles, to accelerate and maintain speeds, to maneuver, and so on. We also need field studies that will relate the amounts of fuel consumption, driver fatigue, vehicle durability, etc. to quantitative measures of the terrain. Such studies are now underway in mineral soils in connection with a VEH mobility research program in Southeast Asia. They should be duplicated in cold regions.

There also is a need to intensify research on remote means of estimating the trafficability of snow and muskeg. Field commanders will not always have the opportunity to make trafficability measurements, simple as they may be. This area of research is certainly a good example of where the interdisciplinary approach can be applied profitably, for here the geologist, the botanist, the engineer, the cryologist and the meteorologist all can play an integral part in identifying and classifying various types of snow and muskeg in terms of their trafficability. It is

also a fertile field for the use of remote sensors, such as infrared rays and radar, to aid in determining the trafficability characteristics of snow and muskeg.

Certainly classical, scientific, laboratory-type studies, of the kind in which Cold Regions Research and Engineering Laboratory and McMaster and other universities engage, to discover, identify and measure just what factors combine and contribute to give strength to snow and muskeg, should be continued and expanded.

Finally, the most potentially fruitful of all the areas of additional research is that aimed at developing fundamental relations between vehicles and the media on which they operate. The Land Locomotion Laboratory and the Waterways Experiment Station both are deeply involved in this type of research, but the problem is so important and so complex that there is room for additional researchers in the field with little danger of duplication.

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A SUMMARY OF WATER-SUPPLY PROBLEMS IN ALASKA*

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The vast size of Alaska, its location high in the northerly latitudes, and the extreme range in climate and topography create diverse hydrologic conditions and, consequently, diverse hydrologic problems. Although many of these problems are basically the same as in other areas, different techniques may be needed to locate, develop, treat and distribute water. Special problems are created by the presence of permafrost in the northern 85% of the state, and the ingenuity of the engineer and hydrologist is taxed to overcome conditions caused by ground that is perennially frozen.

As in other areas, water supplies in Alaska are derived mainly from surface-water or ground-water sources. In some places neither of these is available and supplies must be obtained from sea water or snow and ice. Utilization of any of these sources is controlled, at least in part, by the quantity and quality of water needed for a specific purpose. Obviously, economics is an extremely important factor.

PROBLEMS INVOLVED IN UTILIZING SURFACE WATER

Among the various problems that affect the use of surface water as a source of supply are: freezing, turbidity of stream, chemical quality of the water and contamination.

In arctic and subarctic regions, lakes and reservoirs less than 10 ft deep may freeze to the bottom, thereby eliminating them as a source of supply in the winter. Although deep, swift-moving streams may not freeze to their beds, anchor or frazil ice may plug or damage intake structures.

Although the turbidity of streams is small in many parts of the state, glacial action in other areas contributes appreciable quantities of very fine rock flour. The sediment load of most glacially fed streams varies in response to climate. For

* Publication authorized by Director of U. S. Geological Survey.

example, the sediment load of the Gakona River at Gakona ranged from about one-half ton per day in January 1954 to 198,000 tons per day in August of the same year. Sediment concentrations over 2,000 ppm (parts per million) in glacial streams are common. When rock flour is present, its removal would usually be difficult and costly.

In general, the available data indicate that in regard to chemical quality, surface waters in Alaska are suitable for most purposes with little or no treatment. However, in shallow lakes that do not freeze to the bottom, partial freezing may concentrate dissolved mineral constituents to such an extent that the water is unfit for use or requires special treatment. In addition, trees and various plants contribute organic material which becomes detrimental in standing and slow moving water. This organic material may make the water unpalatable and cause discoloration. It also combines with iron and manganese, making their removal more difficult.

Large-scale pollution of surface waters in Alaska is not widespread. However, as population increases and industrial development takes place, contamination and pollution of streams and lakes are likely to occur, at least in local areas.

PROBLEMS INVOLVED IN UTILIZING GROUND WATER

Problems involved in utilizing ground-water supplies include locating and developing wells and infiltration galleries, permafrost, and chemical quality of ground water.

Locating ground-water supplies in Alaska may be simple or difficult depending on local geologic conditions. The principal aquifers include layers of sand and gravel incorporated within glacial deposits, glacial outwash and alluvial deposits. The most productive aquifers are in the major valleys, such as the Yukon or Tanana, where hundreds of feet of sand and gravel have been deposited by streams. Fairbanks and Anchorage both utilize water from such aquifers.

Consolidated rocks are generally poor aquifers, although they are capable of small yields in most places and locally might yield moderate quantities of water.

The availability of ground water over much of interior, western and northern Alaska is intimately associated with the occurrence of permafrost. North of the Brooks Range, for example, potential aquifers are frozen to as much as 1,300 ft, and even though water is present below permafrost, it is likely to be saline. Permafrost commonly is absent under and in the immediate vicinity of lakes and streams, and if water-yielding materials are present, ground-water supplies are attainable even in areas of thick and extensive permafrost.

Although southeastern Alaska has the highest rainfall of any part of the state, the rugged topography and generally impermeable rocks make development of ground-water supplies difficult. Unconsolidated alluvium and outwash deposits at places in this part of the state provide water to wells, and raised beach deposits may be productive in some areas.

Ground-water supplies are most commonly developed by means of wells, but under certain geologic and hydrologic conditions, infiltration galleries are superior to wells (2). For example, in areas where water-bearing surficial deposits overlying impermeable rocks are too thin or discontinuous to permit drilling, a gallery may be the only way of getting a water supply. Where surficial deposits are absent, bedrock galleries may be used to tap fault zones or other water-bearing fractures in the bedrock.

The chemical quality of ground water affects its use for many purposes. Where certain constituents are present in undesirable amounts, treatment is required. Iron is the most troublesome chemical constituent of ground water in Alaska, although hardness of water is a significant problem in some areas. Ground water of high salinity is a problem in parts of the Copper River basin. Saline ground waters are present in coastal communities such as Barrow, Homer, Kotzebue and Nome.

Corrosiveness of ground waters, due to the high carbon dioxide and dissolved oxygen content, is a common problem in many areas.

Ground waters in some parts of the state have a high organic content derived from ancient vegetation buried with the sediments. The organic material adds to the acidity of the water and combines with iron, making its removal difficult.

Where aquifers are at shallow depths and are overlain by permeable material extending to the surface, there is likelihood of pollution from sewage, fuel oil or other contaminants.

Many of the quality-of-water difficulties can be handled by proper treatment. However, some of them can be avoided by careful prospecting and adequate testing of the hydrologic conditions at a specific site. Proper construction practices can do much to reduce or eliminate contamination and pollution.

PROBLEMS INVOLVED IN UTILIZING SEA WATER

The main problem involved in using sea water as a source of supply is the large amount of energy needed to remove the dissolved minerals. According to estimates by Nehlsen (3), distillation units of the vapor-compression type yield about 25 gallons of water per pound of fuel. Cost of water for a 25-man camp is estimated at \$158 per 1,000 gallons and for a 100-man camp, at \$50 per 1,000 gallons.

The efficiency of most desalting methods is quite low — ranging from less than 1% to about 9% (4). Even though efficiencies are low and the costs are high, the urgency of situations vital to national defense may make cost an insignificant factor.

Operation of some desalting units requires trained personnel, and maintenance may be an important problem in arctic areas far removed from sources of supply of parts for equipment.

To increase efficiency and reduce costs, new methods of desalting sea water are continually being devised and tested. Some of these methods may drastically reduce the high-energy requirement. However, most of them are still in the experimental stage, and because of various technical problems, many may never be practical.

PROBLEMS INVOLVED IN UTILIZING SNOW AND ICE

The main problems involved in using snow and ice as a source of water are the high cost, resulting from the high-energy requirements, and the danger of pollution. W. R. Nehlsen (3)

estimated the cost of producing snow-melt water for a 25-man camp at \$78 per 1,000 gallons and for a 100-man camp at \$62 per 1,000 gallons. These estimates were based on a 2-year camp duration.

As pointed out by Alter (1) low temperature conditions are conducive to prolongation of the life of pathogenic bacteria and promote careless disposal of sewage and waste. The same low temperature conditions lead to the use of surface and shallow ground waters which are subject to pollution. Thus, the need for protection and treatment of such water supplies seems obvious.

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LONG DISTANCE RADIO COMMUNICATIONS IN THE POLAR REGIONS

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Long distance communication with medium power is usually accomplished by using frequencies in the 1 to 30 megacycles per second (Mc/s) region (medium and high frequency bands, MF and HF). These frequencies are reflected by "clouds" or "layers" of free electrons in the ionospheric portion of the high atmosphere. Free electrons are produced by the bombardment of the atmospheric gas constituents with sufficiently energetic particles or photons. Electrons are essentially physically knocked off the atoms during the collision of the particle with the gas atom.

The ionosphere has been classified into regions according to height. The D region is in the 60-90 km range, E is 95-150 km, and F is 200-500 km.

The speed of a wave propagating in a medium containing free electrons is increased from that in free space; thus it is refracted in the usual optical sense. If a ray is obliquely incident upon a slab of electron gas, the ray will be bent so it becomes more parallel to the slab surface. Now, if several slabs of increasing density are present, the ray can be bent sufficiently, that its direction of propagation is away from the slabs. In this case, we say the ray has been reflected.

The electron density and the angle of incidence from the vertical, of the wave upon the layer of electrons determine whether or not a given frequency will be reflected from a given height. Any frequencies f_1 and f_2 will be reflected from a given height if they are related by the secant law:

$$f_1 \cos i_1 = f_2 \cos i_2$$

where i_1 and i_2 are the respective angles of incidence.

Thus for example, if 5 Mc/s is reflected at vertical incidence (0° angle of incidence) from a height of 250 km, at 60° 10 Mc/s and at 80° 29 Mc/s will be reflected from the same height. If the

maximum frequency reflected at vertical incidence is, say, 6 Mc/s and its height of reflection is 400 km, the maximum frequency which could be received from a receiver placed 2000 km from the transmitter (angle of incidence 63.5°) would be about 13.5 Mc/s. For all higher frequencies the receiver would be in the "dead-" or "skip-zone."

The problem, then, is the determination of ionospheric conditions at the mid-point of the path over which communications are desired. This paper will briefly discuss two direct methods presently used to determine ionospheric conditions and to predict communications conditions, and some of the phenomena which change the ionosphere over short periods of time.

If one transmits a signal at oblique incidence, the ionosphere and the ground reflect and scatter the energy. The energy scattered back to the transmitting site is termed oblique backscatter; that which is reflected is termed the forward, oblique signal.

Backscatter from short pulses can be used to determine propagation conditions if the scattering surface is the ground. This technique has been used for some time and is a fairly reliable means for gross, short-term predictions.

Recording the actual signal over the path at various frequencies is a better method because one can determine the best frequency for communications. The problem, of course, is how one communicates between sites to decide which of the allowable frequencies will be used.

In the mid-latitudes the ionosphere seems to be primarily controlled by solar radiation and so is moderately well behaved and predictable. At high latitudes, though, auroral and polar cap precipitation events produce serious changes within a relatively short time and from day to day. At present, we cannot predict what sort of changes will occur, and that is essentially our research task.

Auroral precipitations apparently produce several effects on HF propagation. During an auroral disturbance, abnormal E region ionization appears in the 100 to 120 km region. This sometimes is capable of supporting propagation to great distances even in the VHF region. This sporadic E ionization is thought to be produced through the ionization of the atmospheric gas atoms by the primary auroral particles. Thus, an auroral precipitation can enhance propagation conditions.

If the auroral precipitation is intense enough, a significant amount of its energy can be deposited in the D region, producing abnormal D ionization. This ionization strongly absorbs 1 to 30 Mc/s waves rather than reflecting them as does similar E region ionization, and thus, an auroral disturbance can also produce a serious decrease in signal strength and hence disrupt communications.

There appears to be some evidence that strong auroral disturbances affect the F region. The exact mechanism is presently unknown, but some workers feel that atmospheric heating can cause the atmosphere to expand, thus increasing the gas density in the F region. This increased gas density decreases the mean-free-path in the F region so the free electrons recombine at a higher rate than normal, thus reducing the F region electron density. This is, however, not definitely established, and not everyone agrees.

During a solar, cosmic ray flare high energy particles are emitted from the sun. A significant portion of these particles are protons with energies in the 1 to 100 Mev (million electron volts) range. These particles are excluded from most of the earth's atmosphere by the geomagnetic field, which tends to deflect the particles unless they have very high energies. On the polar cap, however, the magnetic field is almost vertical, and the particles can reach the high atmosphere. These events are rare, occurring only once or twice per year during sunspot minimum. The cut-off latitude for these cosmic rays is quite sensitive to the energy spectrum of the incoming particles and is usually near the auroral zone except for the great events. Above the cut-off latitude the precipitation is considered relatively uniform over the entire polar cap.

Because of the relatively high energy of the solar flare cosmic rays, their major effect is in ionizing the D region in the 60 to 75 km region. Such ionization produces strong MF and HF, and low VHF absorption; thus it seriously affects polar communications even for short distances of a few hundred kilometers.

It is the nearly vertical geomagnetic field which makes the polar regions interesting from a research standpoint. Our program is directed toward the understanding of how and why the polar ionosphere behaves as it does. We use both the oblique backscatter and forward sounding techniques in an effort to determine ionospheric conditions hundreds of kilometers away where no vertical sounding equipment exists. Our interest is in

determining the effect of particle precipitations and the attendant geomagnetic disturbances on the ionosphere. From this knowledge we hope to be able to make better short-term communications predictions.

Figure 1 shows typical F region-supported pulse signals from Greenland and Norway to College, Alaska. From such records one can easily pick the proper communications frequency. Figure 2 shows typical winter signals received during sunspot minimum via the E region. Figure 3 shows the maximum and the average Maximum Observable Frequencies (MOF) recorded between December 1963 and February 1964 from Thule, Greenland, and Andoya, Norway; one notes that frequencies in the 10 to 20 Mc/s band would have been the best to use for communications during that period.

In general, we have found that if long distance communications are disrupted because of some abnormal disturbance, the best technique is to shift to a higher frequency rather than lower as is now the practice. Absorption effects decrease rapidly with frequency, and propagation over non-great-circle paths appears more prevalent at higher frequencies. During great polar cap absorption events, polar communications are probably not possible, but these events occur only rarely. Though they sometimes last up to several weeks, their effects diminish quite rapidly.

Auroral disturbances are not associated with cold weather as is commonly believed. They occur frequently during all seasons of the year. They are observed during cold weather, in the winter, because only then are the arctic skies free of clouds. It is the lack of cloud cover that causes the extreme cold temperatures, and simultaneously allows one to observe the aurora by eye. The proper equipment shows conclusively that auroras are as prevalent during warm, cloudy weather as during cold, clear weather. Weak correlations have been claimed between solar disturbances and the weather, but this is a controversial point.

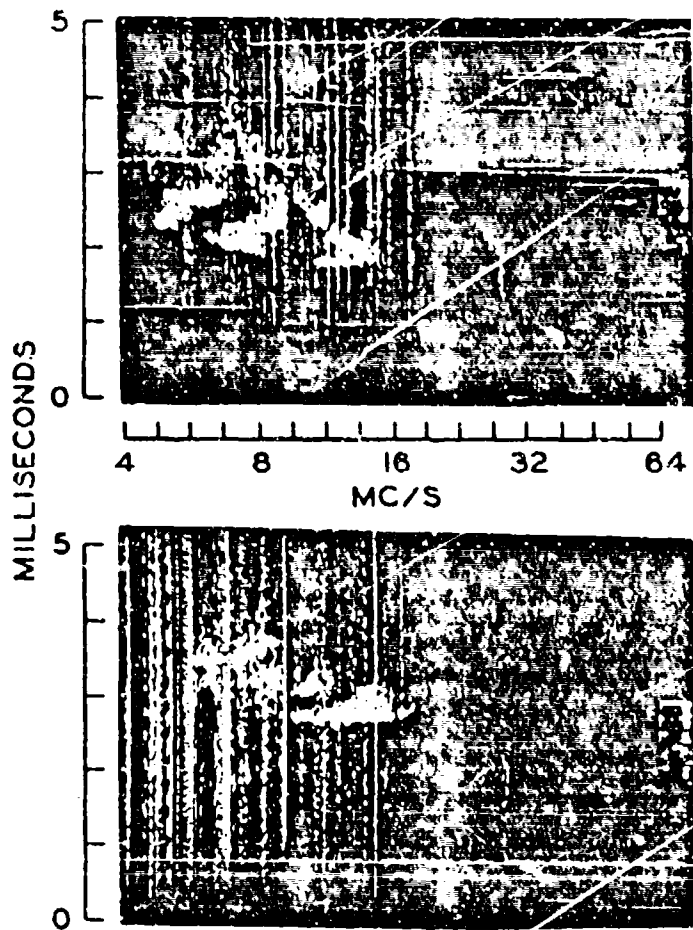


FIGURE 1

Forward oblique ionograms from Greenland and Norway showing F region propagated signals.

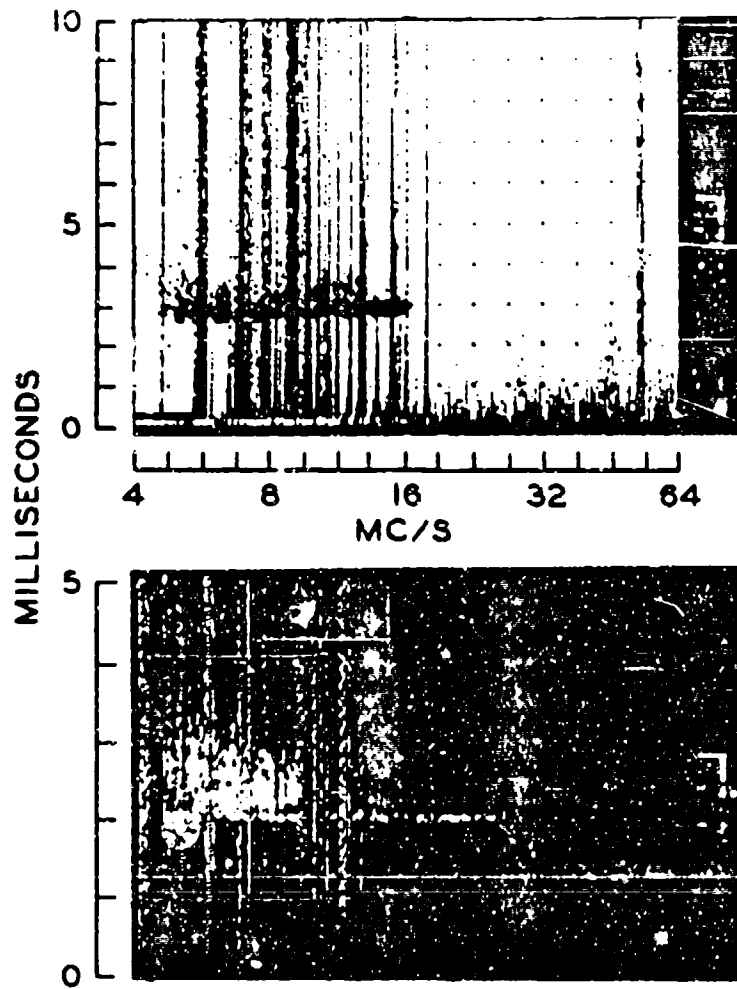


FIGURE 2

Forward oblique ionograms from Norway showing signals propagated via sporadic E ionization.

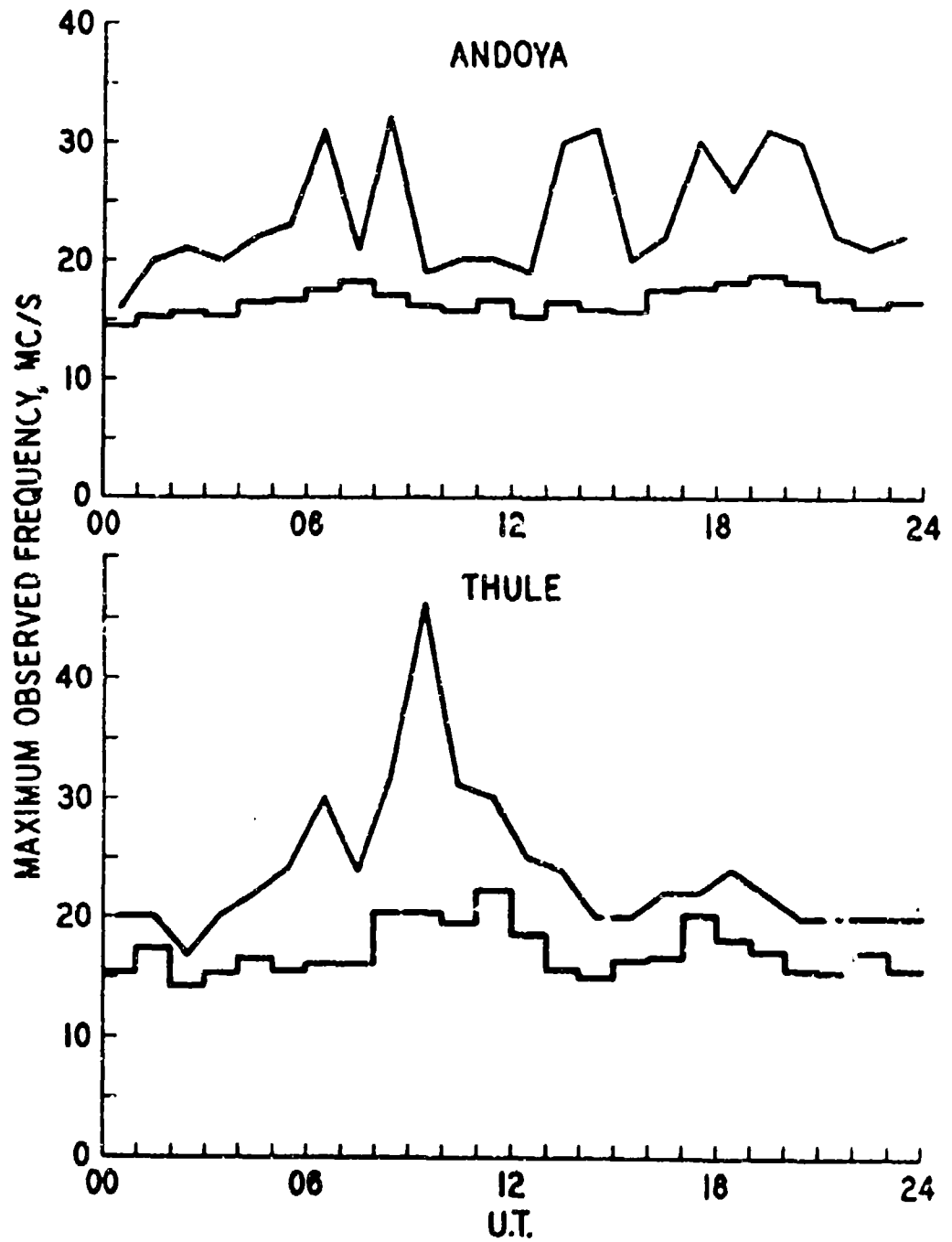


FIGURE 3

Average and maximum MOF values for the Norway and Greenland signals recorded at College, Alaska, from November 27 through February 12, 1964.

A SUMMARY OF ARMY ENVIRONMENTAL RESEARCH IN ALASKA

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MILITARY CONSTRUCTION INVESTIGATIONS

Until World War II, permafrost was a curiosity to the people of the "Southern 48" and of little concern to the military. Then came the need to defend Alaska and utilize it as a supply route to Russia. Highways, airfields and military bases were all needed quickly, and considerable construction was undertaken utilizing procedures and criteria that had been proven in the temperate zones. The results were sometimes disastrous. Runways heaved in the winter and ice melted beneath them in the summer, resulting in a surface from which aircraft ultimately could not operate. Foundations settled and buildings were damaged. Military bases in some cases were poorly sited. It was clear that a research and investigational program was needed to develop criteria for military design and construction in the Arctic and Subarctic. Such a program was initiated by the U. S. Army in 1945 and continues to the present time, covering foundations, pavements, utilities, hydrology and drainage, site selection, thermal regimes, construction materials and many related aspects.

A study of pile foundations in frozen ground conducted under this investigation is the most comprehensive research on this subject carried out on this continent — and probably in the world. Some of the aspects studied have been installation techniques, natural or artificial freezeback, the potential adfreeze strength of the frozen ground and economical measures for preventing or reducing pile heaving caused by frost action.

To substantiate laboratory findings, test sections were constructed at the Fairbanks Field Station a few years ago to measure the relationship between surcharge load and frost heaving. An increase in surface load produces a decrease in frost

heaving. By using sufficient load or depth of gravel fill, frost heaving may be held within tolerable limits. The results of these tests are being used in the design of airfields, roads and building foundations.

U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) is constructing at the Fairbanks Field Station this summer (1964) a short experimental roadway over permafrost. The purpose of this roadway is to study the various thermal parameters which affect its stability. Heat absorption and emission properties of white and black pavements and of gravel will be related to climatological factors and to the long-term thermal balance within the subgrade and the underlying permafrost. In a portion of this roadway, compressed peat blocks will be placed beneath the base course in an attempt to control the rate of permafrost degradation. The white and black pavement surfaces will provide data relative to thermal gradients through such pavements. A very large number of individual studies on construction projects offering special problems have been carried out under the Military Construction Investigation Program since 1945, many of them in the closest cooperation with the Alaska District of the Corps of Engineers. All studies have been aimed at understanding basic principles, but even strictly empirical knowledge has proved highly useful.

While it can be said that construction of any facility can now be undertaken with a confidence that it will remain structurally as stable in Alaska as though it were built in a temperate region, it is also true that the factors of safety may be excessive (because of the incompleteness of our knowledge) and that such construction can be very expensive. Construction costs may be four times or more those encountered in more moderate climates. The additional materials needed for such items as a thicker base course beneath road and airfield pavements and extra insulation for utility pipes etc. amply justify expenditures on research that may reduce costs or permit the use of smaller "factors of ignorance."

APPLIED RESEARCH

In recent years the Army has been devoting increased attention to applied and basic research on operational aspects, in

addition to problems associated with military construction. Recently a series of cratering tests were conducted at a site near Eielson Air Force Base to determine the optimum type and amount of explosive required to produce a foxhole or a crater of any given size in permafrost. The holes to receive the explosive charge were made by augering or by drilling, an operation that might be impractical in time of war. Later a study was conducted which would permit these explosives to be implanted to the proper depth by dropping missiles from the air. Another project developed a capacity to create these holes by use of shaped charges of a special design.

A tunneling project in permafrost is currently active at Fox, a few miles north of Fairbanks. At least four different methods of excavating the tunnel which involve new concepts or adaptations of old techniques have or will be tested. In addition, design criteria for optimum roof spans and roof shapes and for refrigeration and ventilation, as well as specifications to evaluate the shock and blast resistance of such an underground fortification, will be developed. The tunnel is presently deforming (closing) at a fairly rapid rate. This may be attributed to the presence of air in excess of that needed to fill the normal voids in the soil. Correlation of the tunnel closure rate to the temperature, ice content, soil type and overburden pressure is sufficiently complex that our engineers and scientists will be busy on this problem for several years.

Both sea and fresh-water ice are being actively studied. These investigations include measuring the strength properties of ice, from which curves for bearing capacity to support wheel loads can be prepared. USA CRREL has developed a milling machine, sometimes called an "ice chipper," which is capable of being dropped by parachute onto the ice and can quickly cut down pressure ridges and level the ice surface to permit aircraft landings.

A terrain analysis project initiated some 14 years ago to evaluate soil types and permafrost conditions in Alaska by means of aerial photographs is being reactivated and expanded. Aerial photographs aid in determining soil types in various climatic zones. The analysis is then verified by field study. Investigations are also in progress involving the utilization of several geophysical techniques which may provide information about the physical characteristics of the subsurface. One method under study is the use of aerial radio frequency sounding to obtain the depth to permafrost.

BASIC RESEARCH

We are of the opinion that any further substantial progress in the development of the Arctic for military purposes must come from the results of basic research. The amount of effort in this direction is being increased. The following paragraphs summarize some of the work of this type that USA CRREL is now pursuing.

A study of some of the clays found in Alaska is being undertaken. One clay, a bentonite found in the Umiat area, is of a commercial quality; in some respects it is superior to that now generally used in the drilling industry. It has the capacity to swell and hold water up to 20 times its dry volume. This, of course, affects its engineering behavior. For example, much of its water remains unfrozen at temperatures substantially below zero, and thus it still has sufficient liquidity to promote slipping and, in some cases, dangerous slides. Since this clay is almost impervious to the passage of water, it may well affect the ground water characteristics in those areas where extensive deposits are located. Other clays, such as those at Healy, do not swell but remain partially unfrozen and are a cause of slides in these areas. For example, a slide above the Usibelli mine near Healy is now a serious problem. Slides have also occurred during the building of a tunnel for the Alaska Railroad near Healy, and of course, the much publicized Turnagain slide during the Anchorage earthquake took place in a saturated silty clay. Obviously some clays are more detrimental than others in these respects, and the properties of each during freezing and thawing need to be determined to discriminate and identify those that may be a potential hazard to construction. Our basic research on clay is directed toward a study of the mechanism by which clay holds water so tightly that it will not freeze and yet so loosely that "glide planes" exist.

In recent years the Rampart Dam project has received considerable publicity, and the extent that it might alter the local climate of the area has been discussed. If the matter is to be resolved, the magnitude and historical sequence of the climatic fluctuations in the area must be determined. An attempt to gain this knowledge through a method of tree ring analysis shows some promise. There is a significant relationship between radial tree growth of spruce at timber line and temperature during the growing season. Within the confidence limits of the correlation achieved between known summer temperatures and tree growth, we hope to infer the annual and longer term variation of the summer temperatures for the past 200 to 300 years.

Another possible indicator of climatic change is the ecological succession in Alaska's lakes. Subtle changes in the micro-environment lead to the extinction of one plant community and its replacement by another. CRREL, through contract, is conducting a combined air photo and field study of the bog lakes at Northway. These were selected because aerial photography is available over the last nineteen years.

A rather comprehensive research program in permafrost hydrology is being established this year. The program is presently limited to a small drainage basin in Central Alaska (north of Fairbanks). Measurements are being taken to locate the position of the freezing line as it migrates through the snow cover, the surface water and the soil during the freeze-thaw periods of the year. It is also planned to establish the influence of the configuration of the top of the permafrost table on interflow and percolation and to determine the general effects of shallow permafrost on the hydrograph. In addition, the general water balance and the production of sediment will be studied. On a much broader scope, samples will also be collected from various Alaskan rivers to see how adequately sediment sources can be identified by the mineralogy of the suspended material.

For the past 3 years an investigation of the physical and chemical properties of the active layer and the underlying frozen ground has been underway in the Pt. Barrow area. These studies supply basic information related to seasonal and long-term changes in wet arctic soils and provide quantitative data for the interpretation of surficial changes in a cold regions environment. As a result of this study, two observations seem warranted at this time. Based upon seasonal probings and visual observations, it is observed that the depth of the present-day thaw zone is at a maximum for the recent past. This conclusion supports other data which indicate that a warming trend has been in effect during the past century. Secondly, our observations show that in a specific natural tundra area, those soils with a high frost susceptibility, as indicated by soil churning, frost scars, etc., have a lower concentration of soluble salts than similar soils in adjacent areas of less frost susceptibility. The other properties of this soil, which is a fine-grained coastal plain deposit, are substantially the same.

Other basic research tasks that should be mentioned are the snow cover studies (made by the University of Alaska and the Soil Conservation Service for CRREL), the ice fog studies and the work on migration of fine-grained particles through a coarse-grained soil during cyclic freezing and thawing.

FUTURE RESEARCH

The U. S. Army has traditionally been among the pioneers in pushing the frontiers of our country first to the Pacific and now to the Arctic Ocean. It is self-evident that it is much easier to defend and occupy a land that has a healthy economy and a large, stable, non-transient population. In the long run, military research that also assists the State of Alaska to achieve a sound economic growth will prove to be more important than the development of hasty expedient defense techniques.

It is difficult to draw comparisons between the two land masses that border the Arctic Ocean. The Russian areas may be either milder or much colder at comparable latitudes. Obviously the cultures of the two peoples, and their political and economic outlook, are quite different. Nevertheless, it should be pointed out that several million people are permanently established in Siberia at and north of a latitude of about 64° , equivalent to the land mass contained in the upper half of Alaska and the upper half of Canada's Northwest Territories. Most of this increase in population and development of the Soviet Arctic has taken place since World War II. During this time the northern sea route became a reality, making possible the rapid growth of settlements along the Russian Arctic coast. In general, the principal cities were located on the coast at the mouths of north-flowing rivers which intersect the Trans-Siberian railroad to the south. Traffic loops vital to the development of any country were thus established.

If Alaska and Northern Canada are to see equivalent development and growth, they also must create adequate transportation routes. Offroad trafficability is not sufficient on a long-term basis. This truth is, of course, that long-range plans have been prepared for extending the highway system. As a part of this long-range planning and to reduce the cost of a highway construction program, the U. S. Bureau of Public Roads, the State Highway Department of Alaska and the U. S. Army Cold Regions Research and Engineering Laboratory have joined in an agreement to conduct research that will be of mutual benefit.

Alaska must also achieve an industry that processes and produces finished goods for export. It should not be allowed to become only a colonial exporter of raw materials. The key to sound development is power. The world is depleting its reserves of oil and gas. Every year the exploration for, and the development of, producing fields occurs in increasingly more remote

areas. The development of an oil industry in Alaska is inevitable and will eventually be highly important. If oil is simply exported for use elsewhere, its full potential for Alaska's development will never be utilized. An important step in this direction is being taken in the establishment of the new electric power plant at Healy, which gets its energy from coal. This plant may ultimately provide the entire area, including Fairbanks, with power.

Consideration should also be given to exploiting the truly great inexhaustible reserves of hydroelectric power that are available to the state. The problems created by filling river valleys with water, flooding valuable farm land and displacing large populations are still minor in large unoccupied areas of the state. An unlimited amount of cheap power is the foundation for processing raw materials and converting them to finished goods. If the raw materials are contiguous to the power supply so much the better, but proximity is not necessarily vital. Iron ores, for example, now are being brought to the smelters of Pittsburgh from Labrador and South America. Bauxite ores might easily be shipped to Alaskan ports for processing into aluminum. Future processing plants for the production of nuclear fissionable material might be located to use this power and release equivalent amounts in other parts of the U. S. Cheap abundant power to heat homes and factories, and even to support (as a minimum) limited truck gardens under glass may well be major considerations for future growth of the state. By providing clean, economical heat and other residential and industrial power supply, it might also reduce atmospheric pollution and eliminate the ice fog problem. The production of fertilizers and chemicals should be considered, at least for local needs.

A factor to be emphasized in considering Alaska's future is the probable importance of the recreation industry. The projected population figures for the United States and the world would seem to assure that any remaining wilderness area will become more and more attractive to the tourist. With better and more extended transportation routes to and within Alaska, this industry is bound to increase in importance. Already it contributes about \$20 million to the state's income annually, an amount approximately equal to all income from mining and about one-half that derived from forestry.

In the furtherance of this development program, USA CRREL, as previously mentioned, is participating with the Alaska State Highway Department and the Bureau of Public Roads in research to provide better roads at lower costs. The problems associated

with the construction of dams and structures in areas of permafrost are being considered, as are methods of installing piles, power poles, towers, etc. Development of remote sensor systems is in progress to permit better site selection and rapid evaluation of large land areas. Methods for thawing the frozen ground to increase the depth of the active layer are being explored. If a deeper active layer can be established over large areas, it might then be possible to supplement the civilian economy with selected home-grown agricultural products suitable to such an environment.

CRREL by direction of the Research and Development Directorate of Army Materiel Command is reorienting its research program to give increased emphasis to Alaska. We welcome the opportunity to join with others in the building of a stable, vigorous Alaska.

THE LIFE SCIENCES RESEARCH APPROACH TO IMPROVED
MILITARY EFFECTIVENESS IN THE ARCTIC

Lt. Col. William H. Hall, MC
Commanding Officer,
U. S. Army Research Institute of Environmental Medicine

"There is no cheap, easy or comfortable way to be prepared to deter or to defeat calculated and determined aggression aimed at our destruction. The land battle must be fought by soldiers in person on the battlefield; it cannot be conducted by computer; a front line cannot be held by television cameras; radar is not a fully adequate substitute for scouting and patrolling. In short, the personal involvement of the soldier in the land battle has not been relieved by technology; his mind and muscle are augmented, but not supplanted by the machine; his morale, determination and will are not duplicated by any electronic circuit now in existence, or that is likely to be developed."

This observation by General Barksdale Hamlett, then Vice Chief of Staff, U. S. Army, is quoted in the March issue of the Army Information Digest and emphasizes the critical importance of the individual soldier. Science and technology have revolutionized the ways of war, as they have the ways of peace. As new machines and equipment multiply the effectiveness of the soldier, it is easy to be distracted from the fact that loss of the man still reduces the most elegant of his equipment to uselessness.

Man himself is also often the most vulnerable component of a man-machine system. This is especially apparent in the Arctic, where he is so highly vulnerable to the severe stresses of the climate that he must avoid them to survive. Since he is totally dependent upon his clothing and individual equipment, research and development efforts to provide him the best of these are clearly in his interests. What, however, is his need for basic research in the life sciences? No one expects us to somehow produce a superman, as effectively immunized against cold as he can be against smallpox or yellow fever. What then can the soldier reasonably hope for from life sciences research which will improve his capability to fight effectively in cold regions?

In answer, research in the life sciences offers the soldier new knowledge necessary for his improved protection and improved resistance, and to guide his improved utilization in the field. The following discussion attempts to analyze this segment of basic research in terms of these military purposes.

IMPROVED PROTECTION

The current U. S. Army arctic uniform provides excellent protection and implements the layer principle to achieve a high degree of flexibility. By removing layers, the soldier can adjust the maximum protection of the complete ensemble for less severe exposures or for heavy physical activity, with its accompanying multiplication of the rate of body heat production.

Excellent as the present cold uniform may be, however, fundamental improvements can be expected. Prominent among these are: first, improved protection for the extremities, particularly the hands, and, secondly, a reduction of the appreciable bulk and weight of the ensemble. These improvements depend upon advances in clothing technology, which in turn, are impeded by deficiencies in the present state of knowledge of the temperature regulation of cold-exposed clothed man. This complex of man, clothing and environment can be studied as an engineering system, and the production and distribution of heat within it can be analyzed over the entire spectrum of activity and exposure that the soldier might encounter. It should be entirely possible to describe this system by a mathematical model, which would predict the soldier's microclimate if his level of activity, the weather conditions and the heat-transfer characteristics of the clothing were known. Such a model would define the maximum protective effectiveness achievable by any combination of layers of any new fabrics or materials available or even conceivable. It could be composed so as to describe not only conventional systems but also advanced concepts, such as the thermal equilibrium suit. This model cannot be erected, however, until much more is learned, both about the transfers of heat among the layers in clothing and also about the physiological temperature regulation responses involved.

In brief, the biologically determined engineering design parameters for cold weather protective clothing have never been accurately defined. Research in the life sciences contributes to providing the soldier with improved protection by contributing to the detailed scientific description of these requirements.

An improved solution to the problem of cold weather protection for the hands also requires an extension of our physiological understanding. The limits of protection attainable from insulation alone have long been known, and what seems to be maximum achievable protection from insulation alone has long been available. Improvement seems to depend upon auxiliary heating of the hands.

This must be provided within such limits of weight, configuration, durability and reliability as to be a practicable item for the Infantryman in the field. This again poses many problems for clothing design and technology, but again, solution of these problems is interdependent on physiological research. The power requirements for satisfactory auxiliary heating must be precisely defined by a comprehensive analysis of the effects of combinations of exposure, over-all metabolic heat production and an auxiliary heat input on hand temperatures. More complete understanding of the relationship between hand warming and torso insulation is also required to define the optimal over-all clothing system to combine with devices for auxiliary heating of the extremities.

IMPROVED RESISTANCE

Research in the life sciences provides for improved resistance of troops by providing a basis for selection and conditioning of individuals. It is reasonable to expect such research to provide new knowledge which will permit the selection of groups of individuals either intrinsically tolerant of or particularly susceptible to cold exposure, and also to provide techniques for conditioning men to improve their intrinsic cold tolerance.

Detailed epidemiological studies of military cold injury have identified several groups of men especially prone to cold injury. These include Negroes, men from warm climates, men previously cold-injured, fatigued men and men with negativistic personalities. The greater occurrence of cold injury in certain of these may be due chiefly to their exercising less effective self-protection from the cold than do men normally. In other groups, however, there appears to be inherent susceptibility, which present knowledge of temperature regulation mechanisms is insufficient to explain. Neither is it presently possible to characterize in detail the greater cold tolerance which certain men enjoy. Life sciences research can be expected to identify in detail the physiological, psychological or biochemical characteristics which ultimately determine these variable degrees of intrinsic cold tolerance. It seems justifiable to hope that eventually an index of such tolerance could be reduced to sufficient simplicity and reliability to append it routinely to each man's physical profile. Extensive basic research, however, is first required to characterize in detail the extremely complex regulation of the production and distribution of body heat in cold-exposed men, which is the fundamental determinant of their intrinsic resistance.

In addition to identifying individuals by their inherent degree of tolerance to cold, research in life sciences may be expected also to guide the conditioning of men to improve their tolerance. In both animals and man, chronic cold exposure alters the response to cold so that there is greater production of heat biochemically and less severe shivering. In animals there is also an associated increased resistance to cold injury, and this presumably develops in man as well. A detailed knowledge of this process is a prerequisite to attempts to exploit it for the soldier's gain. Further research is needed into the nature of cold acclimatization and into the processes regulating energy metabolism, which is the body source of heat. It is reasonable to expect this research to contribute to improved conditioning regimens and conceivably to identify pharmacological agents that will augment cold tolerance safely by regulating the body chemical reactions producing its heat or by regulating the distribution of this heat to better advantage.

The biological problems involved in these efforts are immensely complex, and attempts at their solution can only be undertaken realistically in a very long-range program. The aims are full scientific understanding of the biological responses to cold. The approach to achieving this understanding is (1) to elucidate the mechanisms for accomplishing temperature regulation in the cold, including studies of the control of shivering and analysis of the metabolic aspects of shivering and non-shivering heat production; and (2) to describe cold acclimatization, including the mechanisms by which it results, indices for its measurement, its relationship to performance and practical techniques for accomplishing it.

IMPROVED UTILIZATION

The soldier can reasonably expect, further, that life sciences research will provide guidance for policies and practices of personnel utilization in the field, which will increase his effectiveness and decrease his danger from cold injury. He can expect a usable index of the degree of danger he experiences from various combinations of temperature and wind, and he can expect improved treatment of cold injury if he should suffer it.

It is not possible at the present state of knowledge to express cold weather climate conditions along a scale which will indicate

the extent of physiological stress they impose. If such an index were available, it would be a useful guide to the safe limits of exposure and could be used in the cold for this purpose, much as the WBGT Index* is used in the heat.

The principal climate features involved in developing such an index are simply air temperature and wind speed, and the Wind Chill Index, which combines the effects of these two factors, provides a good scaled measurement of the effective cooling power of the environment. At the present time, however, it is only possible medically to describe the general ranges of wind chill, which pose either no danger or moderate danger or severe danger of causing exposed flesh to freeze. There is need for such additional information as actual cooling rates of exposed toes, fingers, ears, etc. under various cold climate conditions, before actual safe tolerance times can be predicted reliably from measures of the weather.

Extensive research on the reactions of tissues to injurious nonfreezing cold is also needed to define the range of damaging exposure to nonfreezing cold. From such research, both an improved basis for rational preventive measures and also knowledge to guide improved treatment can be expected.

It is also reasonable to expect improved treatment of actual freezing injury or frostbite from further basic life sciences research. Experimental methods, such as the use of low molecular weight dextran, are of value in test animals, and more must be learned of their potential for benefit to injured men.

SUMMARY

In summary, the life sciences research approach to improved military effectiveness in the Arctic is the generation of knowledge upon which to base the development of new equipment, practices and procedures contrived to provide the soldier with improved protection, improved resistance and safer and more effective commitment.

* Index for measuring temperature: $.7 \times$ wet bulb temperature
 $+ .2 \times$ globe temperature $+ .1 \times$ dry bulb temperature.

Life sciences research contributes to improved protection for the soldier in cold regions by defining the biologically determined engineering design parameters for his environmental protective clothing. This research requires the thermodynamic analysis of the production of heat by the clothed man in the cold and the heat transfers by radiation, evaporation, conduction and convection between him and his environment.

Life sciences research contributes to improved resistance for the soldier in cold regions by providing criteria to judge an individual's cold tolerance and techniques for conditioning individuals for improved cold tolerance, by training, acclimatization or use of pharmacological agents. This research requires long-range detailed analysis of the regulation of the production and distribution of heat in the body.

Life sciences research contributes to improved utilization of the soldier in cold regions by providing him with safety limits of exposure and with improved treatment for cold injury. This research requires detailed analysis of the responses of tissues to intolerable cold exposures and of the clinical and epidemiological characteristics of the resulting injury.

THE ARCTIC SOLDIER: POSSIBLE RESEARCH SOLUTIONS FOR HIS PROTECTION

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Man is still fighting his two oldest enemies — his fellow men and his environment. When not required to battle both simultaneously, modern man has the latter reasonably under control. The cave has given way to the insulated home or the insulated quonset hut, the primitive campfire has developed through indoor fireplaces, the Chinese k'ang to modern central heating, and the bear skin robe has been supplanted by multilayered clothing systems incorporating natural and synthetic materials (21). So successful has man been in his terrestrial triumph over his environment that he now looks beyond wintering in a comfortable microclimate in the midst of the -100° F Antarctic, toward conquering outer space. His success has been almost solely technological; modern man is probably less well adapted biologically for living in the cold than his cave dwelling ancestors, who were inured and acclimated to a degree of cold exposure which modern man has been clever enough to avoid. The technological secret to living comfortably at Thule, Point Barrow or Little America is to avoid the cold and stay in an auxiliary heated microclimate (6). Unfortunately, it is currently impossible to defend against an enemy and simultaneously remain in a heated shelter; for the foreseeable future, man, when giving battle to his enemies, will have to leave the auxiliary heated microclimate of his shelter and face the cold. He then must replace the shelter with a good clothing system, and depend on and conserve his own metabolic heat production for survival.

The current goal for cold weather clothing systems, as stated in the required military characteristics, is 8 hours tolerance while inactive at -40° F when there is a 3 mph wind. This requirement has yet to be met. One of the most frustrating aspects of providing this level of protection is that it is easily done for all but 5 or 10% of the total body. The clothed active soldier in the Arctic has a surplus of body heat which is distributed to the hands and feet by way of the circulating blood. Unfortunately, the circulation to the hands and feet of the inactive soldier drops as he becomes cold, from about 100 cc/min to less than 1 cc/min, thus eliminating almost all circulatory heat input

to the fingers and toes (8). Thus the hands and feet, representing only a very small part of the body, are the limiting factors in tolerance to the cold (14, 20) (Figure 1).

The well recognized geometrical relationships of small cylinders; i. e., that increasing insulation thickness results in an increased area for heat loss, prohibits adequate practical insulation for the fingers and toes at an ambient temperature of even -20°F , using the best available insulating materials (19) (Figure 2).

Thus, conventional solutions are at an end of the line. The logical next step, one which somehow seems beyond the comprehension of many, is to turn again to technology to provide a tolerable microclimate. The history of auxiliary heating, studied since 1944, has recently been reviewed (18). Most of this early work involved extensive available power, as in airplanes; minimal power requirements were unknown but estimated as excessive on the basis of these earlier studies. The present paper summarizes results of a research program on auxiliary heating with minimum power, which has established the feasibility of two approaches: auxiliary heating for the extremities and, in the longer range, a conditioned air clothing system which has perhaps primary application in hot and/or toxic environments but could handle cold easily (17).

METHODS

Subjects were chosen from volunteers in the military test group. All were young men of average stature, in good physical condition and without previous cold injury. The complete Army Quartermaster cold-dry standard clothing ensemble (35 lbs; 4.3 clo*) was worn (Figure 3), except as noted below. The

*An arbitrary unit of thermal insulation, used in expressing the thermal insulation value of clothing. A suit of clothing has a thermal insulation value of one clo when it will maintain in comfort a resting-sitting human adult male whose metabolic rate is approximately 50 kilogram calories per square meter of body surface per hour, when the environmental temperature is 70°F . In terms of absolute thermal insulation units, one clo is 0.15°C

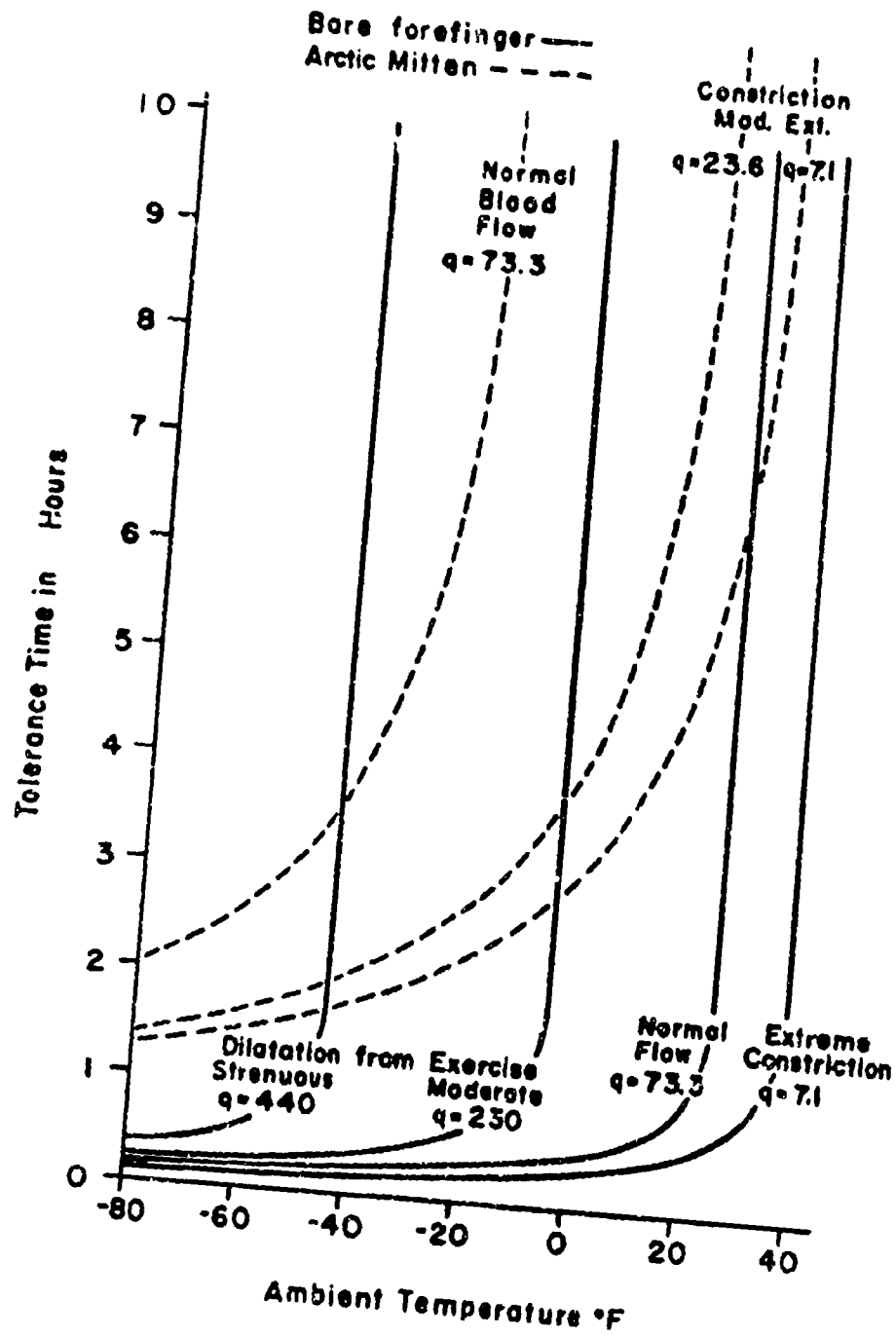
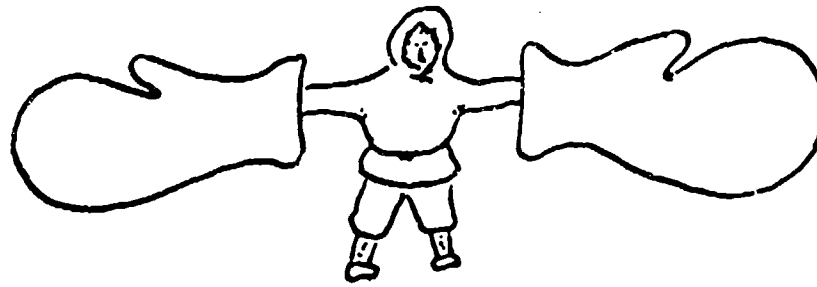
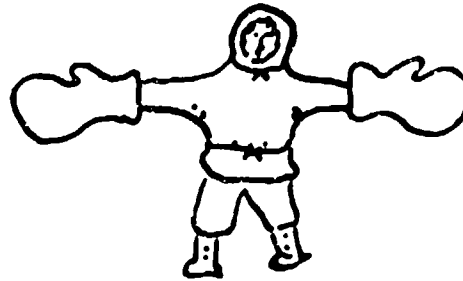


FIGURE 1

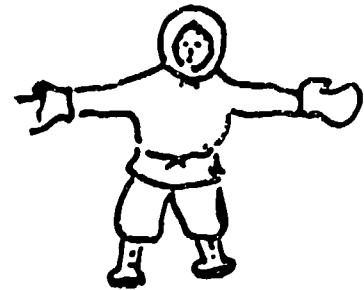
Tolerance time predicted as the time to cool to a finger temperature of 40°F , showing effects of activity level, body heat content and protective mittens.



ANY EXPOSURE, AT REST



6 HOUR EXPOSURE, AT REST



BEST POSSIBLE MITTEN, GOOD FOR

2-3 HOURS, AT REST

STRENUOUS EXERCISE, NO MITTEN NEEDED



FIGURE 2

Relative size of mitten needed for different exposure times at
-20° F.



FIGURE 3

The current U. S. Army standard chemical defense clothing ensemble.

research program was conducted over a 1-year period in five arctic chamber study phases; the first four at -40° F with a 10 mph wind and the fifth at -65° F also with a 10 mph wind. Three to five different subjects were studied in each phase. The subjects spent the majority of the chamber exposure periods (up to 7 hours on a single day) seated, peering through the arctic hood watching television or movies; standing in groups while talking and while eating a light lunch was allowed, but any exertion was prohibited. Rectal (T_R) and mean weighted skin temperature (MWST as the average of 10 points) were continuously measured, using thermocouple probes. Body heat storage (ΔS) was calculated as:

$$\Delta S = 0.83 \times \text{Nude Weight (kg)} \times \frac{(\Delta T_S + 2\Delta T_R)}{3}$$

In phase 1 auxiliary heat was supplied as a fixed flow of heated air delivered to the torso and/or hands and feet via several distribution garments, worn as an extra clothing layer over the long underwear (9); in phases 2 to 5 auxiliary heat was provided as electrical power to gloves and socks knit of wool and insulated resistance wire, worn in place of the standard wool glove and sock. Heat quantities supplied were calculated for the hot air systems by measuring the air flow rate (Brooks rotameter) and the garment inlet air temperature, for the electrical items from their resistance values (Wheatstone bridge) and the voltage output (Weston 0-30 AC voltmeter) of the individual variable transformers (Variac). The Variacs were supplied from a 24-volt transformer, thus limiting voltage and providing electrical isolation. Thermostating of electrically heated items (phases 3 and 4) was accomplished manually, using a thermocouple sited to act as a thermostat-sensing element. Finger cooling from thermostatically controlled set points (phase 4) was studied at hourly intervals (following the second hour of exposure) by shutting off power, removing the outer arctic mitten (a light leather glove was worn between the heating glove and the arctic mitten in this phase) and holding the hands with fingers extended above a chicken wire mesh platform until the fifth finger tip reached 40° F, when the outer mittens were replaced and power provided to rewarm the fingers to the selected set point. Phase 5, at -65° F, 10 mph wind, was conducted to validate the system recommended as a result of the first four studies.

per square meter kilogram calorie per hour. (Blakiston's New Gould Medical Dictionary, First Edition, New York, McGraw-Hill Book Company, Inc., 1949.)

RESULTS

The results of these studies will be presented in terms of typical individual responses, since there was day-to-day variation in heat supplied and in drape and back pressures of distribution garments.

Hot air supplied continuously to the torso in sufficient quantity to maintain body heat content at pre-exposure control levels ($\Delta S \approx 0$) was inadequate to maintain the integrity of the circulation to the hands and feet, and in all cases the exposure had to be terminated within 2 hours, when finger or toe temperatures reached 40° F, the established lower limit for safety in test procedures at this laboratory. A typical result is shown in Figure 4A; 8.6 cfm of heated air, entering the torso distribution garment at 110° F, provided an available mean enthalpy (calculated with reference to the mean skin temperature at 5-minute intervals during the period when air was being provided) of 0.87 kcal/min. This distribution garment allowed a little heat flow over the hands as well as the torso. Rectal temperature remained essentially constant, and mean weighted skin temperature (MWST) increased slightly during the exposure. Body heat storage rate was only 3 kcal/hr, however, under these environmental conditions equivalent to the subject wearing an 11 clo uniform. While finger temperature was maintained for the first 30 minutes and subsequently slowly increased, the temperature of the toes, which had no warming air supply, slowly fell to 40° F at 72 minutes, when the exposure had to be terminated.

Following this demonstration that "adequate" auxiliary heat supplied continuously to the torso was inadequate to maintain the extremities, the subjects were allowed to cool; then enough heat was supplied to the torso to produce not only repayment of the initial heat lost but a pronounced rise of skin temperature, and even a slight rise of rectal temperature above control values. In spite of a significant accumulated heat load, fingers and toes usually did not share in the rewarming. While finger and toe temperatures decreased much more slowly or plateaued when this "excess" heat was being supplied, in four out of six cases the exposures had to be terminated because of extreme malaise and nausea of the subjects. A typical example is presented (Figure 4B), where after initially cooling for 33 minutes at a rate which was appropriate for the 4.3 clo uniform worn (calculated effective clo: 4), the subject was provided with heat to the torso equivalent

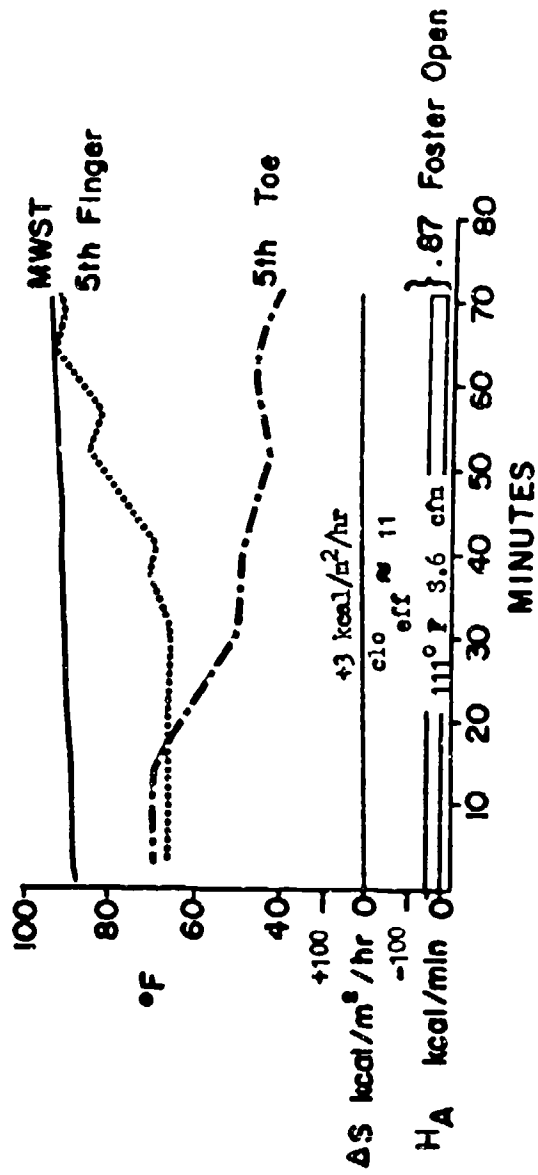


FIGURE 4A

Typical responses to auxiliary heating by hot air supplied primarily to the torso with a small amount to the hands.

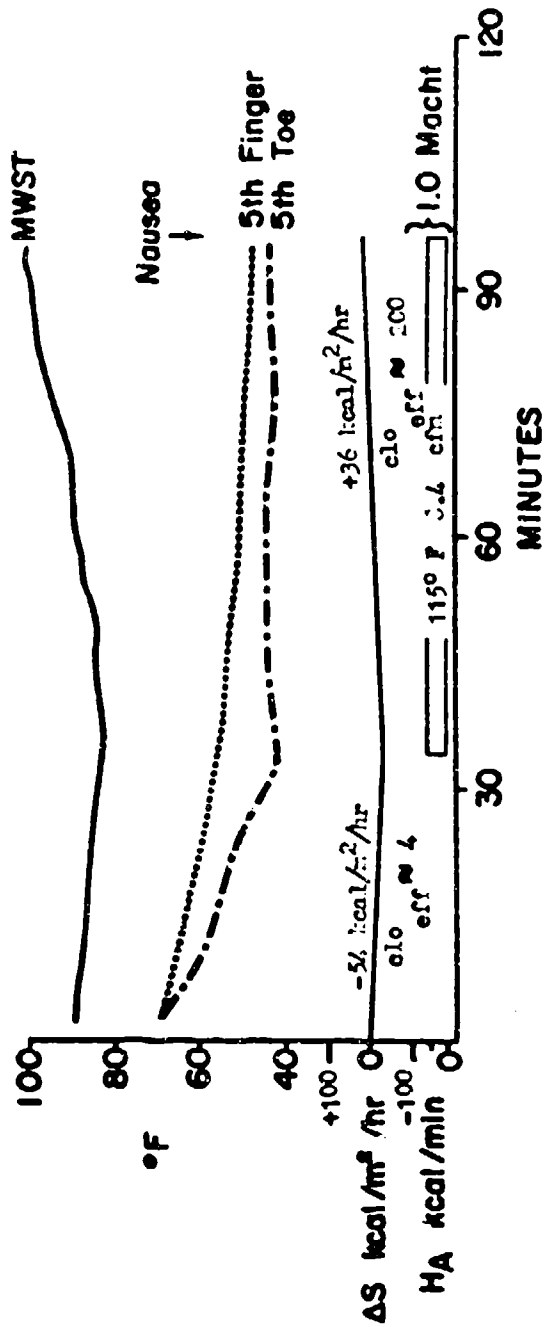


FIGURE 4B

Typical responses to auxiliary heating by hot air supplied in excessive amount to the torso.

to 1 kcal/min. While in general the subject rewarmed as if he were provided with 200 clo of insulation, finger temperature continued to cool, although much more slowly than without the heat to the torso, and toe temperature rose very slightly and then plateaued. After 63 minutes of rewarming of the torso, the subject became dizzy and nauseous, and the exposure had to be terminated.

Taking note of the observation that when rewarming of the fingers did occur (as in Figure 4A), it was associated with the supply of some heated air directly over the surface of the extremity, arrangements were made to supply heated air primarily directly to the hands and feet. Figure 4C demonstrates that with this approach, it was possible to not only maintain the extremity temperatures but also rapidly rewarm extremities that had been allowed to cool. However it was usually difficult, because of differing back pressures, to ensure distribution of heated air to all four extremities, and it appeared that most of the heat supplied was escaping to the ambient environment when the gloves and boots were worn loosely fitted, in order to produce a low pressure drop and thus allow flow of the heated air to the extremity surface.

Accordingly, a second study was initiated to determine the minimum power required to provide heat for the extremities alone, by electrical means. The relationship was sought between power supplied continuously to electrically heated gloves and socks and the extremity temperature maintained. A total of 10 successful man-days of study in which temperatures were maintained at levels above 40° F for 6 hours, and 4 man-days at which power to the hands was inadequate to prevent cooling below 40° F within 2 hours, are represented in Figure 5. It appeared that extremity temperature could be maintained at any desired level between 50 and 105° F, as a function of the power supplied. Above 12 watts of power, which produced a skin temperature of about 85° F, the relationship is linear, a 1° F increase in extremity temperature resulting from each additional watt. Below 12 watts of power the relationship is nonlinear. A minimum of 3 watts per hand or 7 watts per foot is necessary to maintain these extremities above a 40° F temperature. Supply of power levels below these minimums did not appear to extend tolerance times appreciably beyond those experienced without any auxiliary heat. Thus, provision of a total of 20 watts (3 per hand and 7 per foot) appeared to provide adequate protection for continuous exposure at -40° F.

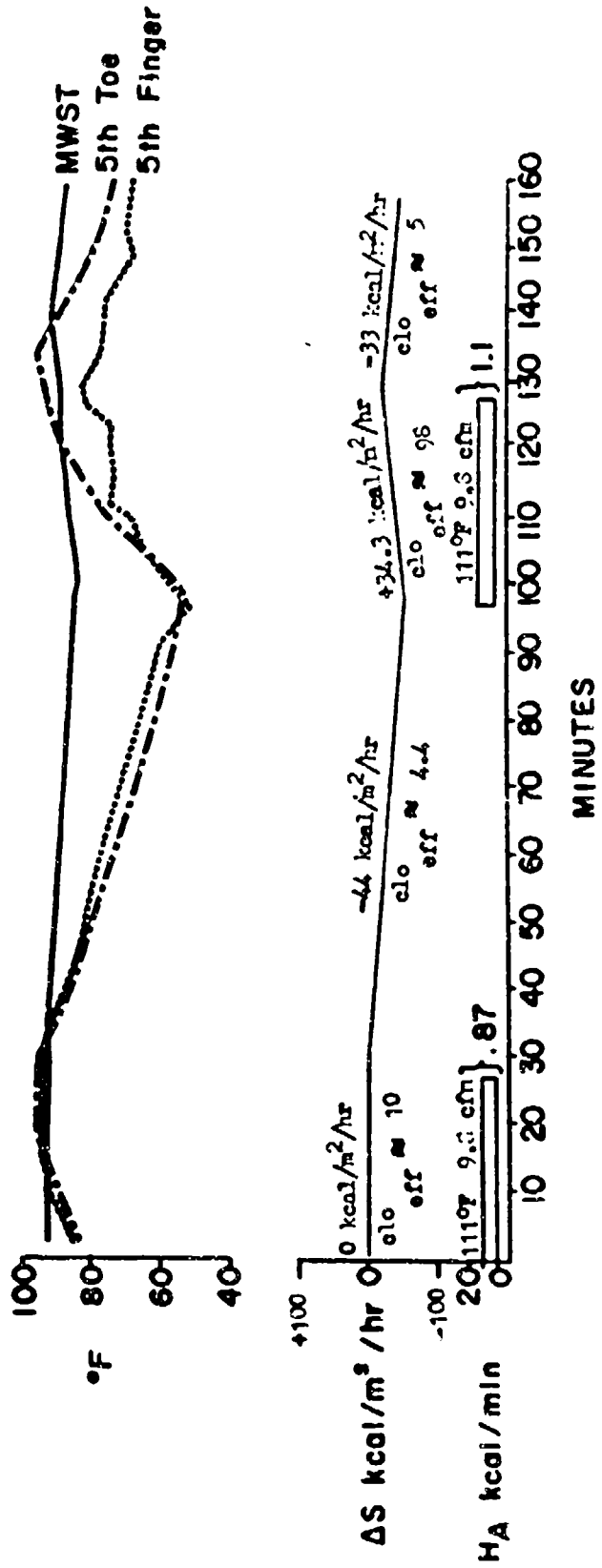


FIGURE 4C

Typical responses to auxiliary heating by hot air supplied only to the hands and feet.

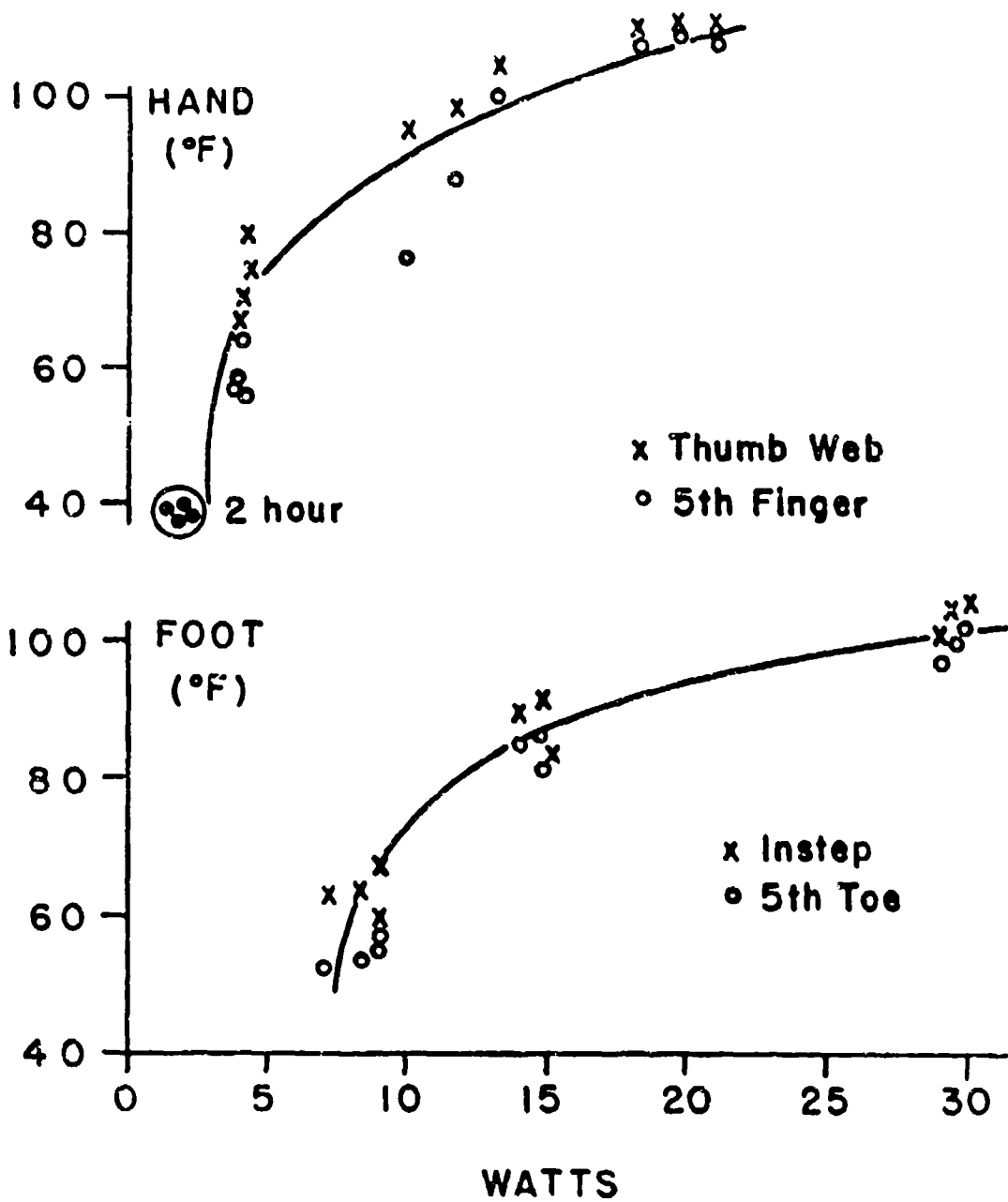


FIGURE 5

The hand and foot temperatures maintained as a function of the power used for auxiliary heated gloves and socks.

10 mph wind. While rectal temperatures fell slightly during the period, the exposures were terminated after 6 hours solely for the convenience of the operating schedule.

Since an active soldier maintains extremity temperatures, and in fact may use the large possible variation in heat input to the extremities as a means of regulating body temperature (15), a third phase was initiated in which thermostating of the extremities was studied. Anatomic consideration suggested that the web between the base of the thumb and the first finger be used as the thermostat site for the hand, but if the footwear were to be thermostated, the most feasible approach was to heat insulated boots rather than the socks. A heated outer glove, rather than the heated liner, was also studied. The results indicated that heating by means of an outer glove doubled the power requirement for the hands, and it was exceedingly difficult to control hand skin temperature from a thermostat sited in the outer glove. On the contrary, very little additional power was required to maintain foot temperatures when the heating element was located in the insulated boot, and thermostating could readily and comfortably be achieved from a site under the fifth toe area in the boot insole. Therefore, it was concluded that the auxiliary heated system should consist of a heated contact glove and a heated insulated boot.

Analysis of the extremity temperatures when the fifth finger was maintained at 60° F identified 68° F as the corresponding temperature for the selected hand thermostat site. However, initial results with this relationship indicated that because of different cooling rates, the fifth finger cooled to 40° F before the thumb web cooled to 68° F. This was corrected by selecting 72° F as the set point temperature; while initially cooling well below the selected 60° F desired maintenance temperature, the fifth finger did not cool below 40° F prior to the initial turn-on of auxiliary heat. No such problem occurred with the feet.

Unfortunately, results indicated that while 3 watts per hand and 7 watts per foot would maintain these extremities, this level of heat was inadequate to produce rewarming to 60° F from the lower initial temperatures occurring before the system came into equilibrium. The power supplied to the thermostated gloves and boots had to be increased to 10 watts each. While this requirement was disappointing, analysis of power demand cycles of four subjects ("on time") revealed that the total power consumption averaged about 20 watt-hours per hand and 40 watt-hours per foot for a 7-hour exposure, or about the same total power consumption

as that required for maintenance of equivalent extremity temperatures with continuous heat. Thus, a power source capable of providing 40 watts was required, but the duty cycle, when the extremities cooled to levels requiring auxiliary heat, would only be about 50% at this power level.

Under the impetus of having to provide a 10-watt-per-hand power level, which would allow an 80° F level of hand temperature to be maintained, in a fourth phase of these studies the additional "tolerance time" (defined as the time to cool any hand point temperature to 40° F) was investigated when the maintained temperature was 80° F rather than 60° F. At every hour of exposure after the second, the four subjects removed the outer arctic mitten. At the same time, auxiliary heat was turned off and cooling to the 40° F level timed. The results in Table I reveal that only 3 or 4 extra minutes were achieved by the considerably greater power consumption required to maintain an 80° rather than 60° F temperature.

The final phase involved a validation of the hardware developed as a result of the first four phases and a study of the capabilities of the system in an extreme environment (-65° F, 10 mph wind). Working in collaboration with clothing and equipment developers of the Army Quartermaster Research and Engineering Center, a snap-acting thermostat was selected, and a 12-volt battery system composed of 11 silver cadmium, 10 ampere, rechargeable cells was fabricated into a canvas vest. The complete system is shown in Figure 6. Since no auxiliary heat is required initially for between 1 to 2 hours, this 120 watt-hour system was designed to provide between 7 and 8 hours of protection for an inactive man at -40° F, 10 mph winds; i. e., 1 to 2 hours of no heat requirement followed by a 50% "on time" demand on four 10-watt heaters for 6 hours. At -65° F, 10 mph wind, five inactive subjects were maintained safely and relatively comfortably for approximately 5 hours, before the drain on the battery power resulted in lowered output voltages and required termination of the exposure.

DISCUSSION

The difficulties of supplying external heat to the body were studied by Belding, who concluded that for available large areas of the surfaces, the amount of heat that can be introduced safely

TABLE I

MINUTES TO COOL FROM A MAINTAINED FIFTH FINGER TEMPERATURE OF 80° F OR 60° F, AFTER POWER WAS SHUT OFF TO A 40° F LEVEL, WITH AND WITHOUT A LEATHER GLOVE WINDPROOF SHELL OVER THE AUXILIARY HEATING GLOVE.

80 to 40° F		60 to 40° F	
With Shell	Without Shell	With Shell	Without Shell
10	8	8	4
11	6	6	2
20*	4	7	3
11	6	7	6
12	6	8	4
11	7	6	4
6	9	8	6
11	9	11	4
11	7	8	3
11	8	8	3
11	7	8	2
6	8	4	7
8	4	3	6
8	3	4	3
7	4	6	4
6	3	3	4
7	2	4	4
8	-**	4	5
8	-	3	4
10	-	3	4
8	-	3	5
Mean 9.6 min	Mean 6.9 min	Mean 5.9 min.	Mean 4.1 min.

Results represent 21 trials on 4 subjects.

* Spontaneous rewarming cycle (Lewis wave) interrupted cooling.

** Blank values represent fifth finger temperature initially below set points.

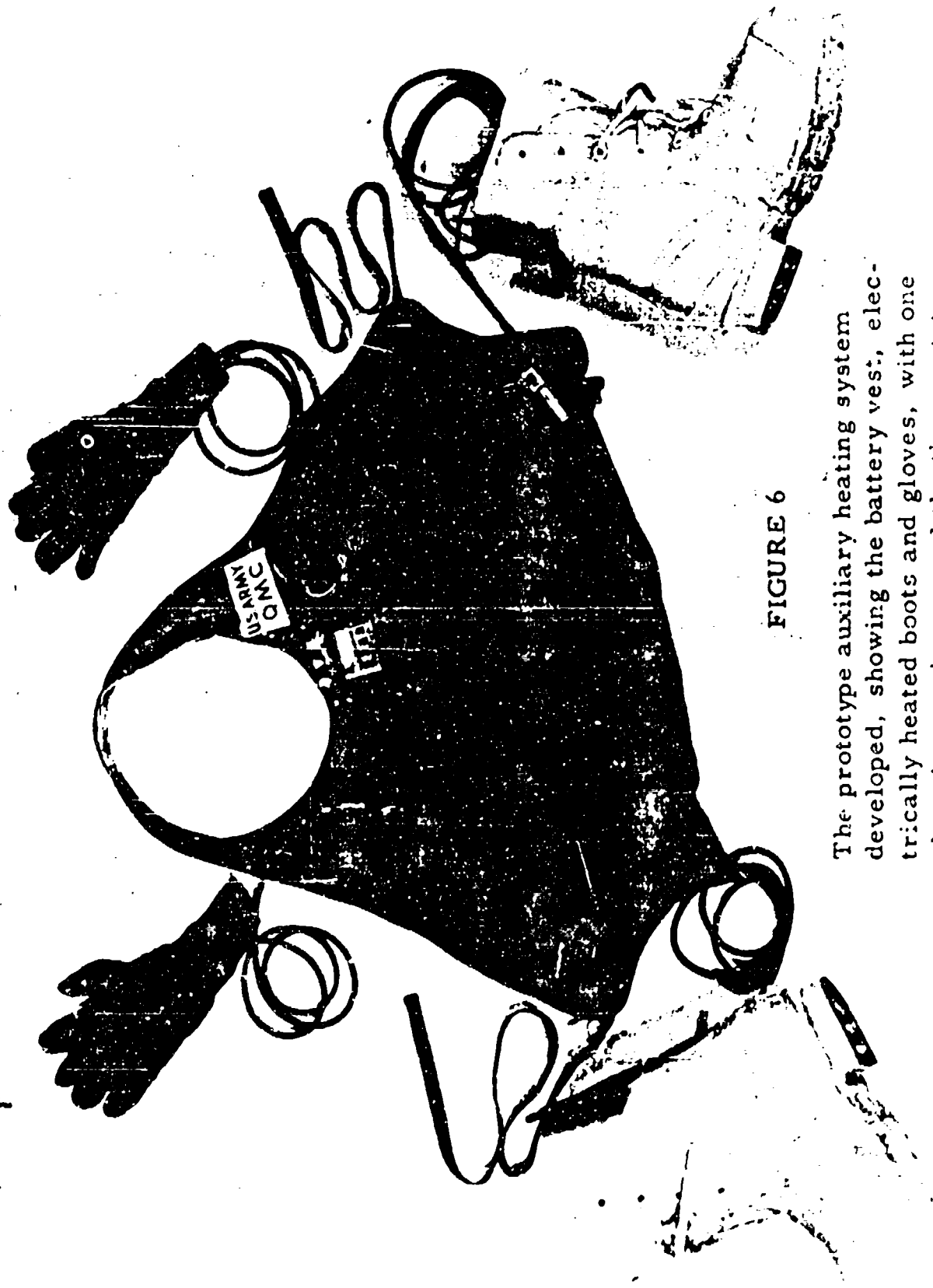


FIGURE 6

The prototype auxiliary heating system developed, showing the battery vest, electrically heated boots and gloves, with one glove inverted to reveal the thermostat.

is about 140 kcal per square meter of heated surface per hour. Calculations based on the requirements for heat in the cold and the surface available for heat input indicate that maintenance of overall thermal balance by auxiliary heat, in the absence of adequate insulation, is an impossibility (2). The present inability to maintain extremity temperatures, or rewarm cooled extremities, by heating the torso even in excessive amount is in general agreement with this work. The subjective malaise and nausea noted in this study with prolonged excessive heat is reminiscent of the "vasovagal syncope" occasionally seen during studies of finger cooling conducted in comfortable ambients (11), but may be more appropriately related to the location of the hot air inlet just above the solar plexus. Without the imposed restriction of activity, it seems probable that rewarming of the extremities would have occurred from this overheated state with very little exercise, as Ames et al have shown that the internal heat production by exercise is one of the most efficient means of rewarming (1). As a final comment on torso heating, a number of studies on mechanisms of indirect warming have led to the concept of "trigger areas," specific body sites where application of heat resulted in vasodilatation of the extremities (5, 7, 12). However, the ambient conditions did not approach the severity of those in the present study, and while an apparently consistent response could be obtained with warmer subjects who were presumably at most mildly vasoconstricted (12), other studies involving heating of a number of suggested trigger areas have failed to consistently produce rewarming when a more severe vasoconstriction of the extremity blood vessels existed (10).

Thus, it appears most practical to supply auxiliary heat directly to the extremity surface. While different thermal lagging of areas of the hand with differing mass to surface-areas (such as the fifth finger and the thumb web) makes maintenance of a uniform extremity temperature difficult and produces problems as noted during the initial cooling with the 68° F thermostat settings, it is sufficient to maintain the "weakest link," the fifth finger tip, at 60° F. This choice corresponds with the lowest hand skin temperature for unaffected manual performance in the cold; it has been shown that performance is severely hindered at a fifth finger tip temperature of 55° F (4). Additionally, very little extra tolerance time was found in the present study when 80° rather than 60° F was selected. While more power capacity is required to rewarm a cooled extremity than to maintain a given temperature with continuous heat, thermostating is well worthwhile. First, because when the man is initially exposed or when he is exercising, no power is required; second, because the majority of

excess heat required to produce rewarming is apparently stored in the hand and/or the proximal insulation, so that the total watt-hour demand is approximately the same with or without thermostatting, the equality being regulated through the relative lengths of the duty cycle.

Biophysical calculations on the relationship between the auxiliary heat supplied electrically and the increase in heat content of the hand (specific heat of tissue \times mass $\times \Delta$ temperatures), in the face of such an extreme skin-to-air temperature gradient with only a 2.4 clo insulating arctic mitten assembly, indicate that the electrically supplied heat is grossly insufficient to account for the increased hand temperatures. The slight, continuing decrease in rectal temperatures noted during experiments when auxiliary heating of the extremities was utilized further suggests that under the influence of a warmer extremity microclimate produced by the auxiliary heat, the blood flow from the body core is not as severely limited, and thus heat from the core accounts for the temperature levels maintained during auxiliary heating, particularly over the 55 to 85° F extremity skin temperature range. The shape of the power-temperature maintained relationship (Figure 5), when compared with the data of reference (8) as presented by Molnar (13) for both blood flow through the hand as a function of air temperature and especially hand skin surface temperature as a function of air temperature, further suggests that at the low levels of auxiliary heat being supplied, it is primarily the alteration in blood circulation to the extremities, occurring under the influence of the warmer microclimate produced by auxiliary heating, that accounts for the temperature levels maintained.

Protection for the inactive soldier in extremely cold environments has now been resolved in terms of the parameters of weight and cost. The 7-lb prototype system is adequate to meet the current required military characteristics of providing 8 hours of protection for the inactive man at -40° F with a 3 mph wind. More severe conditions can be met merely by addition of greater watt-hour capacity batteries, at least for conditions up to -65° F with a 10 mph wind; i. e., a windchill of 2400. Since over 90% of the weight of this system is batteries, improvement in the weight factor can be anticipated as power source development improves over the current 16 watt-hours per lb. Reconsideration of the need for some of the current clothing items if auxiliary heat is added also seems practical; e. g., the parka and liner, which weigh 5-1/2 pounds, may prove unnecessary. As torso insulation they may not be necessary per se, and if their role is

to maintain a warm enough body core so that during even mild activity blood flow to the hands and feet is increased to aid in the dissipation of the extra metabolic heat production, then the parka and liner can well be replaced with the far more effective auxiliary heat. This approach would also aid the overheating during exercise and the resultant production of extra sweat, which collects in the uniform and remains to evaporate after the end of the work period, producing the familiar "after exercise chill." The cost problem would be resolved by quantity procurement.

An even more important immediate use of auxiliary heated handwear and footwear is in areas where power is available. All vehicles, most radio and radar equipment and many missiles all have available power. The auxiliary heating system developed is compatible with a 12- or 24-volt AC or DC power source. Over 90% of the weight and cost of the present system, the battery supply, would be eliminated. Thus, a simple, low cost solution is available for such problems as providing manual dexterity, allowing use of vehicles without heated cabins (such as the mechanical mule) and permitting reasonably long periods of light work in restricted but underheated or unheated areas. This solution has not as yet been exploited.

This solution is also useful in the area of extending research. Almost all tests of cold weather clothing have been terminated because of cold extremities, and identification of improved torso clothing has been confounded by these related, but not totally dependent, appendages to the torso. There is also a hierarchy of the weak links in protection in the cold; after the hands and feet comes the face, but face protection has been unresolved, in part because of the dominance of the problems of protecting the extremities. From the present studies, we have already identified the next weak link with the current cold-dry uniform — the lower legs and arms. Previously overlooked, perhaps unrecognized as a result of the dominance of the extremity problem, is the fact that the insulation provided the lower arms and legs is less effective than that provided the rest of the body. This weakness may be contributing to the problem of protecting the extremities. Finally, in terms of the long-range goal of a comfortable, adjustable microclimate for the soldier or space man, produced without excessive weight by a synthesis of advanced clothing, physiological, mechanical and electrical knowledge, auxiliary heating of the extremities seems to be an encouraging step in the right direction.

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ENHANCING THE EFFECTIVENESS OF THE INDIVIDUAL IN THE ARCTIC THROUGH CLOTHING AND EQUIPMENT

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It has been said that up to 75% of a soldier's energy and attention in the extreme cold is taken up by mere survival. Whether this is a correct figure or not, it may serve to illustrate the general character and dimension of the challenge presented to the developer of clothing and equipment for soldiers who must be prepared to fight in such climates.

One major concept of functional design of cold climate clothing which can be utilized to reduce this loss of efficiency is to extend the period during which the clothing will keep the body warm when the man is inactive.

The classical solution to this problem, as practiced in civilian-type clothing, has been to add more insulation as the temperature drops lower. Taken by itself without consideration of other factors, however, this solution can be self-defeating.

The range of temperatures for which cold weather clothing is needed extends from +65° F to -65° F — a total range of 130 degrees F. The range of temperature within even as short a span of time as a week, while a soldier is wearing a given set of clothing, may vary from 40 to 50 degrees F or even more. There must, accordingly, be a capability of varying the amount of insulation in the clothing system required to meet this range of temperatures.

There must also be the capability of meeting the even greater moment-to-moment variability in body activity. Measured in terms of heat output, the level of body activity may vary from 60 kcal/m²/hr for an inactive man to a potential of eight times that much, of 480 kcal/m²/hr for a very active man.

The effect of this variation in body heat output upon the need for protective clothing was well illustrated a number of years ago in the classic illustration of the mittens. The highly active man needs little protection for his hands. The inactive man simply

cannot be provided with enough protection for his hands if he is inactive for a long period of time. For an inactive man at low temperatures, therefore, a good deal of insulation is required. However, the inactive soldier may, at any time, become very active. Unless the clothing system can be designed to allow these "spurts" of heat output to pass out of the clothing, the body will accumulate heat and respond by sweating. Sweat which cannot evaporate is ineffective in counteracting the heat build-up.

More significant, if it accumulates in the clothing it will drastically reduce the insulation which the clothing is intended to provide. Then, when the subject returns to a lower activity level and lower heat production, and really needs the full measure of his clothing insulation, he will find that the sweat has reduced the effectiveness of the insulation below what it was when dry, and quite probably below the required level for adequate protection. This problem is often referred to as "after-exercise chill."

The providing of effective insulation, therefore, actually calls for a highly efficient insulation system when the man is inactive, combined with an efficient design-and-materials system for the dissipation of body heat when the man is very active.

It is generally understood today that the effective insulation in a clothing system is comprised simply of trapped dead-air spaces. We therefore want a design-and-materials system having the highest possible ratio of air spaces per unit of weight. In other words, we need all of the trapped-air spaces we can get without having to pay for them in weight of materials.

There are, then, three major functional concepts in making cold weather clothing: first, to find the lightest weight insulating material it is possible to produce; second, to trap the dead air in spaces between loose-fitting layers of clothing, so that when the man is active the spaces between layers can act as channels or chimneys (the closer to the skin the better) by which the heated air can move to escape through vents; and third, to design the clothing so that it can easily be opened for venting warm, moist body air to the surrounding atmosphere, and allow cold outer air to penetrate close to the skin surface for cooling during times of high body activity.

There are other essential requirements which should not be overlooked, such as wind resistance of the outer layer, so that the trapped-air spaces may not be disturbed; water resistance of the outer-layer fabric, so that external moisture will not get in.

and lower the insulating value of the material; launderability; speed of drying when materials do get wet; and so on.

The most efficient system, with a large volume of air spaces trapped in the clothing, will tend to be bulky — just the opposite of the tight-fitting stretch materials now being promoted for civilian "appearance-type" outdoor clothing. It will be comprised of a number of layers, rather than just a single added garment (a system in which these layers can be added or removed to adjust to body activity and to temperature variations), and as light in weight as possible.

We have moved through four types of insulating material since World War II in this search for an ideal type: an artificial fur pile fabric, a double-faced wool pile, a frieze fabric and a napped frieze.

However, the recent development of satisfactorily launderable battings of polyester fiber has provided perhaps the most important breakthrough since World War II toward increased efficiency of a cold weather clothing system. Liners made of these materials, weighing no more than a pound and a half to cover the entire body, will provide adequate insulation for an inactive man for a 30° drop in temperature. The insulation liners required to carry him down to -65° F will weigh only three pounds. (His extremities will still provide a problem however.)

We have tried to use this same insulating material in sleeping bags. However, it lacks the desirable characteristic of waterfowl down and feathers of being compressible to small bulk. This means that sleeping bags made of it, having the requisite thickness for extreme cold, have nearly 30% extra bulk compared to the standard cold weather sleeping bags. However, through the ingenuity of Dr. Terris Moore, consultant to the Natick Laboratories, a way has been found to utilize this polyester batting inside the inflatable pad. By attaching a full inch of this insulating batting to the upper surface, we can provide the equivalent of two clo* of insulation underneath the man when the pad is inflated. This batting in the pad keeps convection currents of air inside the pad from being a source of heat loss to the man.

* An arbitrary unit of thermal insulation, used in expressing the thermal insulation value of clothing. A suit of clothing has a thermal insulation value of one clo when it will maintain in comfort a resting-sitting human adult male whose metabolic rate is

We have, then, as the biggest unsolved problem for research in cold weather clothing, this matter of developing a really efficient system for getting rid of the rapidly generated heat when the wearer goes quickly from a state of inactivity to high activity. It is an area of clothing design research where a great deal of work is needed.

The simple answers of ventilating by use of bellows run by some aspect of body movement or by the use of a power-driven fan, for which the man carries the fuel and the engine, present difficult engineering problems, some of which are being studied under our thermal equilibrium program.

A most promising approach appears to be the "Climastat" principle proposed by Robert L. Woodbury. The "Climastat" system proposes using an insulating layer of lightweight, non-wettable, impermeable foam material having a large number of "holes" punched through it in which air is trapped when the man is motionless, but through which air circulates when he is active.

During body movement, the pressure differentials inside the clothing and the turbulence created by movement of the clothing as the man walks or runs would tend to cause a continuing interchange through these holes of the warm, moisture-laden air near the body and the colder air in the outer layers of clothing. With proper venting, warm air could be forced out and cold air brought in, in some kind of controlled fashion. Concepts of design by which such a system could be optimized, the right size and location of holes in the insulating material, and the selection of the material itself have posed problems for materials and clothing design research which appear formidable at this time and yet which should be capable of solution with adequate research. The major problem we have encountered up to this point with the "Climastat" approach has been in obtaining the range of needed adjustment within the theoretical scope of this approach.

approximately 50 kilogram calories per square meter of body surface per hour, when the environmental temperature is 70° F. In terms of absolute thermal insulation units, one clo is 0.18° C per square meter kilogram calorie per hour. (Blakiston's New Gould Medical Dictionary, First Edition, New York, McGraw-Hill Book Company, Inc., 1949.)

Related to the matter of insulation is the continuing effort to extend the period before the onset of fatigue, through lightening the weight of everything the soldier carries and so designing his clothing and equipment as to reduce energy expenditure in every possible way.

Many years of intensive studies of the design of load-carrying equipment and the proper placement of a load to be carried by a man have shown that placement of the load can have a significant effect on energy expenditure. For example, any weights placed on moving or swinging parts of the body, such as the mid-thighs, will cause three times the energy cost of a similar load placed on the back. Present load-carrying approaches attempt to distribute the weight evenly over the shoulders, back and hips of the carrier. To the extent that different designs of equipment succeed in balancing the load on the torso, they are essentially equal in their energy demands on the soldier.

There is little that can be done to conserve the energy of the combat soldier through different load-carrying designs, other than through lightening the weight of the equipment and improving its versatility. Our latest development has been the lightweight rucksack, which has reduced the weight of the Army rucksack from 7 lbs to 2-3/4 lbs.

This item has just completed tests at the Arctic Test Center with a favorable recommendation for adoption by the Army for arctic use. It has already been adopted for Special Forces use and has undergone extensive field use in South Vietnam. We are currently expanding the concept of a lightweight pack frame as part of a universal load-carrying system, in the development of load-carrying equipment for indigenous forces in Southeast Asia.

This matter of lightening the load of the combat soldier has recently been receiving a great deal of well-merited attention and does not need extensive comment here. It would be well to note, however, that one cannot always have his cake and eat it. The critical point is where this matter of lightening the load stands in terms of priority. If it is to have a high priority, something else may have to be given up. If you want a man to be fully comfortable at -65° F for 6 to 8 hours, he is going to have to carry around a lot of insulating material. However, if you can be content to keep him moderately comfortable and out of danger from cold injury at very low temperatures, the weight of his clothing can be reduced commensurately. The tendency to seek to give a man everything he needs for comfort, which unfortunately is typical of most armies in peacetime only, adds to the weight of what he must carry.

Beyond the matter of lightening the load as a means of conserving energy, there is a great need for research in clothing design to minimize energy expenditure. We have introduced slippery layers of nylon lining into the cold weather clothing system to reduce internal friction as the man moves his arms and legs, and with such action moves parts of his clothing over each other.

However, the energy expended in moving the clothing as part of normal body movement has never been measured, nor has adequate study been given to the determination of how to minimize such energy expenditure. Model systems for study of this problem can be developed, but extensive research is needed. A third approach to enhancing the effectiveness of the individual in the Arctic involves providing assurance that cold injury to the extremities can be positively prevented. Fortunately, a fundamental solution to the problem of cold injury to the feet through the sealed insulation boot was developed by Dr. Paul Siple and the late C. H. Bazett in 1944 as part of the Quartermaster research and development program. Although a practical boot was not developed until 1951, it was then made available to our forces in Korea. It contributed to the almost complete elimination of cold injury to the feet during the winter 1952-1953 and subsequent years.

While outright cold injury can now be almost entirely eliminated by the sealed insulation boot, there are hygienic problems connected with it. Daily or even more frequent change of socks is needed to minimize softening of the skin tissues. Ventilating of the boot has been attempted, but a satisfactory construction has not yet been achieved, nor would this fully solve the problem.

Natick Laboratories now have a program to develop a lighter weight version of the sealed insulation boot. However, a final type of lightweight, cold weather footwear, which fully meets the needs for protection and comfort, is going to require a great deal of further research and development.

There is also the problem of summer footwear for muskeg-type terrain. In the wet areas of the tropics, we expect the foot to always be wet and accordingly provide drainage outlets in the boot so that water can drain out to let the foot dry itself whenever it is possible to do so. In the typical muskeg areas of the North, however, ground water is much colder, and the solution for the jungle is neither a satisfactory nor a safe one. No present type of footwear, whether made of leather, fabric or rubber, really meets this requirement. It is an area in which we would like to have recommendations based on field experience.

The recent adoption of an all-purpose ski to satisfy the needs of both cross-country and alpine oversnow mobility lessens the logistical burden but does not resolve the dilemma of rapidly providing effective mobility to troops unaccustomed to oversnow travel by virtue of a warm climate background. Development of an all-purpose binding, which is still in the offing, will further simplify logistics but will not improve individual proficiency. The operational implications will persist where troops can be readily trained to use snowshoes, with a highly significant limitation in mobility, or else extensive training must be given to develop a competent military skier. Barring the development of some unforeseen technique for rapidly training men to ski well or the unlikely invention of some easy-to-use individual oversnow device, the level of individual oversnow mobility in the Arctic remains a command decision between the use of skis or snowshoes, with the attendant consequences in training requirements and degree of mobility.

The utilization of a person's fingers and hands in the Arctic is probably the most difficult single problem to be solved in clothing design. We have the diametrically opposed requirements of maintaining dexterity and tactility, and at the same time giving sufficient insulation to keep the hands warm.

We have recently adopted a principle of utilizing differential insulation in our curved handwear by placing lightweight insulating batting over the back of the hands where the big blood vessels come close to the skin surface. This has the advantage that added insulation at this point does not interfere with dexterity or tactility.

Another recent significant development has been a means whereby we can curve the fingers and palms of leather handwear to provide "natural hand" gloves and mittens. The importance of this became evident in our development of impermeable gloves for handlers of fuels for guided missiles several years ago. In this type of handwear only a minimum of muscular effort was needed to utilize the fingers for manipulating any type of equipment.

Through our invention of a new device for stitching leather and fabric gloves, we have been able to introduce this same natural hand shape into cut-and-sewn cold weather handwear. Here the back of the hand is 1-1/2 in. longer than the palm. The importance of this will be evident when one considers that the back of the hand lengthens 1-1/8 in. in bending the hand.

Currently, our interest in handwear is turning to the utilization of waterproof cold weather handwear. We have carried out extensive research in attempting to make leather waterproof, but because of the structure of leather, it has not been possible to achieve this. However, if greater efficiency in cold weather handwear is to be achieved, it will have to include the development of handwear that remains dry even after picking up and handling wet objects. Several approaches to this are being undertaken in connection with our current research and development program.

However, for many conditions in the extreme cold, particularly for the inactive man, there will simply not be enough heat in his body system to keep his hands warm. Accordingly, auxiliary heating is the only answer. We have developed a simple type of wired glove which can be worn as an insert next to the skin and which is furnished with thermostats which will prevent either overheating or excessive cooling. This glove either can be connected to a portable battery system or plugged into any power source that may be available. For vehicle drivers exposed to the cold, and for operators of other types of powered equipment, such auxiliary heating is clearly the most practical solution for the problem of keeping hands warm.

There is one further area where the effectiveness of the individual is definitely affected by his clothing; that is in the loss of sensory perception which he experiences in the cold from the clothing he wears. There is significant loss of hearing from the hood worn over his head, and there is substantial loss in the range of his vision from the shielding against the wind provided in his headgear.

We, who are concerned with clothing design, have tried to deal with these problems by providing flexibility and adjustability in the headgear. We have also sought to develop hearing cells which will both reduce attenuation of sound and amplify the sound coming to the man through his hood.

This is an area where far more study is needed from the standpoint of design than has been accomplished up to this point. Thus, no fully satisfactory head protection for the soldier in the Arctic has ever been developed. Our new insulating cap to be worn underneath the helmet is the first successful development which permits keeping the helmet stable and still provides essential warmth.

We are currently launching a program for an extensive study on the entire problem of protection, with particular attention to the protection of the head in the cold, in the interest of reducing the number of items involved and enhancing the sensory perception of the individual.

A more radical solution to providing body warmth in the Arctic is that of our thermalibrium clothing system. The thermalibrium concept, as formulated by our research group, is an approach to combining essential protective mechanisms into a single, total body clothing system. It envisions the use of three major components:

1. A combined protective headgear assembly.
2. A multi-functional garment and appropriate handwear, footwear and load-carrying equipment.
3. A lightweight, self-contained heat regulation device that can be integrated with the basic ensemble.

The headgear would consist of a well-insulated ballistic helmet with a built-in voice communication system, a protective face shield and a powered filtering system to purify the incoming air for breathing when the face shield is closed. A lung-actuated emergency breathing system would be built into the headgear assembly to be used if necessary.

The body clothing would consist of three separate multi-functional components: (1) a two-piece reversible overgarment with OG fabric on one side and a camouflage fabric on the other, (2) the basic ventilating ensemble and (3) a form-fitting knitted underwear.

Heat and moisture regulation inside the clothing system would be accomplished by circulation of conditioned air obtained from a lightweight, self-contained heating and cooling device integrated into the clothing system.

The inherent insulation properties of this over-all clothing system would be of such value that if the heat regulation device failed in extreme cold, the individual would not become a cold weather casualty; if the system failed, it would "fail safe."

When we consider the microenvironment and the soldier in its totality, it is evident that the separate equipment we are now

furnishing for separate but related functions of clothing, sleeping gear, shelter and a heating system should be restudied in its totality so that a truly integrated system might be developed to serve these related functions.

At the present time the equipment we furnish the man for these functions weighs a total of 82 lbs per man. This figure includes the man's arctic sleeping gear, his individual clothing, one-fifth of the weight of an arctic tent, stove and gasoline for heating.

Under our present development programs, including the new integrated clothing system and the Moore sleeping pad, and a new type of tent, we can foresee this weight being cut by 20 lbs — a very sizeable saving.

Further reduction of this weight of clothing and equipment without significant impairment of the protection afforded to the individual soldier will require a great deal of research, on both materials and design concepts.

In summary, progress in this area is dependent heavily upon the results of materials research and development, particularly the production of new types of materials which can contribute greater efficiency in a cold weather system, and upon research in clothing design and construction. Research in clothing design for the extreme cold holds far more potential for enhancing the efficiency of the soldier than is generally recognized. It probably holds the key to making the arctic soldier a more efficient soldier, more than could be done by any new type of weapon or mechanical equipment that could be provided to him.

Also, there is a need for an organized approach to the science of clothing, as Dr. Newburg defined this area some years ago. It is difficult to apply scientific approaches in an industry which is, to a large extent, based upon crafts. For this reason, close collaboration of the clothing designer is needed with research people in the other areas which embrace what we call the biophysics of clothing: physiology, medicine, psychology, anthropology, human engineering, physics, military geography and textile technology.

The problems of protection of the man need to be studied as a whole instead of being dealt with solely within the partitions of separate scientific disciplines. Information in these various fields is largely scattered and uncorrelated; its existence is often unknown to workers in the field of clothing or to other workers in this cross-boundary area, and difficult to locate on a timely basis.

We are now creating an information center at Natick Laboratories in this area of the performance aspects of clothing and equipment in their use by the individual, and the properties of materials in relation to their use in clothing and equipment. We hope in this way to bring together information from all of the scientific disciplines which can contribute significantly to this area.

Through such interdisciplinary studies and research in this cross-disciplinary area of the biophysics of clothing, we believe that improved types of clothing and equipment can be developed which will further enhance the effectiveness of the individual in the Arctic.

EFFECT OF AIR MOVEMENT ON ATMOSPHERIC COOLING POWER

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The wind chill index was devised by Siple and Passel (2) as a unitary criterion of the combined effect of wind and low temperature in cooling exposed parts of the body. It has proved useful in the frigid zones as a roughly quantitative measure of the cooling power of the environment consistent with subjective experience of cooling and discomfort. Persons unaccustomed to the index and its history have had some trouble in using it, however — possibly because of the strangeness of the units (namely, kilocalories per square meter per hour). A way out of this difficulty for the practical user has been sought by expressing any wind chill value as an "equivalent temperature" that would have the same cooling power with no wind. It was thought, and rightly so, that an equivalent temperature could be understood immediately and evaluated intuitively by a man with no knowledge of the wind chill index.

A practical error in estimate has resulted, however, since the equivalent temperature is always referred to a condition of zero wind speed. This is unrealistic. It results in an estimated equivalent temperature that is too cold. For example, in a table prepared at the U. S. Army Medical Research Laboratory in 1961 (reprinted in Consolazio, Johnson and Pecora, 1), it is seen that at a dry bulb temperature of 50°F (10°C), a wind speed of 10 miles per hour (4.5 meters per second) gives an "equivalent temperature" of about -12°F (-24°C). But practical experience tells us that 50°F with a wind of 10 mph (defined on the Beaufort Scale as a "gentle breeze") just does not feel like "12 below zero" with no wind. (See also Appendix.)

A more realistic estimate, in keeping with practical experience in the cold, results if a value of 4 mph (1.8 meters per second) is chosen for the minimum effective wind speed that impinges on exposed flesh outdoors. In the first place, about a heated body there are always natural convective air movements, resulting from the very fact that the body is warmer than its environment. This random wind velocity will effectively equal about 2 mph in the cold even when there is said to be a "dead calm." And so it

"calms" seldom occur; there is usually some drift velocity factor. Finally, man is seldom still. In the cold he often will be moving himself directionally at rates up to 4 mph or moving his exposed parts randomly at somewhat greater rates. Thus, even in "calm" conditions the effective wind velocity will equal at least 2 mph but will seldom be greater than 4 mph. The latter figure is chosen as the minimum effective wind velocity that impinges on the exposed flesh of man in cold environments.

Using this value of 4 mph as a reference velocity instead of zero wind, the estimate for a temperature equivalent to 50° F with a 10 mph wind changes to a realistic 40° F, in place of the unrealistic -12° F cited previously.

EXPLANATION OF TABLES

Tables I and II are identical in column and line headings. Column headings are dry bulb ambient temperatures from 10° to -50° C, in 5° C intervals. Line headings are wind velocities from 5 to 50 mph, in 5 mph intervals. Table I lists wind chill values for the indicated combinations of wind and temperature, computed using the formula of Siple and Passel (2):

$$K_o = (\sqrt{100 V + 10.45 - V}) (33 - T_a)$$

where K_o = heat flow, in kcal/meter²/hr.

V = wind velocity, in meters/sec.

10.45 = an empirical constant

33 = temperature of exposed skin, in °C.

T_a = ambient dry bulb temperature, in °C.

For example, where $T_a = -10^{\circ}$ C and $V = 8.9$ meters/sec. (20 mph), $K_o = 1350$ kcal/meter²/hr.

Table II lists the temperatures in degrees Celsius which would have the same cooling power under calm conditions (i. e., wind velocity of 4 mph or less) as each of the listed temperature and wind combinations. These temperatures are referred to as "ET calm."

For example, where $K_o = 1350$ as cited above, ET calm = -28° C. That is, a temperature of -10° C with wind velocity

TABLE I

Wind Velocity (mph)	Wind Velocity (meters/ sec)	Dry Bulb Ambient Temperature (°C)														
		10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50		
		WIND CHILL (kcal/meter ² /hr)														
Calm	Calm	510	620	730	840	950	1060	1170	1280	1390	1500	1610	1720	1830		
5	2.2	530	650	760	880	1000	1110	1230	1340	1460	1570	1690	1810	1920		
10	4.5	620	760	890	1030	1170	1300	1440	1570	1710	1840	1980	2110	2250		
15	6.7	680	830	980	1130	1270	1420	1570	1720	1870	2010	2160	2310	2460		
20	8.9	720	880	1040	1190	1350	1510	1660	1820	1980	2140	2290	2450	2610		
25	11.2	750	920	1080	1240	1410	1570	1730	1900	2060	2220	2390	2550	2710		
30	13.4	770	940	1110	1280	1450	1620	1780	1950	2120	2290	2460	2620	2790		
35	15.6	790	960	1130	1310	1480	1650	1820	1990	2160	2340	2510	2680	2850		
40	17.9	800	980	1150	1320	1500	1670	1850	2020	2190	2370	2540	2720	2890		
45	20.1	810	980	1160	1330	1510	1690	1860	2040	2210	2390	2560	2740	2920		
50	22.4	810	990	1170	1340	1520	1700	1870	2050	2230	2410	2580	2760	2940		
		LITTLE DANGER					INCREASING DANGER					GREAT DANGER				

Danger from freezing of exposed flesh (for properly clothed persons)

TABLE II

Wind Velocity (mph) (meters/ sec)	Dry Bulb Ambient Temperature (°C)												
	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
	EQUIVALENT TEMPERATURE (°C) (equivalent in cooling power on exposed flesh under calm conditions)												
Calm	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
5	9	4	-2	-7	-12	-17	-23	-28	-33	-38	-46	-49	-54
10	5	-1	-8	-14	-20	-26	-32	-39	-45	-51	-57	-63	-69
15	2	-5	-11	-18	-25	-32	-38	-45	-52	-58	-65	-72	-79
20	0	-7	-14	-21	-28	-35	-42	-50	-57	-64	-71	-78	-85
25	-1	-9	-16	-23	-31	-38	-46	-53	-61	-68	-75	-83	-90
30	-2	-10	-17	-25	-33	-40	-48	-56	-63	-71	-78	-86	-94
35	-3	-11	-18	-26	-34	-42	-50	-57	-65	-73	-81	-89	-97
40	-3	-11	-19	-27	-35	-43	-51	-59	-67	-75	-82	-90	-98
45	-4	-12	-20	-28	-36	-44	-51	-60	-67	-75	-83	-91	-99
50	-4	-12	-20	-28	-36	-44	-52	-60	-68	-76	-84	-92	-100
	LITTLE DANGER			INCREASING DANGER					GREAT DANGER				

Danger from freezing of exposed flesh (for properly clothed persons)

of 20 mph is equivalent in cooling power to -28° C under calm conditions.

Table III is identical with Table II except for the conversion of all temperatures to $^{\circ}$ F.

Table IV is given for the convenience of readers in estimating wind velocity where anemometers are not available or not applicable.

Table V relates values for ET calm, as interpolated from Tables II and III, to the wind chill indices of comfort tabulated by Wilson (3). It is notable that frostbite is rarely observed at wind chill values less than 1400 (3). Hence, this value was taken as the basis for defining the partition between conditions of "Little Danger" and "Increasing Danger" on Tables I, II and III. The other partition indicates a wind chill value of 2000. At wind chills above this value there is indeed "Great Danger" of freezing exposed human flesh (3).

USEFULNESS OF THE EQUIVALENT TEMPERATURE CONCEPT

Persons unfamiliar with the wind chill index and with little formal education can, nevertheless, understand the concept of an equivalent temperature under calm conditions. The U. S. Army, Alaskan Command, has adopted this concept as a guide for assessing the cooling power of winter environments. Several thousand copies of Table III are now available in the form of a pocket-size multicolored card. Some improvements could be made in the present format to make it even more convenient for potential users.

TABLE III

Wind Velocity (mph) (meters/ sec)	Dry Bulb Ambient Temperature (°F)												
	50	41	32	23	14	5	-4	-13	-22	-31	-40	-49	-58
	EQUIVALENT TEMPERATURE (°F) (equivalent in cooling power on exposed flesh under calm conditions)												
Calm	50	41	32	23	14	5	-4	-13	-22	-31	-40	-49	-58
5	48	38	29	20	10	1	-9	-18	-28	-37	-47	-56	-65
10	40	29	18	7	-4	-15	-26	-37	-48	-59	-70	-81	-92
15	36	24	13	-1	-13	-25	-37	-49	-61	-73	-85	-97	-109
20	32	20	7	-6	-19	-32	-44	-57	-70	-83	-96	-109	-121
25	30	17	3	-10	-24	-37	-50	-64	-77	-90	-104	-117	-130
30	28	14	1	-13	-27	-41	-54	-68	-82	-97	-109	-123	-137
35	27	13	-1	-15	-29	-43	-57	-71	-85	-100	-113	-127	-142
40	26	12	-3	-17	-31	-45	-59	-74	-87	-102	-116	-131	-145
45	25	11	-3	-18	-32	-46	-61	-75	-89	-104	-118	-133	-147
50	25	10	-4	-18	-33	-47	-62	-76	-91	-105	-120	-134	-148
	LITTLE DANGER.			INCREASING DANGER						GREAT DANGER			

Danger from freezing of exposed flesh (for properly clothed persons)

TABLE IV

Beaufort Wind Scale*		
Velocity (mph)	Description in Forecasts	Noticeable Effect of Wind (on Land)
<1	Calm	Smoke rises vertically.
1-3	Light air	Direction shown by smoke drift, but not by vanes.
4-7	Light breeze	Wind felt on face; leaves rustle; wind vanes move.
8-12	Gentle breeze	Leaves and twigs in motion. Wind extends a light flag.
13-18	Moderate breeze	Wind raises dust and loose pages and moves small branches.
19-24	Fresh breeze	Small trees in leaf begin to sway.
25-31	Strong breeze	Large branches begin to move. Telephone wires whistle.
32-38	Moderate gale	Whole trees in motion.
39-46	Fresh gale	Twigs break off. Progress generally impeded.

* From: Consolazio, Johnson and Pecora, (1), p. 405.

TABLE V*

Wind Chill Index	Equivalent Temperature under Calm Conditions (approximate) (°C)	(°F)	Subjective and Empirical Evaluation of Cooling Conditions
600	6	43	Very cool. Considered as comfortable when dressed in wool underwear, socks, mitts, ski boots, ski headband, and thin cotton windbreaker suits, and while skiing over level ground at about 5 km/hr (11 mph).
800	-3	26	Cold.
1000	-12	10	Very cold. Considered unpleasant for travel on foggy and overcast days.
1200	-21	-6	Bitterly cold. Considered unpleasant for travel on clear sunlit days.
1400	-30	-23	Freezing of exposed human flesh begins, depending upon degree of activity, amount of solar radiation, character of skin and circulation. Travel or living in temporary shelter becomes disagreeable.
2000	-57	-71	Travel or living in temporary shelter becomes dangerous. Exposed areas of flesh will freeze within less than 1 minute for the average individual.
2800	-72	-97	Exposed areas of flesh will freeze within less than 1/2 minute for the average individual.

* Table is derived mainly from Pople and Passal as modified by Wilson (3). Equivalent temperature data are taken from Tables II and III.

APPENDIX

EXAMPLE OF UNREALISTIC ESTIMATE OF EQUIVALENT TEMPERATURE

From the Army Information Digest, Vol. 19, No. 1, January 1964, p. 9:

"You can freeze at a temperature of 35° F if the wind velocity is 20 miles an hour, according to Department of Army Circular No. 40-24, 28 August 1963. Under such conditions, the effect on exposed flesh is about the same as being in a deep freeze at temperature of 38° below zero. This year the Army has again made all-out preparations to protect troops in the field against hazards of cold injury. Timely requisitioning of clothing and equipment, training, and dissemination of meteorological forecast data by all major unit commanders to subordinates all are part of the campaign conducted by Preventive Medicine Division, Office of the Surgeon General."

(An interpolation from appropriate values in Table III shows that where $T_a = 35^\circ \text{F}$ and wind = 20 mph, a realistic value for ET calm* is about 9°F . It is noteworthy that even if the wind speed were much higher, exposed flesh would not freeze when $T_a = 35^\circ \text{F}$. Ambient dry bulb temperature [T_a] must be below 32°F before freezing can occur.)

* "ET calm" means the temperature equivalent in cooling power under calm conditions.

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THE EFFECT OF ARCTIC ISOLATION ON HUMAN PERFORMANCE

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This study was designed to evaluate group behavior and performance in isolated small military groups (predominantly in arctic areas), on the basis of a broad spectrum of relevant social-psychological factors, while functioning under "stressful" conditions. Only one of the effects will be discussed in this paper: that of performance (or productivity) as a function of adjustment.

Stress has been defined in several ways (1, 2, 3, 8) but will be defined here as the pressures, whether psychological or physical, imposed or perceived by the individual (7). The term isolation also has manifold meaning. As pointed out by Manning (4), isolation is a poorly defined variable for psychological experimentation. It is not the all-or-none concept defined in terms objectively specifiable by physical determinants, but a dimension which is response defined. Isolation is as real psychologically to an individual whose duty station is connected by road to a town or village as it is to one who endures the hardships of a barren rocky windswept mountain site overlooking the Chukchi Sea. Isolation as used in this paper will be considered (a) confinement to a limited space, (b) separation from valued stimuli and (c) separation from environment by reduction of stimulation (6).

The methods in this study largely involved the use of observational techniques, supplemented by focused interviews on a number of United States Air Force remote radar stations called AC&W (Aircraft Control and Warning) sites. The observations and interviews extended over approximately 2 months on each site in different seasons, during which time the investigator could become familiar with facets of the mission, operation and problems of the stations. The investigator also became part of the operation, so to speak, thus gaining the confidence of both officers and men. Interviews were arranged at the convenience of the personnel, so as not to interfere with the mission. Observations went on at any time.

Regardless of the degree of isolation and stress imposed or perceived for the group in the arctic study, three definite phases

of adjustment are apparent, which produce different levels of performance. These responses seem to be constant from station to station. Rohrer (5) points out that antarctic studies reveal "three distinct behavioral phenomena." The "phenomena" are of the same type found during this study with slightly different aspects. There appears one variable in adjustment differences between arctic and antarctic studies, according to Rohrer. Commitment to isolation in the Antarctic means no escape in emergencies, but arctic commitment to isolation offers possibility of escape.

In the first 2 months of the 12-month tour at each arctic station, there appears the quiet anxiety and apprehensiveness associated with placement into a new environment. The feeling of isolation is heightened at this point because the individual is not part of a group or part of the operation. On many stations the individual is given KP for the first 30 days, enhancing the feeling of isolation even further. He has not yet learned the workings of the station, the group or the environment. Performance is well below capacity during the learning process of this phase. During this period of heightened anxiety, significant psychological problems not detected in the social milieu of a secure stateside setting may come to the surface. Unfortunately, those already secure in the group may tent to "hop" on those idiosyncrasies, further isolating the individual and causing more anxiety. These cases have not been numerous and should not be considered as a primary problem. Productive output is limited.

As adjustment increases, efficiency increases, and consequently performance in the primary tasks becomes greater as the first phase comes to an end. It blends into the second phase, which lasts for approximately 9 months. Performance of duties has now attained a relatively stable level (it may not be full capacity), as the individual settles into the routine patterns of behavior displayed by the group. He probably has learned his position, both in the job and status: what is expected of him and what is to be expected from others. He takes on the ideas, complaints and routine behavior of his work group and interaction groups. Feelings of isolation and stress, although still present, becomes less preoccupying. He has become part of the "total picture" of group interaction and task performance.

At the eighth or ninth month of the tour, performance begins to taper off in all tasks, signaling the beginning of the third and final phase of adjustment. Symptoms of anxiety and apprehension reappear in the form of sleeplessness, roaming (at odd hours) and

increase in sensitivity. This sensitivity may show itself in a number of ways depending on the individual, the impact his group had upon him or attitudes of others, especially superiors. In most cases it appears as an "I could care less" attitude on the surface. But usually the person becomes cautious in word and action. He generally performs the bare essentials on duty and almost always completely curtails non-duty tasks which may jeopardize his chance to leave the station. Sometimes aggressive behavior is displayed and the individual becomes loud and intolerant. This period becomes the most nonproductive because these behaviors are "understandable" and tolerated by the command group.

The third phase also shows the adoption of various status symbols of the "short-timers." The symbols may be bright ribbons, large safety pins, arm bands or anything that would bring attention while worn on the duty uniform. The symbols call attention to the fact the date of rotation is near.

These three phases of adjustment are but one aspect of the observations. Behavior and performance must also consider the multivariant factors of: attitudes of leaders, group cohesiveness (how the group works as a team), stability of the organization, frequency of mail delivery, degree of actual physical isolation, management principles and many others.

In terms of the adjustment factors, however, some tentative solutions may be possible. One obvious solution is an improved selection and indoctrination program for personnel assigned to remote arctic sites. Selection is difficult in view of the varied conditions under which personnel must function at different stations. It might be useful to group sites with similar environmental characteristics and have special selection criteria for each group. In addition, a thorough program of indoctrination for both officers and men might be emphasized. It is probably impossible to completely eliminate the first phase of adjustment because of the unique character of arctic duty, but if the men are given an idea of what to expect, anxiety and insecurity could be reduced and performance in the primary stage of the tour improved. The possibility of rotating personnel as a functional group, rather than as individuals, should be considered and might also serve to decrease the length of the initial adjustment phase. Certainly, additional study and investigation is needed to solve these problems.

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