SPECIAL REPORT 15

GEOLOGIC HAZARDS OF THE FAIRBANKS AREA, ALASKA

By
Troy L. Péwé

First Edition, 1982
by
Department of Natural Resources
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS
Fairbanks, Alaska
Reprinted 1993

Cover photo: *Inactive ice wedges exposed during excavation of a roadcut in organic-rich, retransported silt in the east wall of the Dawson Cut, Fairbanks D-2 Quadrangle, Alaska. Photograph by T.L. Péwé, June 23, 1981.*

STATE OF ALASKA
Walter J. Hickel, *Governor*

DEPARTMENT OF NATURAL RESOURCES
Glenn A. Olds, *Commissioner*

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS
Thomas E. Smith, *State Geologist*

Address mail orders to the Fairbanks office. DGGS publications may be inspected at the following locations.

Alaska Division of Geological & Geophysical Surveys
794 University Avenue, Suite 200
Fairbanks, Alaska 99709-3645

Department of Natural Resources
Public Information Center
3601 C Street, Suite 200
Anchorage, Alaska 99510

This publication, released by the Division of Geological & Geophysical Surveys, was produced and printed in Anchorage, Alaska, at a cost of $7 per copy. Publication is required by Alaska Statute 41, "to determine the potential of Alaskan land for production of metals, minerals, fuels, and geothermal resources; the location and supplies of groundwater and construction materials; the potential geologic hazards to buildings, roads, bridges, and other installations and structures; and shall conduct such other surveys and investigations as will advance knowledge of the geology of Alaska."

FOREWORD

Alaska's environment is complex and, in many ways, very hostile. Many unfamiliar geologic processes may adversely affect us, our activities, and our property and cause considerable loss of life, time, and money. As we learn about these processes, we become better prepared to overcome or avoid their consequences. Educating the public and various decision-making organizations about Alaska's geologic environment is a primary responsibility of the Alaska Division of Geological and Geophysical Surveys (DGGS).

This is the first in a series of reports designed to provide specific information about geologic constraints in various communities in Alaska. The choice of Fairbanks as the subject of the initial report was based on several considerations. First, numerous geologic processes potentially threaten residents of the Fairbanks area. Second, the degree of risk from geologic hazards increases as local populations expand and prime locations become occupied. Attempts to build on marginal or hazardous locations in the Fairbanks area have increases markedly in the past decade. Third, although a wealth of technical information on geologic conditions in the Fairbanks area exists, much of it is not readily available or is scattered through various agencies and publications. Collection of these data is useful to scientists and the public. Finally, in Dr. Troy L. Péwé we recognized an outstanding authority who is uniquely qualified to establish the standards for subsequent reports in this series. As a geologist with the U.S. Geological Survey (USGS), and a faculty member and Chairman of the Department of Geology, University of Alaska, Fairbanks from 1953 to 1965, Dr. Péwé extensively studied the environmental problems of the Interior. His expertise is evident in the dozens of publications on permafrost and related problems of frozen ground he has prepared during the past 30 years. He is a member and chairman of several national and international commissions on frozen-ground phenomena. Further, his role as an educator properly prepared him to provide the educational emphasis necessary for this series.

Because of the widespread popularity of Special Report 15, DGGS stocks have been depleted in the past 10 years. Numerous requests continue to be received, so we have decided to reprint the 1982 report.

Thomas E. Smith
State Geologist

CONTENTS

CONTENTS (Cont.)

FIGURES

FIGURES (cont.)

FIGURES (cont.)

FIGURES (cont.)

TABLES

INTRODUCTION

One spring day Jack Smith* closed the front door of his new $250,000, full-basement house near Farmers Loop Road and wondered why the door had been sticking lately. His wife also complained that when the kitchen floor was mopped all the water ran to a corner of the room. By the following fall, cracks had appeared in the foundation and walls, and the water line ruptured as the house settled 5 inches during the first year. This house is a typical example of many structures in the Fairbanks area that require expensive, long-term maintenance, or are eventually abandoned, as ice-rich permafrost thaws and the ground subsides under the house.

One winter day Kitty Jackson* called her husband at the office to explain that water was bubbling from their basement floor and running outside into the -40°F weather. She couldn't stop the water flow and soon most of the basement was filled. Outside, as the running water froze, a sheet of ice---locally called a 'glacier'---accumulated. Little did the residents realize that during the next few days artesian water would continue flowing and eventually partially bury their automobiles and houses, forcing them to relocate.

Numerous similar events have occurred in the Fairbanks area when people build improperly or in the wrong location. Unfavorable geologic conditions have required costly maintenance on bridges on the Alaska Railroad and caused abandonment of parts of highways, destruction of property through gullying of loess, and loss of lives and property by flooding.

Although these experiences may be viewed as horror stories, they have helped identify some natural hazards that occur in the Fairbanks area. A geologic hazard is a perfectly normal geologic event, process, or condition that becomes a problem only when it affects man, his property, or his pocketbook. Early recognition of geologic conditions, along with careful planning and engineering can, in many cases, reduce or eliminate the loss of time, money, and lives resulting from the natural activities of geologic processes.

The flooding, landslides, earthquakes, and slope erosion common in the Fairbanks area also occur elsewhere. However, hazards such as ground subsidence due to thawing of ice-rich permafrost; frost heaving of roads, airfields, and other structures; and formation of icings on roads and private property are characteristic of northern regions.

SOURCES OF INFORMATION

The most effective use of private and public land requires detailed site-specific geologic information. Broad training and an intensive study of the Earth prepare the geologist to inform city and borough planners, developers, engineers, state and local policy formulators, and the general public about geologic conditions on an areal and site-specific scale. To protect the public from geologic and hydrologic disasters, guard against loss of life and property damage, and conserve resources, geologists and planners must work together to develop practical and constructive solutions to geologic-hazard-related problems.

Providing information to the scientist, planner, and man on the street in the Fairbanks area is one of the primary functions of the DGGS, the USGS, and the U.S. Soil Conservation Service (SCS). These agencies have published a wealth of information on land-use-related geologic hazards.

The public has become increasingly aware of the extensive test holes drilled by the State of Alaska Department of Transportation and Public Facilities during highway foundation investigations, and numerous individuals have used this information in making decisions about land acquisition. Test holes along the roadway may yield information on depth to water table, thickness of silt over gravel, amount of moisture in permafrost, presence of loess, and character of bedrock. Because new test holes are drilled each year, considerable information is now available for the road network in the Fairbanks area.

Where can individuals go to find information on flooding in the Fairbanks area? For historic data, the University of Alaska Museum and libraries should be consulted. Detailed records and publications are available at the U.S. Army Corps of Engineers and the USGS in Anchorage and Fairbanks. Flood-insurance information is available at the Fairbanks offices of the City Engineer, the North Star Borough, and the U.S. Department of Housing and Urban Development.

In addition to the numerous publications on earthquakes in central Alaska, information can be obtained from scientists at the University of Alaska Geophysical Institute, as well as from seismologists and geologists with the USGS and DGGS.

This report lists pertinent references, by chapter, concerning geology, frozen ground, ground water, flooding, landslides, hillside erosion, and earthquakes in the Fairbanks area.

ACKNOWLEDGMENTS

In compiling this report on geologic hazards in the Fairbanks area, I have drawn heavily on my experience with the Alaskan Branch of the USGS. It has often been necessary to refer to and receive generous aid from

*Names changed to protect the innocent—but ill advised—on geologic hazards.

friends and colleagues in the USGS and on the faculty of the University of Alaska, Fairbanks. To these associates I extend a sincere thanks.

It is a pleasure to acknowledge the cooperation of Richard D. Reger in this work. Dr. Reger, who coordinates the geologic-hazards program for DGGS, suggested the project as part of a state-wide program to evaluate natural hazards. He recognized that the scientific literature on the subject could be recast and brought to the attention of geologists and nongeologists. He helped locate information, provided photographs, and reviewed the entire manuscript. George Plafker, J.R. Williams, and Oscar Ferrians, Jr., geologists with the USGS in Menlo Park, California, carefully reviewed the sections on earthquakes, ground water, and permafrost, respectively. D.M. Ragan, Arizona State University, also reviewed the section on earthquakes, and J.M. Childers, hydrologist with the USGS in Anchorage, kindly reviewed and offered valuable suggestions on the section on flooding. H.R. Livingston, engineering geologist for the Alaska Department of Transportation and Public Facilities in Fairbanks, and R.G. Updike, DGGS geologist, reviewed the entire manuscript.

Many persons have contributed their most recent data in their particular field. I gratefully acknowledge E.H. Beistline, Dean, School of Mineral Industry, University of Alaska, Fairbanks; P.R. Berrian, former Planning Director, Fairbanks North Star Borough; N.M. Biswas, geophysicist, University of Alaska, Fairbanks; John Carlson, Mayor, Fairbanks North Star Borough; J.M. Childers, hydrologist, USGS, Anchorage; T.C. Fuglestad, Chief Engineer, Alaska Railroad, Anchorage; Calcord 'Rusty' Heurlin, artist, College; Woodrow Johansen, Interior Regional Engineer, Alaska Department of Transportation and Public Facilities, Fairbanks; K.A. Linell (retired), U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire; James and Sally Murphy, Fairbanks; G.L. Nelson, hydrologist, USGS, Anchorage; E.S. Philleo and staff, Philleo Engineering and Architectural Services, Inc., Fairbanks; George Plafker, geologist, USGS, Menlo Park, California; R.D. Rayburn, District Conservationist, SCS, College; Mike Evans, U.S. Army Corps of Engineers, Alaska District, Anchorage; Thomas Snapp, Editor, All-Alaska Weekly, Fairbanks; J.B. Townshend, Chief, College Observatory, USGS, College; M.J. Turner, Acting Authorized Officer, Alaska Pipeline Office, U.S. Department of Interior, Anchorage; F.R. Weber, geologist, USGS, College; J.R. Williams, geologist, USGS, Menlo Park, California; Ernest Wolff, Professor, University of Alaska, Fairbanks; and G. Zimmerman, Arizona State University, Tempe.

The presentation of material is greatly enhanced by the diagrams prepared by Susan Selkirk, Artist-in-Residence, Museum of Geology, Arizona State University, Tempe, and Karen S. Pearson, DGGS cartographer, Fairbanks. Cheri L. Daniels, DGGS publications specialist, escorted this report through various steps of the complicated publishing procedure and provided many helpful suggestions to improve the manuscript.

PHYSICAL SETTING OF THE FAIRBANKS AREA

TOPOGRAPHY AND GEOLOGY

Fairbanks is located about 100 miles south of the Arctic Circle on the north side of the broad Tanana River Valley near the base of the hills of the southern Yukon-Tanana Upland. This east-trending upland between the Yukon and Tanana Rivers is an area of rounded ridges 2,000 to 3,000 feet in elevation (fig. 1). Scattered groups of higher mountains project above ridges to altitudes of 5,000 to 6,000 feet. Summits in the Fairbanks area reach elevations of 1,250 to 1,800 feet and local relief ranges from 600 to 1,300 feet.

South of the Yukon-Tanana Upland is the wide Tanana River lowland, a sediment-filled trough between the uplands to the north and the towering, glaciated Alaska Range to the south. Huge alluvial fans extend northward from the Alaska Range to the vicinity of Fairbanks.

The Fairbanks area is subdivided by physiography and geology into loess-covered bedrock hills, lower hillslopes and creek-valley bottoms, organic-silt lowlands at the base of hills, and the Chena and Tanana River flood plains (fig. 2). Bedrock hills consist mainly of schist, slate, and gneiss, which are intruded by quartz veins ranging in thickness from less than 1 inch to 2 feet. Some hills are composed of granitic rock, and dark basalt crops out locally. Less than 3 feet of loess covers bedrock on hilltops and steep slopes. Loess thickness increases on middle and lower hillslopes.

Loess is a homogeneous deposit of silt-size particles transported by strong winds from the Tanana River flood plain. It is from 1 to 200 feet thick and is composed of the same material that covers the landscape in Illinois, Iowa, and Indiana, where it forms excellent agricultural soils. Many farms in the Fairbanks area are located on these sediments.

Stream-deposited silt fans and small areas of organic silt and peat occur in the valley bottoms. Lower slopes and organic-silt lowlands are perennially frozen and contain large masses of ice (figs. 3, 4).

A 1- to 15-foot-thick layer of mica-rich, sandy silt covers the surface of the flood plains of the Chena and Tanana Rivers. Sandy gravel (40 percent sand and 60 percent gravel) of variable thickness lies beneath this silt mantle. Cobbles up to about 3 inches in diameter are common. Alternating lenses or beds of silt, sand, and gravel extend to a depth of about 700 feet. Permafrost is present in the flood-plain sediments, but is generally absent under rivers and lakes (figs. 3, 4). Frozen flood-plain sediments contain ice in the form of intergranular fillings rather than the large ice masses common in retransported silt of the lower slopes and lowlands.

CLIMATE

Fairbanks has the most rigorous climate of any city in the United States. Weather records from 1904 to the present indicate that the region has a continental climate characterized by an extreme range of temperatures (fig. 5). The minimum recorded temperature is -66°F and the maximum is 99°F. The mean annual number of days with freezing temperatures is 233, but freezing temperatures have been reported during every month except July.

Mean annual air temperature is not the best measure of duration and intensity of cold. A more accurate method uses the freezing index, which is the number of degree days during a freezing season. The degree days for any one day equal the difference between the average daily air temperature and 32°F. An average daily air temperature of -30°F yields 62 degree days when calculating the mean annual freezing index. The mean annual freezing index for Fairbanks---based on a 45-year air-temperature record---is 5,220 degree days. In contrast is Anchorage with 3,000 degree days, Barrow with 8,500 degree days, Minneapolis, Minnesota with 1,560 degree days, and Burlington, Vermont, with 1,260 degree days.

Although summers in central Alaska are the warmest in the state, the mean temperature for June, July, and August is only 57.8°F. The mean annual air temperature is 26.1°F. The mean date for the last killing spring frost is May 22, and August 31 is the mean date for the first autumn killing frost. The longest recorded period of frost-free days is 137. Of major importance to development in the area are the warm summers and many possible hours of summer sunshine.

Even though swampy conditions exist on lower slopes and in valley bottoms during the summer, the Fairbanks area has scant precipitation and is classed as semi-arid (fig. 6). Most of the 11.7 inches of annual precipitation falls as light summer showers, although thunderstorms do occur. In fact, 63 percent of the annual precipitation falls from May through September. Although more than half the summer days are cloudy, there are many hours of sunshine because the summer days are very long. Mean annual snowfall is 66.6 inches (fig. 6).

SELECTED REFERENCES

American Geological Institute, 1976, Dictionary of geological terms: Garden City, New York, Anchor Press & Doubleday, 472 p.

Bennett, H.H., and Rice, T.D., 1919, Soil reconnaissance in Alaska, with an estimate of the agricultural pos-

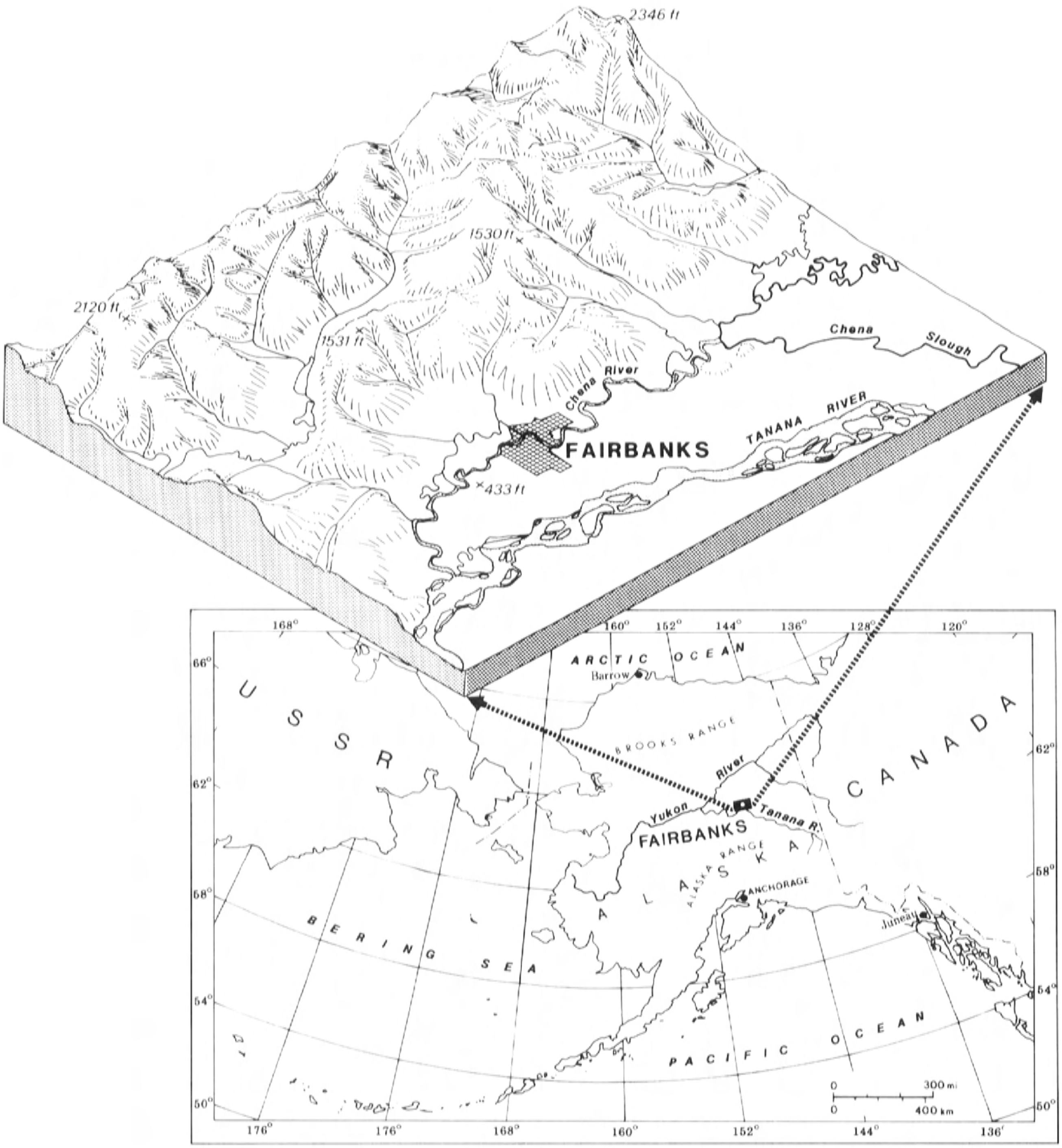

Figure 1. Index map of Alaska showing location of the Fairbanks area.

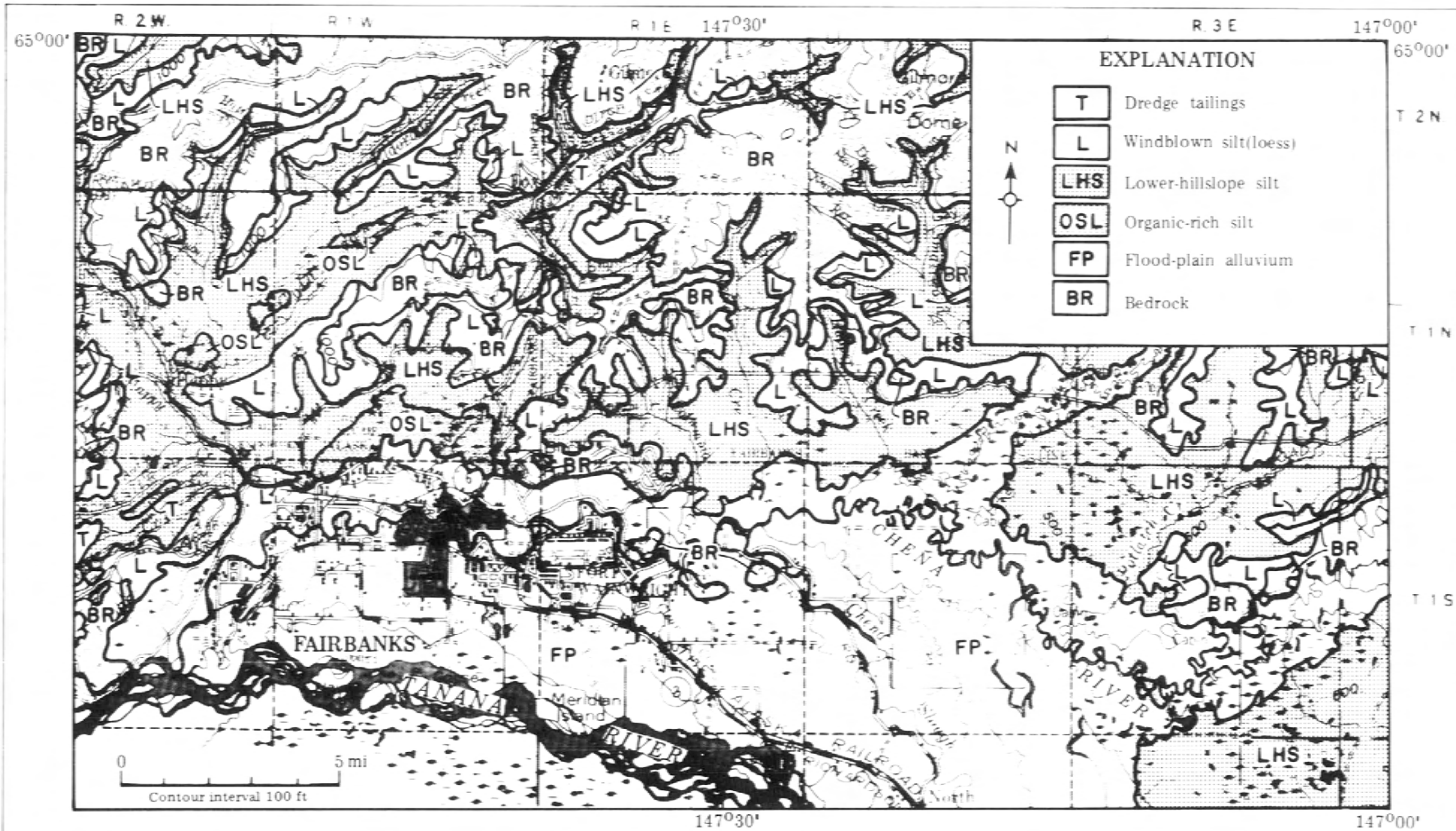

Figure 2. Geologic map of the Fairbanks area (modified from Péwé, 1958; Williams, Péwé, and Paige, 1959).

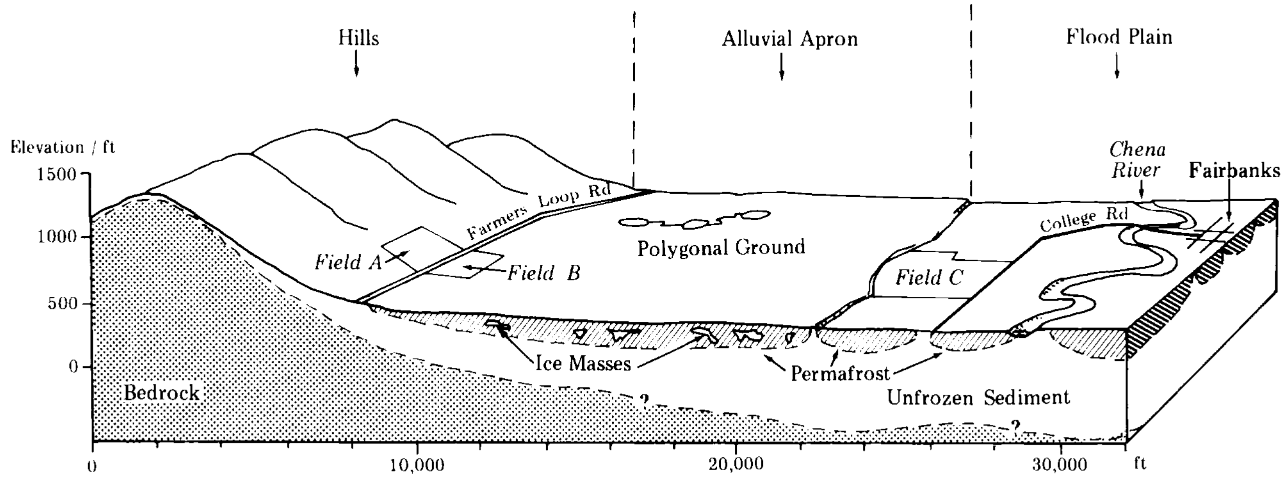

Figure 3. Diagrammatic sketch showing the character and distribution of permafrost in the Fairbanks area. Field A is not underlain by permafrost. Field B is underlain by permafrost containing large ice masses; thermokarst mounds and pits may form when the ice melts. Field C is underlain by permafrost without large ice masses; mounds and pits will not form at the surface and ground subsidence is negligible.

sibilities: U.S. Department of Agriculture Bureau of Soils Field Operations, 1914, 16th Report, p. 43-236.

Blackwell, M.F., 1965, Surficial geology and geomorphology of the Harding Lake area, Big Delta Quadrangle, Alaska: Fairbanks, University of Alaska unpublished M.S. thesis, 91 p.

Campbell, Ian, 1977, The influence of geologic hazards on legislation in California: California Geology, v. 30, no. 10, p. 219-222.

Coulter, H.W., Hopkins, D.M., Karlstrom, T.N.V., Péwé, T.L., Wahrhaftig, Clyde, and Williams, J.R., 1965, Extent of glaciations in Alaska: U.S. Geological Survey Miscellaneous Geological Investigations Map I-415, scale 1:2,500,000.

Griggs, G.B., and Gilchrist, J.A., 1977, The earth and land-use planning: North Scituate, Massachusetts, Duxbury Press, 492 p.

Karlstrom, T.N.V., and others, 1964, Surficial geology of Alaska: U.S. Geological Survey Miscellaneous Geological Investigations Map I-357, scale 1:1,584,000.

Keller, E.A., 1976, Environmental geology: Columbus, Ohio, Merrill, 488 p.

Mertie, J.B., Jr., 1937, The Yukon-Tanana region, Alaska: U.S. Geological Survey Bulletin 872, 276 p.

Péwé, T.L., 1958, Geology of the Fairbanks D-2 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-110, scale 1:63,360.

______________, 1968, Loess deposits of Alaska: International Geologic Congress, 23rd, Prague, 1968, v. 8, p. 287-309.

______________, ed., 1969, The periglacial environment: past and present: Montreal, McGill-Queens University Press, 487 p.

______________, 1975, Quaternary geology of Alaska: U.S. Geological Survey Professional Paper 835, 145 p.

______________, ed., 1977, Guidebook to the Quaternary geology, central and south-central Alaska: Fairbanks, Alaska Division of Geological and Geophysical Surveys, 141 p.

Péwé, T.L., and Bell, J.W., 1974, Map showing distribution of permafrost in the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geological Investigations Map I-829B, scale 1:24,000.

______________, 1975a, Map showing distribution of permafrost in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668A, scale 1:24,000.

______________, 1975b, Map showing ground water conditions in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668B, scale 1:24,000.

______________, 1975c, Map showing construction materials in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668C, scale 1:24,000.

______________, 1975d, Map showing foundation conditions in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668D, scale 1:24,000.

______________, 1975e, Map showing distribution of permafrost in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669A, scale 1:24,000.

______________, 1975f, Map showing ground water conditions in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669B, scale 1:24,000.

______________, 1975g, Map showing construction materials in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669C, scale 1:24,000.

______________, 1975h, Map showing foundation

Figure 4. Oblique aerial view of Fairbanks. Photograph by U.S. Army Corps of Engineers (1946) from 15,000 feet above mean ground level.

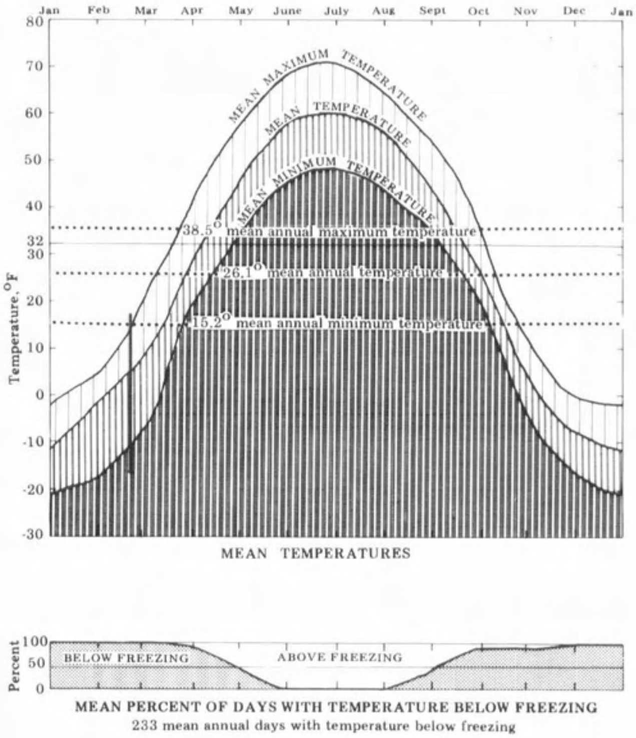

Figure 5. Temperature data for the Fairbanks area.

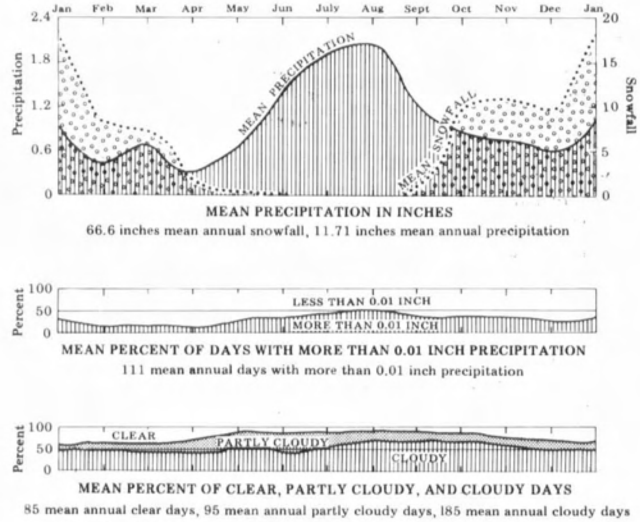

Figure 6. Precipitation and cloud-cover data for the Fairbanks area.

conditions in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669D, scale 1:24,000.

_______________, 1975i, Map showing distribution of permafrost in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-670A, scale 1:24,000.

_______________, 1975j, Map showing ground water conditions in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-670B, scale 1:24,000.

_______________, 1975k, Map showing construction materials in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-670C, scale 1:24,000.

_______________, 1975l, Map showing foundation conditions in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-760D, scale 1:24,000.

_______________, 1975m, Map showing distribution of permafrost in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671A, scale 1:24,000.

_______________, 1975n, Map showing ground water conditions in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671B, scale 1:24,000.

_______________, 1975o, Map showing construction materials in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671C, scale 1:24,000.

_______________, 1975p, Map showing foundation conditions in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671D, scale 1:24,000.

_______________, 1976a, Map showing ground water conditions in the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-829C, scale 1:24,000.

_______________, 1976b, Map showing construction materials in the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-829D, scale 1:24,000.

_______________, 1976c, Map showing foundation conditions in the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-829E, scale 1:24,000.

Péwé, T.L., Bell, J.W., Forbes, R.B., and Weber, F.R., 1976a, Geologic map of the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-950, scale 1:24,000.

_______________, 1976b, Geologic map of the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-907, scale 1:24,000.

_______________, 1976c, Geologic map of the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-942, scale 1:24,000.

_______________, 1976d, Geologic map of the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-829A, scale 1:24,000.

Péwé, T.L., Bell, J.W., Williams, J.R., and Paige, R.A., 1976, Geologic map of the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-949, scale 1:24,000.

Péwé, T.L., Church, R.E., Andresen, M.J., 1969, Origin and paleoclimatic significance of large-scale patterned ground in the Donnelly Dome area, Alaska: Geological Society of America Special Paper 103, 87 p.

Péwé, T.L., and Rivard, N.R., 1961, Geologic map and section of the Fairbanks D-3 Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geological Investigations Map I-340, scale 1:63,360.

Péwé, T.L., Wahrhaftig, Clyde, and Weber, F.R., 1966, Geologic map of the Fairbanks Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-455, scale 1:250,000.

Robinson, G.D., and Spieker, A.M., 1978, Nature to be commanded: U.S. Geological Survey Professional Paper 950, 95 p.

Selkregg, L.L., 1977, Alaska regional profiles - Yukon region: Anchorage, University of Alaska Arctic Environmental Information and Data Center, 346 p.

Tuck, Ralph, 1940, Origin of muck-silt deposits at Fairbanks, Alaska: Geological Society of America Bulletin, v. 51, no. 9, p. 1295-1310.

U.S. Geological Survey, 1949, Interpreting ground conditions from geologic maps: U.S. Geological Survey Circular 46, 10 p.

Wahrhaftig, Clyde, 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p.

Williams, J.R., Péwé, T.L., and Paige, R.A., 1959, Geology of the Fairbanks D-1 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-124, scale 1:63,360.

Wold, Joanne, 1971, Fairbanks, the $200,000,000 gold rush town: Fairbanks, Alaska, 42 p.

FROZEN GROUND

The most widespread geologic hazard in the Fairbanks area---and perhaps the most costly overall---is frozen ground. Floods and earthquakes are spectacular but relatively rare, and problems with seasonally and perennially frozen ground are constant. They range from irksome frozen wells and frost-heaved porches to the enormous engineering obstacles involved in construction of the Trans-Alaska Pipeline System.

Perennially frozen ground, or permafrost, is certainly a costly phenomenon in polar and subpolar regions, but seasonally frozen ground is an equally important geologic hazard. Surprisingly, seasonally frozen ground is not limited to northern climes but is common (and destructive) in Minnesota, Iowa, and Arizona.

SEASONALLY FROZEN GROUND

DEFINITION

Frost action refers to the seasonal freezing and thawing of moisture in ground materials and its effect on these materials and related structures. During the winter, ice formation causes an upward displacement of the ground called frost heaving. When the ground ice thaws in the spring, there is a resultant loss of bearing strength and ability to support structures.

THE PROBLEM

In cold regions, especially in areas of fine-grained sediments such as silt and clay, frost heaving and loss of bearing strength are major problems that should be considered in land-use planning. Frost action affects the works of man by distorting structures during heaving; structural damage occurs when the ground loses bearing strength during seasonal thaw.

Differential movement is the critical problem that causes extensive damage to above-ground structures and to foundations and basements. Frost heaving may disturb bridges, buildings, railroads, highways, airfields, pipelines, and other structures.

CAUSE OF FROST HEAVING

The growth of seasonal ice in pore spaces between coarse-grained sediments causes limited volume expansion and therefore slight ground distortion. This volume change is generally due to the expansion of interstitial water when it changes from a liquid to a solid, and amounts to a volume increase of about 9 percent.

Volume expansions of up to 140 percent have been recorded during seasonal freezing of fine-grained materials when excess water is drawn into the freezing soil. Such activity is common in silt and clay, whose physical properties allow migration of moisture to the ice crystal, or freezing front. The result is extensive ground heaving caused by the formation of ice lenses and other types of clear-ice segregations. The intensity of this activity varies according to temperature, soil texture, and soil moisture.

FROST ACTION IN THE FAIRBANKS AREA

The extensive blanket of silt, long periods of freezing, and poor drainage in the Fairbanks area provide ideal conditions for intense seasonal frost action. Four broad zones of frost-action intensity are present: a) loess-covered hills, b) lower hillslopes and creek-valley bottoms, c) organic-silt lowlands, and d) flood plains of the Chena and Tanana Rivers (fig. 7). These zones coincide with the area's permafrost zones.

Hilltops and steep or moderate south-facing hillslopes are not underlain by permafrost and, except for flat summits and saddles, are well drained. Frost action in these areas is absent to mild, and damage to engineering structures is rare. Where drainage is poor, frost action is locally intense.

The impermeable substratum of permafrost in silt deposits on lower hillslopes and in creek-valley bottoms results in poor drainage. As a result, frost action is intense in near-surface silts, and many structures on these slopes and in valley bottoms (except near the contact with the permafrost-free loess) have been damaged.

Areas most intensely affected by frost action are the organic-silt lowlands between Farmers Loop Road and College Road and two small lowland areas in Goldstream Valley (fig. 7). These poorly drained areas of organic silt and peat are underlain by continuous permafrost and support few structures. College Road previously crossed the lowland, but was rerouted because of damage caused by seasonal frost and the thawing of ice-rich permafrost.

The Chena and Tanana River flood plains (fig. 7) support most engineering structures in the Fairbanks area, including the city, international airport, and Fort Wainwright. Flood-plain silt is poorly to fairly well drained. Many meander scars, swales, and intermittent drainage channels filled with 1 to 30 feet of organic silt trend sinuously across the flood plain (fig. 8). Highways and buildings on these poorly drained deposits have been seriously damaged by alternate freezing and thawing of soil moisture. Drainage improves when the vegetation is removed, because the permafrost table is subsequently lowered.

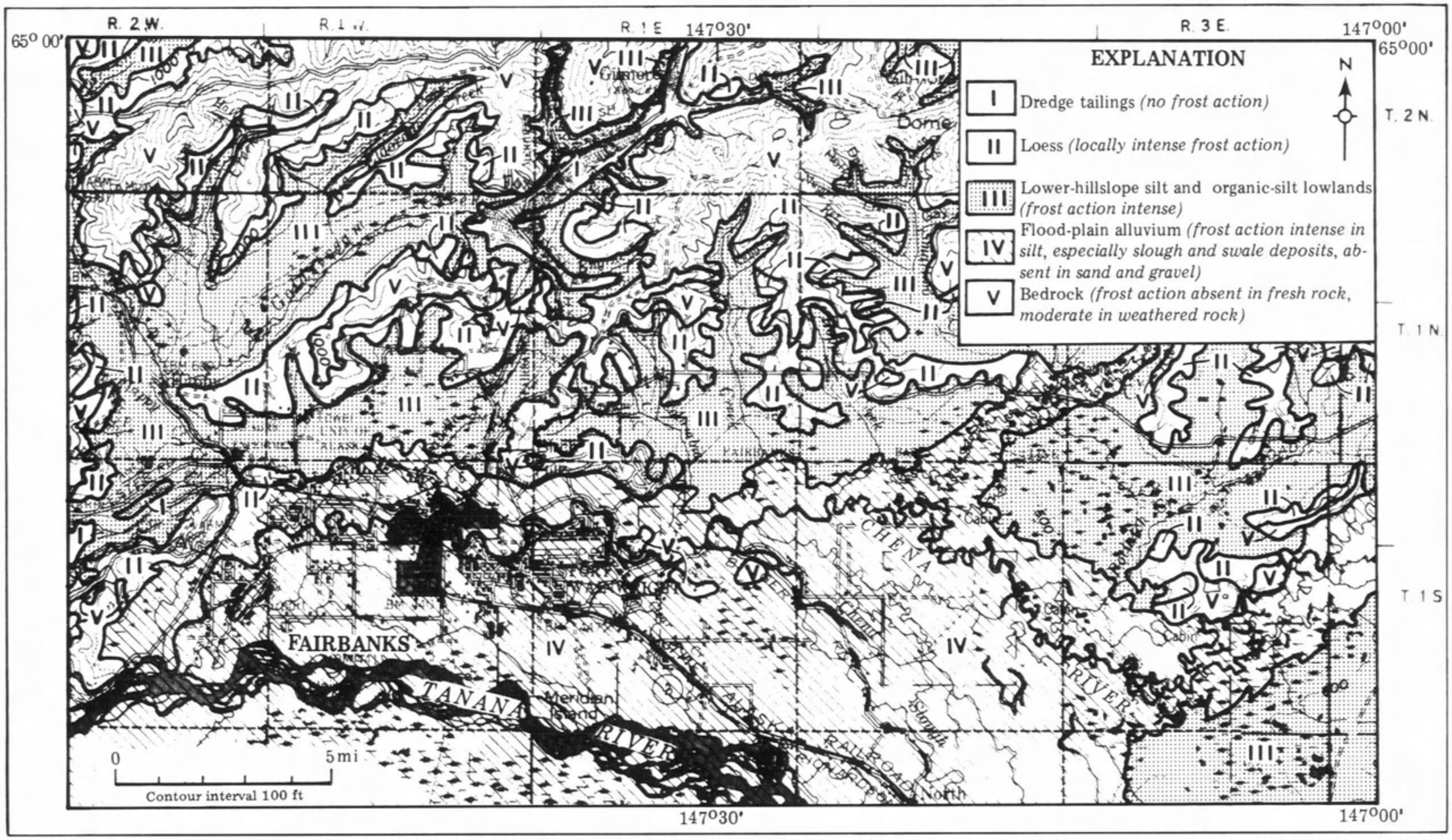

Figure 7. Map of seasonal-frost-action zones in the Fairbanks area (modified from Péwé, 1958; Williams, Péwé, and Paige, 1959).

FROST ACTION ON PILE CONSTRUCTION

A major problem in the subarctic is the frost heaving of structures supported by piles. Although pile construction is as widespread in cold regions as in warmer regions, the problems related to pile engineering are quite different. In warm climates, the chief reason for using piles is to obtain an adequate bearing capacity. In cold regions, where piles are used to prevent melting of permafrost, it is often difficult to keep piles in place because of seasonal freezing of the ground. If they are heaved by frost action, displacement may cause damage or destruction of the structures they support.

In winter, seasonally freezing ground firmly grips the pile and forces it upward as ice grows in fine-grained, poorly drained sediments. The forces holding the pile in place are the load on the pile, the weight of the pile, and the grip of the soil on the lower unfrozen part of the pile, also called the skin friction bond (fig. 9). The upward forces increase as the seasonal-frost layer thickens. Consequently, most heaving occurs during late winter. If the pile penetrates the underlying permafrost, however, the strong grip of the permafrost acts to hold it in place. Probably the most widespread effects of frost action involve structures built on piles, such as bridges, buildings, and pipelines.

HIGHWAY BRIDGES

Many highway bridges in Alaska, especially smaller ones, are distorted and even destroyed by seasonal frost heaving of piles. Wood, steel, and concrete piles, as well as concrete piers, are affected. Piles supporting a highway bridge at the outlet of Clearwater Lake, 6 miles northeast of Delta Junction and 80 miles southeast of Fairbanks (fig. 10), were heaved 11 feet in one year. Piles supporting a bridge in Siberia were heaved 24 inches in a single year.

THE ALASKA RAILROAD

The Alaska Railroad roadbed and bridges have been significantly affected by frost action. The rigorous climate and fine-grained, poorly drained sediments in Goldstream Valley---from Fairbanks west 35 miles to Dunbar---have promoted annual frost heaving of the track and of many wood-pile railroad bridges. This frost action has resulted in misalignment and track elevation disturbances that necessitate speed reductions to avoid uncoupling or shifting of cargo.

To maintain a uniform track elevation during the winter and early spring, wedges are inserted under the rails near the ends of bridges. Up to 8 inches of cumulative shimming have been sometimes necessary to maintain a uniform height between the ends of the bridges and the elevated portion, which often rests on frost-heaved piles (figs. 11a,b). During the summer, several inches are trimmed from bridge beams or the tops of the supporting frost-heaved piles and shims are removed to lower the disturbed rails; eventually new piles become necessary. During the 1950's, the per-pile-replacement cost was $125; it is considerably higher now.

The Alaska Railroad estimated the cost of shimming and rail and tie replacement at $200,000 per year (during the 1960s) for the 31 miles of track between Dunbar and Happy, about 7 miles west of Fairbanks. The cost of reduced train speeds over frost-heaved track must also be considered. In the 1950s, it cost $10 to reduce the speed of a 70-car freight train from 40 to 20 mph and then regain the original speed. These costs have, of course, increased significantly.

TRANS-ALASKA PIPELINE SYSTEM

One of America's engineering marvels is the Trans-Alaska Pipeline System, which transports crude oil from Prudhoe Bay to Valdez. A large percentage of the $8-billion-project budget was devoted to overcoming permafrost- and seasonal-frost-related problems. Because the crude oil is warmer than 32°F, frozen ground will thaw in areas of pipeline burial. To prevent thawing of ice-rich zones---and its disastrous effects---382 miles of the 798-mile-long pipeline were elevated. These portions of the pipeline are supported on 123,000 piles---termed vertical-support members (VSMs)---which are 18-inch-diameter steel pipes installed in pairs to support the 48-inch-diameter oil pipe on a cross beam (fig. 12). To avoid frost effects, the VSMs were filled with hydrous gas to ensure freezing into the permafrost.

OTHER FROST-HEAVE PROBLEMS

Highways are subject to intense seasonal frost action in the Fairbanks area, particularly on the flood plain where they cross meander scars, swales, and intermittent drainage channels filled with organic silt (figs. 4, 7).

Unheated buildings are affected by seasonal frost action, especially those with basements that permit water to move along the outside (or even inside) of the building. Buildings from the smallest outhouse (fig. 13) to the largest apartment complex may be damaged. If buildings are heated, no seasonally frozen ground will form beneath them.

An interesting example of extensive frost-induced damage in the Fairbanks area occurred along Airport Way, when a series of steel-reinforced, 6-inch-thick, poured concrete foundations were constructed on flood-plain silt in the fall of 1953. These apartment foundations were temporarily abandoned until the next construction season. Cold winter temperatures and abundant moisture that accumulated in depressions excavated for basements resulted in extensive ice formation, and the concrete structures were destroyed by heaving (figs. 14a-c). The fractured foundations were

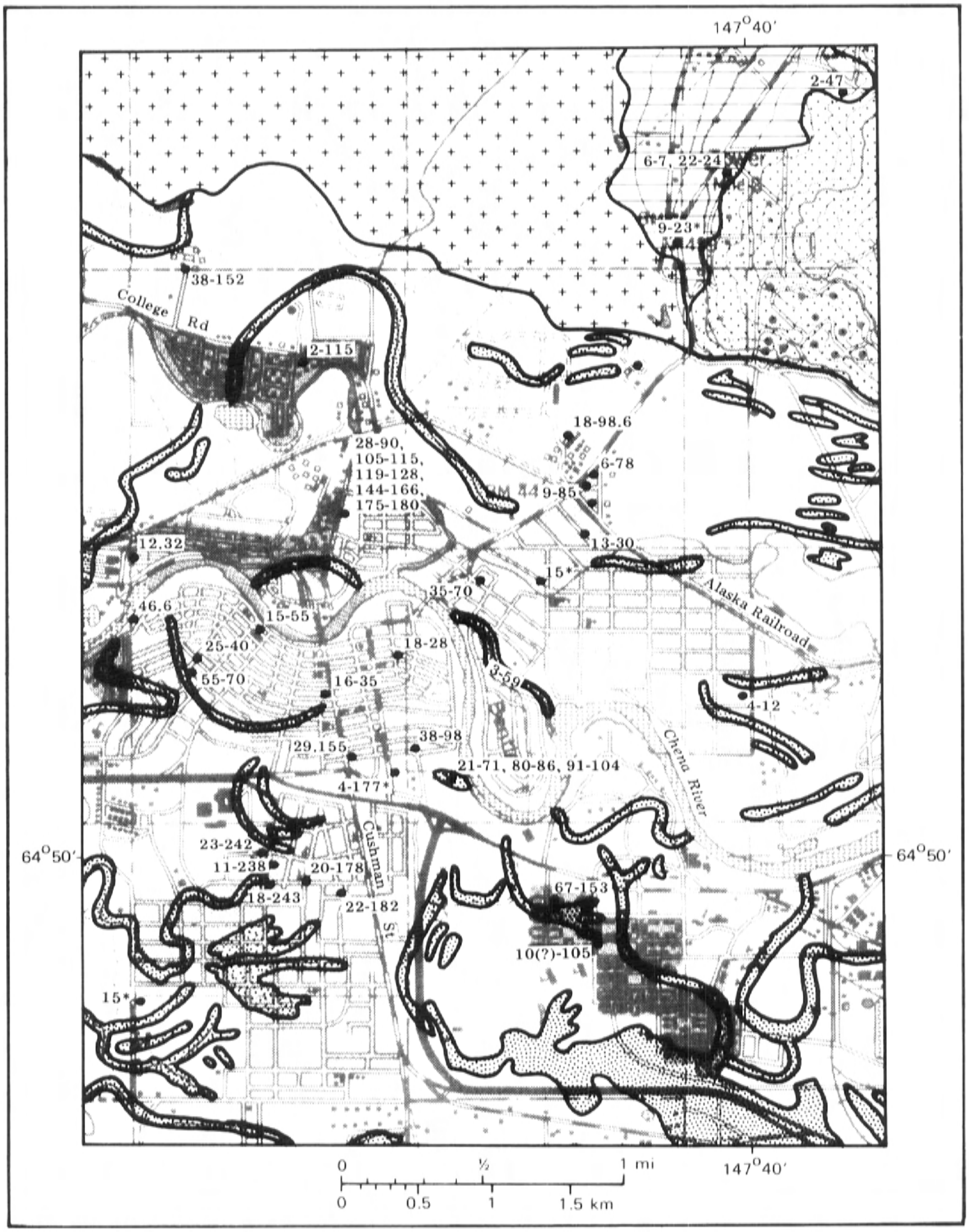

Figure 8. Permafrost and frost-action zones in the Fairbanks area (modified from Péwé and Bell, 1975b).

EXPLANATION

DESCRIPTION OF MAP UNITS

Permafrost-free areas

FLOOD-PLAIN SILT, SAND, AND GRAVEL
Permafrost with low ice content

Permafrost is discontinuous beneath lakes, rivers, and creeks. If frozen, 1-15 feet of silt overlying sand and gravel may have low to moderate ice content in the form of thin seams; underlying sand and gravel have low ice content, which is primarily restricted to pore spaces. Depth to permafrost 2-4 feet in older parts of flood plain and more than 4 feet on inside of meander curves near river. Depth to permafrost 25-40 feet in clear areas; permafrost 5-275 feet thick. Seasonal-frost layer 2-9 feet thick; silt may undergo intense seasonal-frost action, but sand and gravel will undergo none. Silt will show some subsidence upon thawing; sand and gravel will show none.

FLOOD-PLAIN SLOUGH AND SWALE DEPOSITS
Permafrost with moderate to high ice content

Broad, basinlike areas and elongate, sinuous meander scars may be perennially frozen. Permafrost is discontinuous; young sloughs and swales, especially those with intermittent streams, generally contain no permafrost. If frozen, thickness of permafrost 5-30 feet with moderate to high ice content as thin seams and small lenses; depth to permafrost 1½-4 feet. Depth to seasonal-frost layer 1½-4 feet; seasonal-frost action intense. Moderate to great subsidence upon thawing.

VALLEY-BOTTOM MUCK
Permafrost with high ice content

Silt on lower slopes and in valley bottoms is perennially frozen. Top layer (3-30 feet thick) has moderate to high ice content in form of seams and lenses; lower layer contains abundant ice as seams, horizontal and vertical sheets, wedges, and saucer-shaped and irregular masses 1-50 feet in diameter. Near upslope contact with unfrozen silt zone, ice content may be low and permafrost intermittent. Depth to permafrost 1½-3 feet on lower slopes and valley bottoms, 5-20 feet near contact with unfrozen silt zone, 10-25 feet under cleared areas; thickness of permafrost 3-175 feet; average temperature of permafrost 31-32°F. Seasonal-frost layer 1½-3 feet thick; seasonal-frost action intense. Great subsidence upon thawing.

VALLEY-BOTTOM PEAT MUCK
Permafrost with high ice content

Organic silt containing peat in valley bottoms and low, flat areas is perennially frozen. Ground ice is abundant as seams, horizontal and vertical sheets, wedges, and saucer-shaped and irregular masses 1-50 feet in diameter. Massive ice near ground surface results in large (25-100 feet in diameter) polygonal ground pattern. Depth to permafrost 1½-3 feet; thickness of permafrost 1-140 feet. Seasonal-frost layer 1½-3 feet thick; seasonal-frost action intense. Great subsidence upon thawing.

DEFINITION OF ICE CONTENT

Low—Ice generally restricted to pore spaces between particles and to thin seams less than 1/16 inch thick in silt and clay.

Moderate—Ice generally restricted to pore spaces between particles and to thin seams greater than 1/16 inch and less than 1/4 inch thick in silt and clay.

High—Ice generally in seams greater than 1/4 inch thick and large ice masses. As much as 50 percent of ground may be ice (confined to upper 30 feet).

MAP SYMBOLS

—— Contact. Generally indefinite or gradational.

21-64 Borehole location. First number indicates depth to top of permafrost; second number indicates depth to bottom of permafrost or to bottom of hole, if bottomed in permafrost. "*" indicates hole bottomed in permafrost.

Modified from Péwé, T.L., and Bell, J.W., 1975, Map showing foundation conditions in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey, Miscellaneous Field Studies Map MF-669D, scale 1:24,000, 2 sheets.

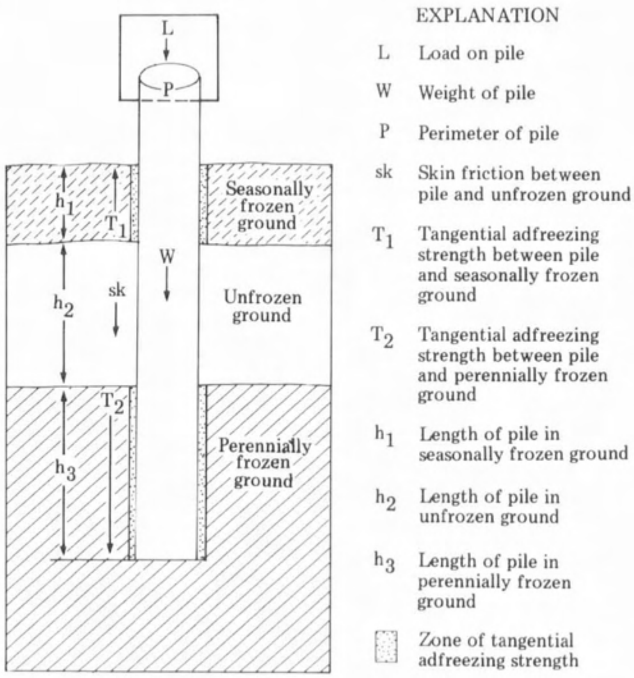

Figure 9. Forces affecting frost heaving of piles.

bulldozed into the depressions and buried at an estimated present-day loss of $250,000.

The septic disposal building at the Fairbanks Waste Water Treatment Facility near Peger Road, half a mile south of Van Horn Road, was tilted by frost action (written commun., E.S. Philleo, November 23, 1977). Construction on the building began during the fall of 1975 in the moist, organic slough and swale deposits (fig. 8) that overlie the flood-plain gravel. The silt was not excavated to gravel, and consequently, during the winter of 1975-76, a footing and wall were heaved out of line. During the next winter the south wall was elevated 2 inches, causing the buildings to tilt and making overhead doors inoperative. Further excavation revealed 6 to 12 inches of peat and about 2 feet of silt overlying flood-plain gravel beneath the south-wall footing. The problem was caused by failure to excavate to gravel, and by construction on frost-susceptible silt and peat that heaved prior to regular heating of the building. To correct the problem, the building was leveled on jacks and placed on concrete piers that extended into the flood-plain gravel. A 3-inch-thick, 8-foot-wide blanket of styrofoam was placed around the base of the building to prevent further freezing. To date the building has remained level.

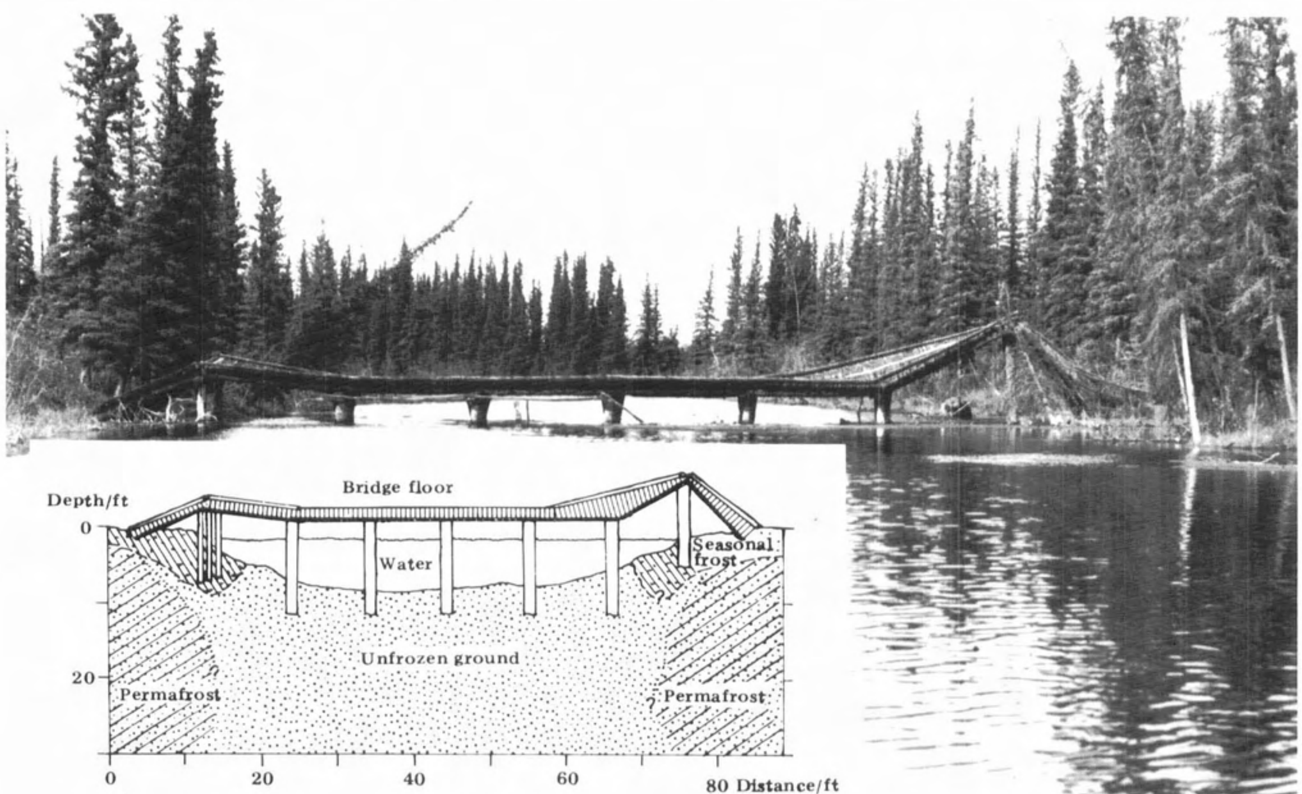

Figure 10. Frost-heaved wood piles of bridge spanning outlet of Clearwater Lake, 6 miles northeast of Delta Junction. Center piles are not affected by frost heaving because ground under creeks that are deeper than 3 feet does not freeze. Photograph 591 by T.L. Péwé, August 15, 1951 (modified from Péwé and Paige, 1963).

Figure 11a. View looking north of wood-pile bridge at Mile 458.4 of the Alaska Railroad. Center of bridge was frost heaved 5 inches during the winter of 1955-56. Photographs 1250-53 by T.L. Péwé, February 3, 1956.

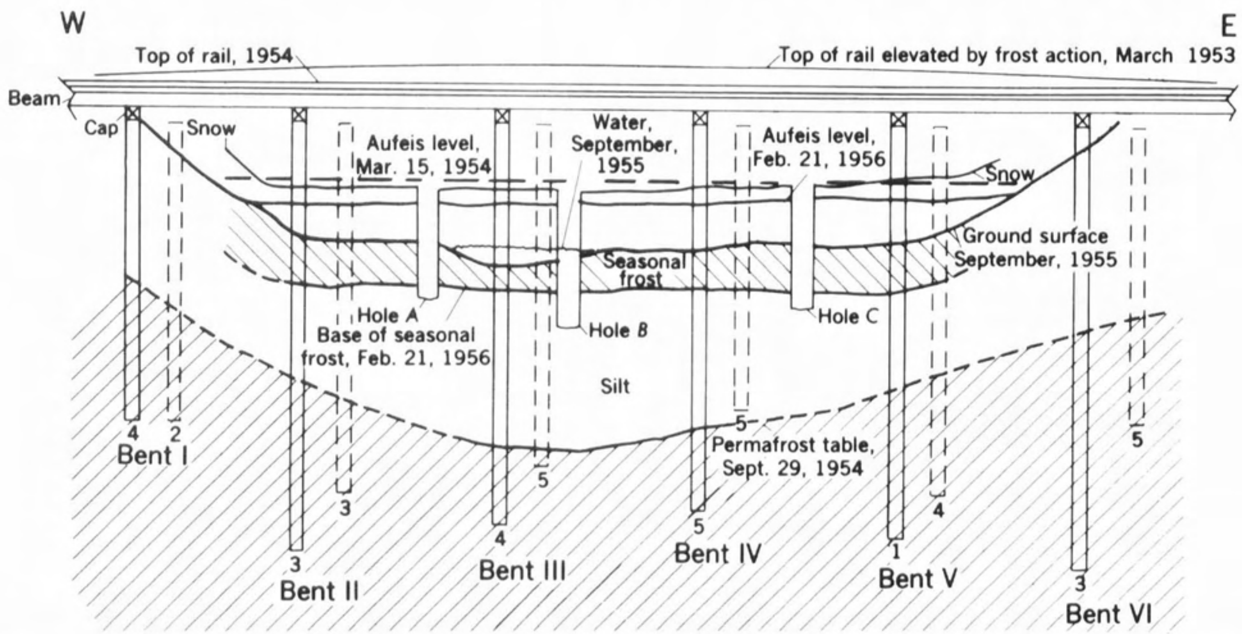

Figure 11b. Cross section of railroad bridge at Mile 458.4. Dashed lines represent disturbed piles emplaced in 1923 and forced upward by frost action through the years. To relevel the bridge, the tops of the piles were periodically trimmed. Although the replacement piles installed in 1954 (solid lines) were rooted more deeply in permafrost, they were also frost heaved and the bridge was again deformed (modified from Péwé and Paige, 1963).

LOSS OF BEARING STRENGTH

Because frost-susceptible soil often attracts additional water as it freezes, the soil is saturated during spring thaw, which results in a considerable loss of bearing strength. The weight and movement of vehicles across road surfaces cause such thawed, waterladen soils to squeeze through breaks in the surface pavement or gravel and form 'frost boils' (fig. 15). Vehicle weight limitations must be placed on roadways constructed on poorly drained, fine-grained sediments during 'spring breakup' (fig. 16).

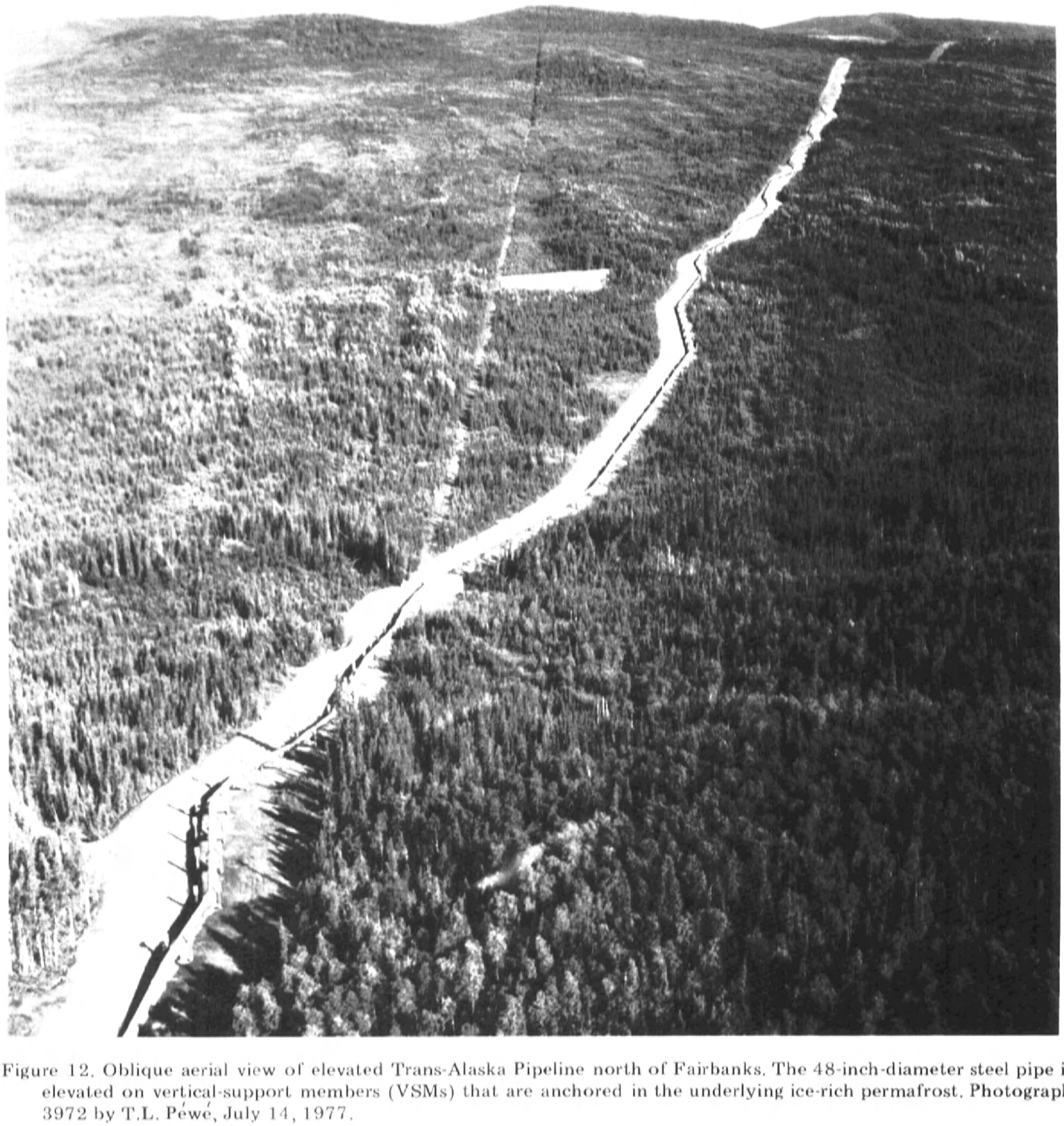

Figure 12. Oblique aerial view of elevated Trans-Alaska Pipeline north of Fairbanks. The 48-inch-diameter steel pipe is elevated on vertical-support members (VSMs) that are anchored in the underlying ice-rich permafrost. Photograph 3972 by T.L. Péwé, July 14, 1977.

Figure 13. Frost-heaved outhouse on ice-rich, perennially frozen silt, Farmers Loop Road at crossing of Pearl Creek, 2 miles northeast of College. Photograph 950 by T.L. Péwé, June 19, 1954.

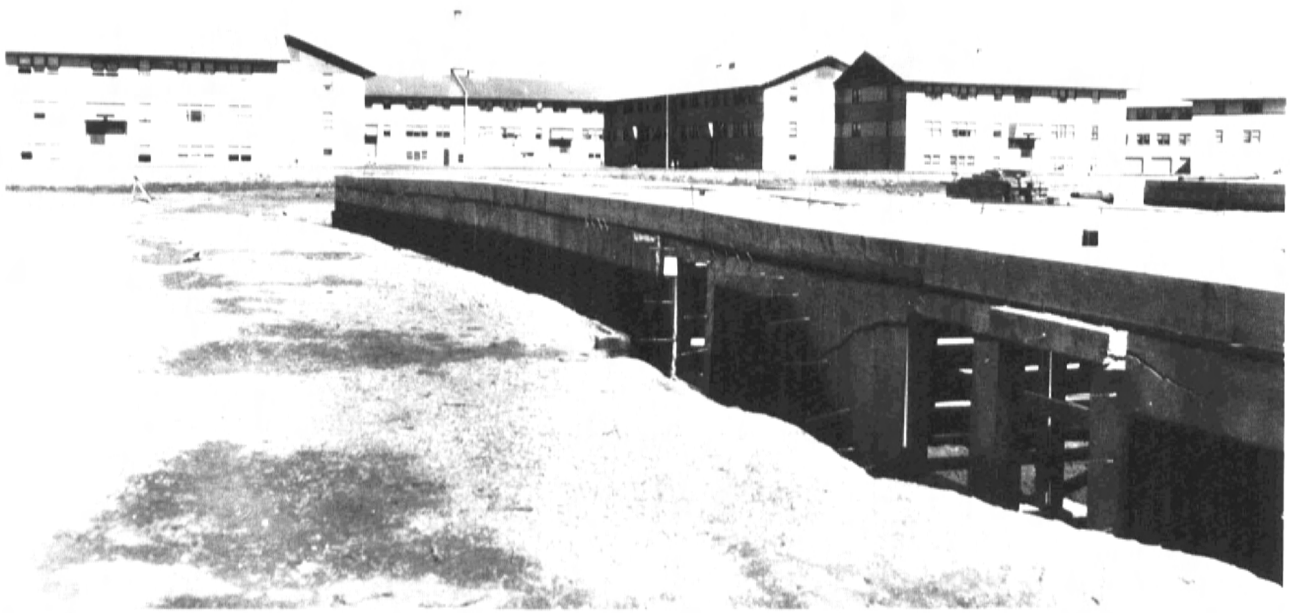

Figure 14a. Fracturing of 6-inch-thick, steel-reinforced, concrete foundation on Airport Road in Fairbanks by frost heaving during winter of 1953-54. Concrete walls and uprights heaved from 6 to 12 inches. Photograph 930 by T.L. Péwé, May 8, 1954.

Figure 14b. Concrete upright fractured at base. Photograph 936 by T.L. Péwé, May 8, 1954.

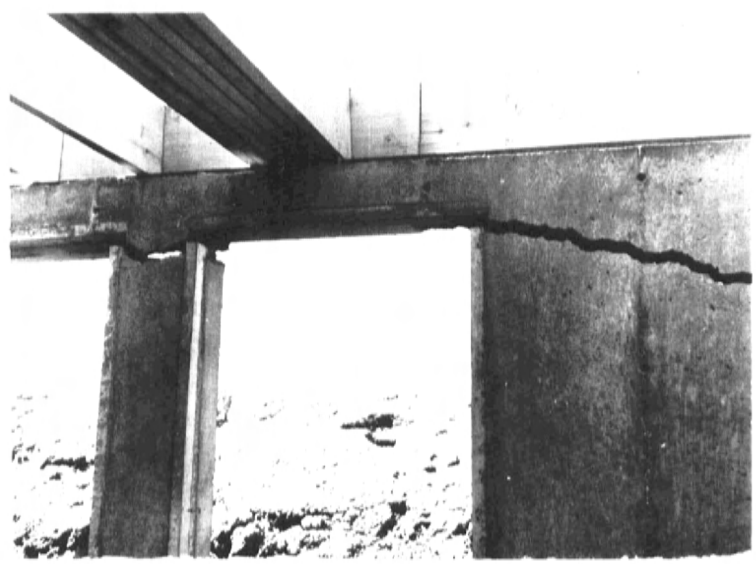

Figure 14c. Inside of fractured and uplifted foundation wall. Photograph 932 by T.L. Péwé, May 8, 1954.

Figure 15. Disintegration of section of Farmers Loop Road north of Fairbanks during spring breakup. Thawing of seasonally frozen subgrade results in loss of bearing strength, and vehicle weight pushes pavement down into the underlying thawed, wet sediment. 'Frost boils' form when sediment is forced upward through breaks in pavement. Stakes and branches have been placed in holes to warn motorists. Photograph PK 6813 by T.L. Péwé, 1961.

SOLUTIONS TO THE FROST ACTION PROBLEM

The best way to prevent frost-action-induced losses in the Fairbanks area is to avoid construction on poorly drained, fine-grained sediments. Geologists and soils engineers using geologic maps and reports can locate frost-susceptible soils. If construction on fine-grained sediments is necessary, improvements in subsurface and surface drainage or installation of an insulation blanket between the subgrade and fill will reduce the frost action problem. Careful preconstruction planning will overcome many frost-action problems.

To combat frost heaving of piles, methods must be devised to decrease the upward forces on the pile or increase the forces holding the pile in place (fig. 9). The upward forces on the pile may be temporarily decreased by improvement of drainage around the pile or by insulating the ground with moss or straw to prevent deep seasonal-frost penetration. The grip of seasonally frozen ground on the pile may also be reduced by placing a steel sleeve around the section of pile in the seasonal-frost layer. When seasonal freezing occurs, the sleeve will slide upward but the pile will not be affected. If the sleeve is not anchored, it will eventually be jacked out of the ground.

The most effective method to reduce or eliminate frost heaving is to firmly anchor the pile and thereby increase the forces holding it in place. In permafrost areas piles are driven into the perennially frozen ground, and because the grip of the permafrost is greater than the upward force generated by seasonal frost, heaving is avoided. It is better to drive piles into the ground than steam thaw holes for emplacement (fig. 17), because the permafrost is less disturbed. Today, most piles are placed in dry-augered holes that are backfilled with a silt-water slurry (fig. 18). As a rule of thumb, the pile should be

Figure 16. Thawing of seasonal frost and resultant loss of bearing strength necessitate vehicle-load limitations each spring. Water in adjacent ditch will not drain because seasonally frozen ground is present at depth under the ditch and downslope under the road. Farmers Loop Road; photograph PK 6805 by T.L. Péwé, 1961.

placed in permafrost to twice the depth of the seasonal-frost layer.

Mechanical refrigeration of piles is very expensive. Thermal piles were successfully used on the Trans-Alaska Pipeline to eliminate frost heaving of VSMs. The supports were frozen firmly into permafrost, filled with hydrous ammonia gas, and equipped with heat-radiating fins (fig. 19). Each winter the ammonia gas rises to the top of the VSM, cools, liquifies, and sinks to the bottom, where it warms, boils, and again rises to the top, thereby chilling the ground whenever the ground temperature is warmer than the air temperature. The devices are nonmechanical and self-operating, and require no external power source.

PERMAFROST

DEFINITION

Permafrost is a naturally occurring material with a temperature colder than 32°F for at least 2 years. Permafrost is defined exclusively on the basis of temperature. Part or all of its moisture may be unfrozen,

Figure 17. Installation of wood piles in Goldstream Valley, Mile 456.7 on the Alaska Railroad, 6 miles northwest of Fairbanks. Over the years, the old bridge piles were frost heaved, resulting in irregular track elevations. To rectify the problem, the tops of the piles were trimmed, but eventually installation of new piles was necessary. Steam-thawing of holes for piling emplacement, as demonstrated in this photograph, is unsatisfactory because the thawed hole is larger than necessary. In fact, thawing for a series of holes often produces a mud trench. While this technique permits easy installation of piling, considerable time is required to satisfactorily refreeze the permafrost around the piling to prevent frost heaving. Both old and new piling can be seen under the bridge. Rubber hoses in the foreground are steam lines. Photograph 837 by T.L. Péwé, February 11, 1954.

depending on the chemical composition of the water or depression of the freezing point by capillary forces. Permafrost with saline soil moisture, such as occurs under the Beaufort Sea, may be colder than 32°F for several years, yet it contains no ice and thus is not firmly bonded. Ice-bonded permafrost also exists offshore.

Most permafrost is cemented by ice, but permafrost without water, and thus without ice, is termed dry permafrost. The upper surface of permafrost is known as the permafrost table. In permafrost areas, the layer of ground that freezes each winter and thaws each summer---called the active layer---varies in thickness according to its moisture content. Generally, this thickness is from 1/2 to 1 foot in wet, organic sediments and up to 6 to 9 feet in well-drained gravels.

THE PROBLEM

Long, cold winters and short, cool summers in polar and subpolar regions produce a layer of frozen ground that does not completely thaw each year. This perennially frozen ground, or permafrost, uniquely affects many human activities in the Arctic and Subarctic. Permafrost hazards have materially impeded coloniza-

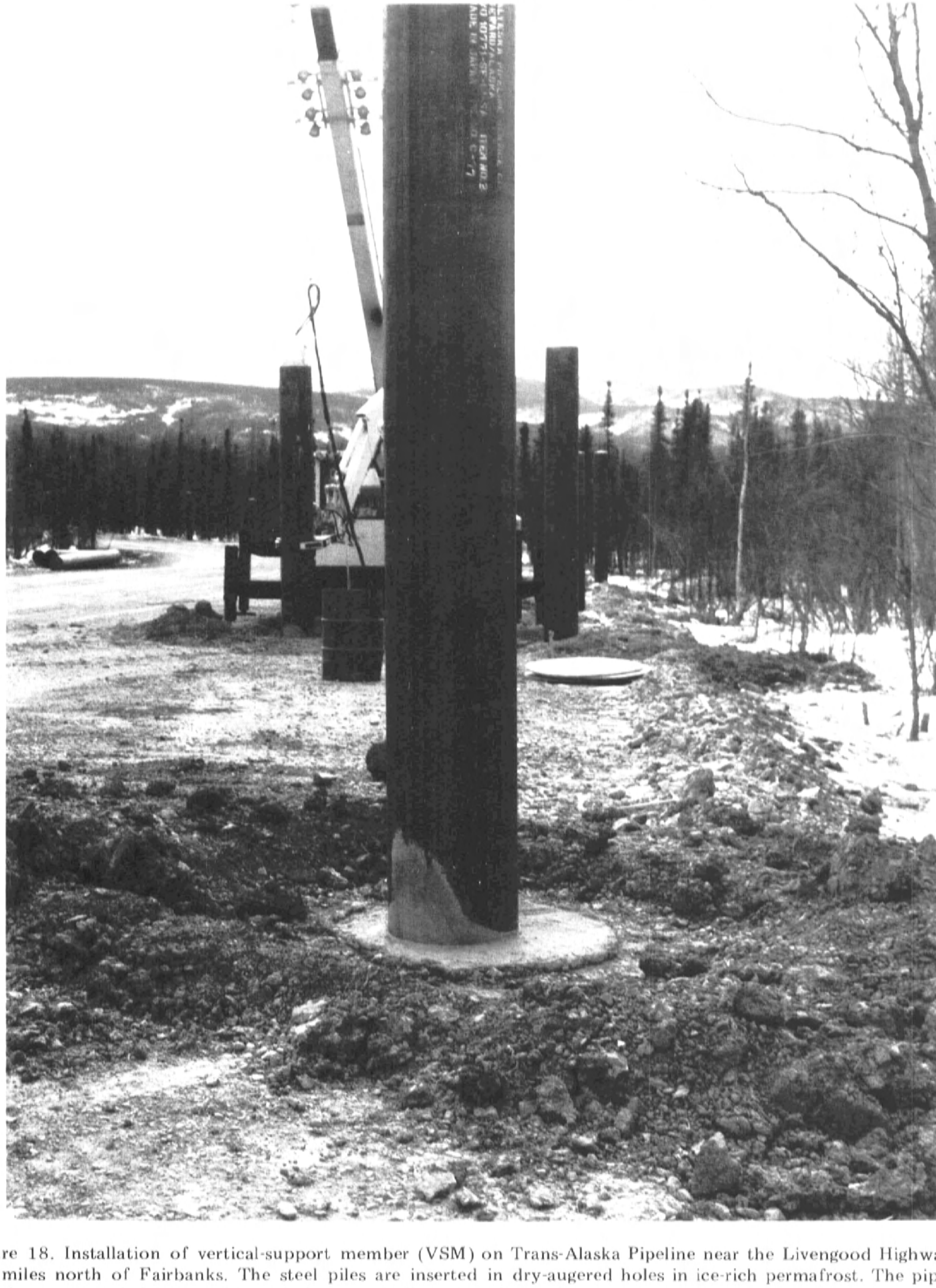

Figure 18. Installation of vertical-support member (VSM) on Trans-Alaska Pipeline near the Livengood Highway, 29 miles north of Fairbanks. The steel piles are inserted in dry-augered holes in ice-rich permafrost. The pipes are then surrounded by a cold mud slurry and allowed to freeze firmly into the permafrost before any stresses are applied. Photograph 3723 by T.L. Péwé, April 5, 1975.

Figure 19. Elevated section of Trans-Alaska Pipeline at Engineer Creek, 5 miles north of Fairbanks. The pipeline is supported by a horizontal brace connecting two vertical-support members (VSMs). The thermal radiation fins on top of VSM enable the piles to remain frozen in the ground, thus preventing frost heaving and destruction of the line. The pipe is insulated with 4 inches of resin-impregnated fiberglass jacketed by galvanized steel. Photograph 3986 by T.L. Péwé, July 17, 1977.

tion and development of extensive and potentially rich areas in the north. Development in polar regions demands understanding and the ability to cope with environmental problems produced by permafrost. The most dramatic, widespread, and economically important examples of the influence of permafrost on life in the North deal with construction and maintenance of roads, railroads, airfields, bridges, buildings, dams, sewers, oil and gas pipelines, and communication systems.

For the past 100 years, scientists and engineers in the Soviet Union have been studying permafrost and actively applying the results to development of their country. Similarly, prospectors, explorers, and especially employees of the U.S. Smelting, Refining, and Mining Company---located in Fairbanks and elsewhere in Alaska---have long been aware of permafrost. But it was not until World War II that systematic studies of perennially frozen ground were undertaken by scientists and engineers in the United States and Canada.

Conventional engineering techniques must be modified---at additional expense---when building in areas of permafrost. Agriculture, mining, water supply, sewage disposal, and construction are seriously affected by subsidence of the ground surface caused by thawing of ice-rich permafrost and by associated problems due to soil flowage and frost action. A less than thorough understanding of the thermal and mechanical problems unique to permafrost may result in impassable roads, unusable airstrips and agricultural fields, and abandoned buildings and pipelines.

ORIGIN AND THERMAL REGIME

When the mean annual air temperature drops below 32°F, ground frozen during the winter may not completely thaw in the summer, and a layer of permafrost may form. This layer may continue to thicken below the seasonally frozen ground. The thickness of the permafrost layer is controlled by the balance between the mean annual air temperature and the geothermal gradient. The average geothermal gradient is about 1°F/300 feet of depth. Eventually, the thickening permafrost layer reaches an equilibrium at which the amount of geothermal heating of the subsurface equals the amount of heat lost to the atmosphere. At this point downward thickening of the frozen ground ceases. Achievement of this state of equilibrium may take thousands of years in permafrost that is hundreds of feet thick.

Examples of temperature changes in frozen ground with depth and of the upper and lower limits of permafrost are shown in figure 20. The annual winter to summer air-temperature fluctuation is reflected in a subdued manner in the upper few feet of the ground. This fluctuation diminishes rapidly with depth, from only a few degrees at 25 feet to barely detectable at 60 feet. The level at which fluctuations are hardly detectable (30 to 60 feet) is termed the level of zero amplitude. If the permafrost is in thermal equilibrium, the temperature at the level of zero amplitude is generally regarded as the minimum temperature of the permafrost; this approximates the average air temperature at the ground surface. Below this depth, the temperature increases steadily under the influence of heat from the Earth's interior. The temperature of permafrost at the depth of minimum annual seasonal change varies from 32°F at the southern limit of permafrost to 12°F in northern Alaska and 8°F in northeastern Siberia. Where permafrost is widespread, its temperature is colder than 23°F.

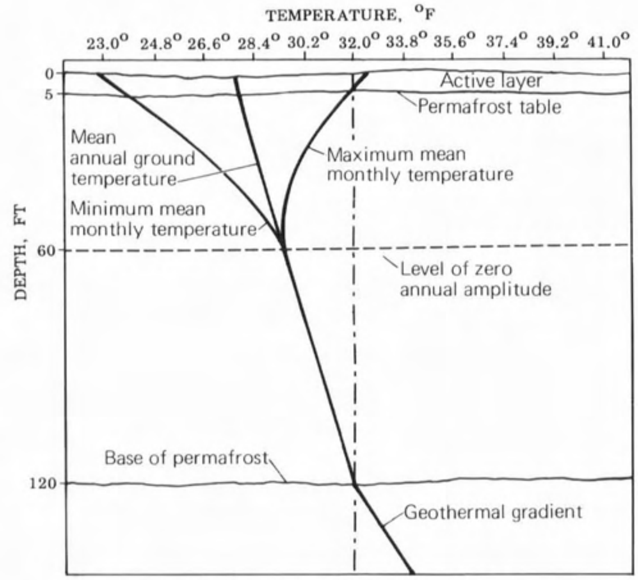

Figure 20. Hypothetical example of typical temperature profile and thickness of permafrost in central Alaska.

As the climate becomes colder or warmer---but the mean annual temperature remains below 32°F---permafrost thicknesses correspondingly increase or decrease by changes in the position of the base and top of the frozen ground. These changes depend not only on the amount of climatic fluctuation, but also on the amount of moisture in the ground and on the combination of geologic factors that in part control the geothermal gradient. Thus, if the geothermal gradient and mean air temperature are known, and if the surface temperature is stable for a long period of time, it is possible to predict the thickness of permafrost in areas remote from water bodies.

Although some permafrost is the result of the present climate, ground-temperature profiles show that many permafrost areas are not in equilibrium with the present climate and thus are a product of a colder past climate.

DISTRIBUTION AND THICKNESS

Permafrost is essentially a phenomenon of polar and subpolar regions. About 20 percent of the world's land is underlain by permafrost. Perennially frozen ground is most widespread and thickest in northern regions of the northern hemisphere. Fifty percent of the Soviet Union and Canada, 82 percent of Alaska (fig. 21), and probably all of Antarctica are underlain by permafrost. Twenty percent of China, mainly the high plateau country, is underlain by permafrost. Perennially frozen ground is 2,000 feet thick in northern Alaska and progressively thins to the south. In the northern hemisphere, perennially frozen ground is differentiated into two broad zones of lateral continuity: the continuous permafrost zone and the discontinuous permafrost zone. In the continuous zone, permafrost is present everywhere except under lakes and rivers that do not freeze to the bottom. The discontinuous zone includes numerous permafrost-free areas that progressively increase in size and number from north to south.

Small bodies of permafrost exist in temperate areas

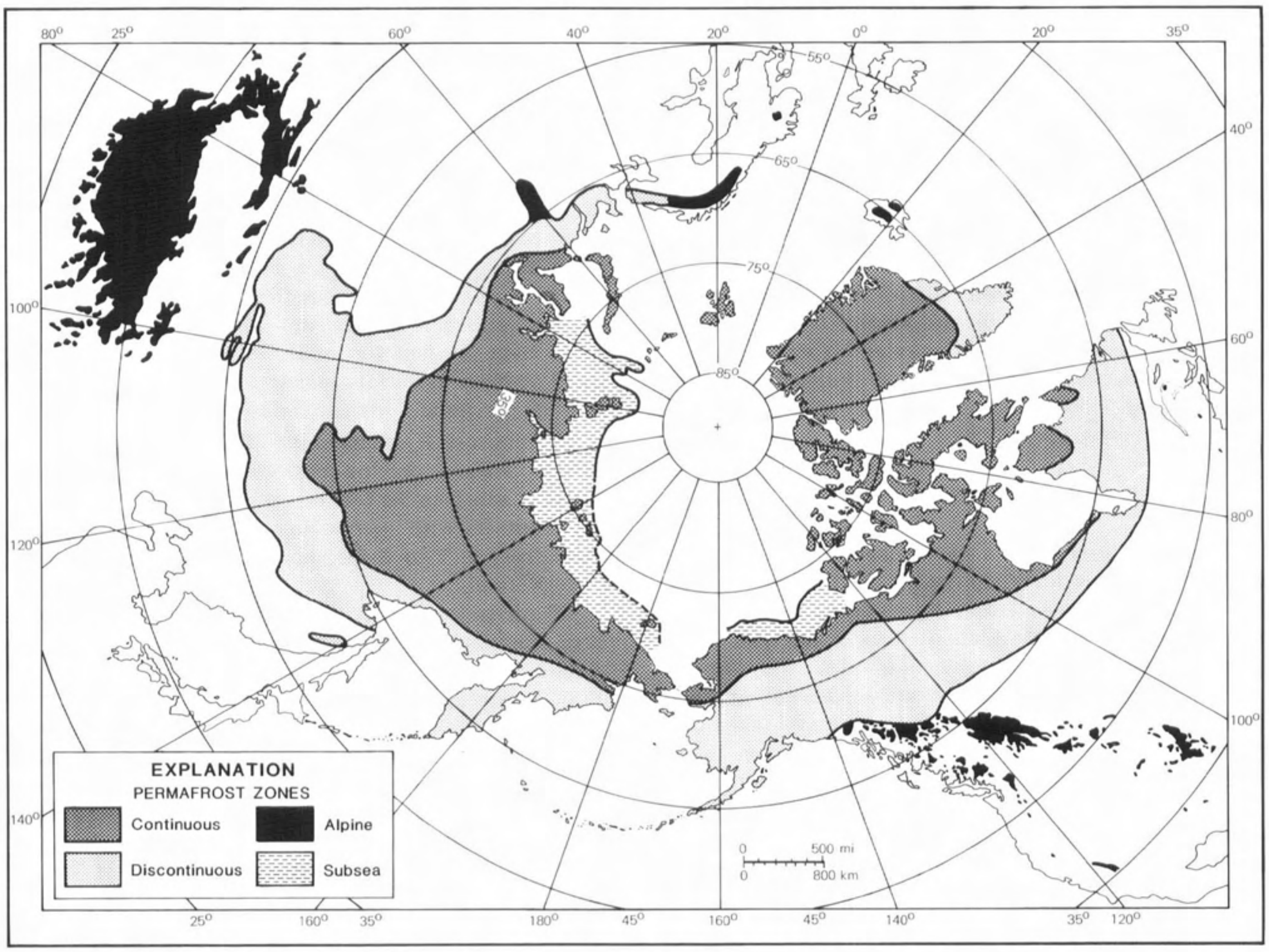

Figure 21. Distribution of permafrost in the northern hemisphere (compiled by T.L. Péwé, 1981). Isolated areas of alpine permafrost exist in high mountains and outside the map area. References: United States, land area (Péwé, 1981, unpublished); subsea (Hopkins and others, 1977; P.V. Sellmann, oral commun., May 26, 1981); Canada, land area (R.J.E. Brown, written commun., December 20, 1979); subsea (Hunter and others, 1976; A.S. Judge, oral commun., March 3, 1981); Greenland (Weidick, 1968; O. Olesen, written commun., 1976); Iceland (Thorleifur Einarsson, written commun., 1966; Priesnitz and Schunke, 1978); Norway (B.L. Andersen, written commun., 1966; L. King, oral commun., June 26, 1980; H. Svensson, written commun., 1966); Sweden (Rapp and Annersten, 1969; King, 1977); Svalbard (Liestol, 1977); Mongolia (Gravis and others, 1973); USSR, land area (Karpov and Puzanov, 1970; Gorbunov, 1978, a,b); subsea (M. Vigdorchik, written commun., 1978); China (Institute of Glaciology, Cryopedology and Desert Research, Academy of Sciences, Lanzhou, 1975, oral commun., Shi Yafeng, May 25, 1980); Tibet and Himalayan and adjacent mountains (Fujii and Higuchi, 1978; Y. Fujii, written commun., May 7, 1978; Gorbunov, 1978).

where the mean annual air temperature is colder than 32°F. Patches of permafrost are reported in the Rocky Mountains of the United States, in Canada, in the European Alps, and even at the tops of Mt. Fujiyama in Japan and Mauna Kea in Hawaii.

In addition to the two permafrost zones delineated on land, permafrost also exists on the submerged continental shelves in polar areas. The Arctic Ocean just north of Siberia is underlain by thousands of square miles of permafrost, and detailed studies are underway to delineate the distribution and thickness of subsea permafrost in the Beaufort and Chukchi Seas. Twenty-two-hundred-foot-thick layers of permafrost have been measured off the mouth of the Mackenzie River in Canada.

PERMAFROST IN THE FAIRBANKS AREA

Permafrost is present nearly everywhere in the Fairbanks area except beneath hilltops and moderate to steep south-facing slopes (fig. 22). The Tanana River flood plain is underlain by perennially frozen ground interspersed and interstratified with zones of unfrozen sediments; large ice masses are absent. Gently sloping alluvial fans and colluvial slopes extend from the upland to the flood plain and creek-valley bottoms and are underlain by continuous permafrost with abundant, large ground-ice masses.

PERMAFROST OF THE FLOOD PLAIN

Flood-plain sediments are perennially frozen, often in more than one layer, to depths of at least 265 feet. The thickness of these frozen layers varies considerably. Permafrost is absent beneath existing or recently abandoned river channels, sloughs, and lakes (fig. 4), and elsewhere layers of frozen sand and silt are intercalated with unfrozen layers of gravel. Because gravel layers are commonly lenticular in shape, no single unfrozen layer of broad lateral extent exists. Unfrozen areas are often connected by irregular unfrozen passages throughout the flood-plain permafrost.

Depth to permafrost in undisturbed areas ranges from 2 or 3 feet in the older parts of the flood plain to more than 4 feet on the inside of river meanders. As river meanders migrate, permafrost progrades into recently deposited materials on the inside of meander curves. Since 1903, fires, clearings, and construction have increased the depth to permafrost by 25 to 40 feet in some areas.

Ice commonly occurs as granules and cement between mineral grains in perennially frozen sediments of the flood plain. The large ice masses common beneath lower hillslopes are not found in flood-plain deposits.

PERMAFROST OF ALLUVIAL FANS, COLLUVIAL SLOPES, AND SILT LOWLANDS

Permafrost in alluvial fans, colluvial slopes, and silt lowlands (termed lower-hillslope silt and creek-valley silt, fig. 22) probably extends from the flood plain to the hills and is absent only under larger lakes. The apices of the broad, gently sloping, coalescing alluvial fans extend into the upland valleys, in some places almost reaching the hillcrests. Low-angle silt aprons on lower hillslopes and between alluvial fans contain continuous permafrost (fig. 4), and small lowlands of organic-rich silt and peat that extend from the toe of the fans to the flood plain just north of College Road and in Goldstream Valley are also underlain by continuous permafrost. Permafrost may also occur in isolated, small bodies near the contact with permafrost-free slopes.

Perennially frozen ground in silt fans and beneath slopes is at least 175 feet thick near the flood plain, thins toward the hills, and pinches out at the base of steep, south-facing slopes. On north-facing slopes, it may extend to the summits. The thickest known permafrost in the Fairbanks area occurs in upper Isabella Creek valley near the junction of McGrath and Farmers Loop Road, where a 360-foot-deep well did not penetrate through perennially frozen ground.

Permafrost is encountered 3 to 4 feet below the ground surface on lower slopes and in creek-valley bottoms and 5 to 20 feet below the ground surface near the contact with permafrost-free slopes. Depth to permafrost is 1 to 3 feet in the silt lowland north of College Road.

Permafrost in fans, slopes, and lowlands contains large horizontal or vertical sheets, wedges, and saucer-shaped and irregular masses of ice (fig. 23). These ice bodies range up to 15 feet in thickness and from 1 to 50 feet in length. Although some ice is clear, some contains silt particles that impart a gray color. The ice is often arranged in a honeycomb network that encloses silt polygons 10 to 40 feet in diameter, and subsurface polygons produce a polygonal surface pattern in some areas (figs. 24, 25). Ice masses occur at depths of 5 to 25 feet in fans and on colluvial slopes and 1-1/2 to 5 feet in silt lowlands.

BOUNDARIES BETWEEN PERMAFROST AND NONPERMAFROST AREAS

The boundary between permafrost and permafrost-free areas (fig. 22) is determined by plotting ground temperature measurements, well-log data, distribution of thermokarst features in cleared fields, presence of surface ice-wedge patterns, and changes in vegetation.

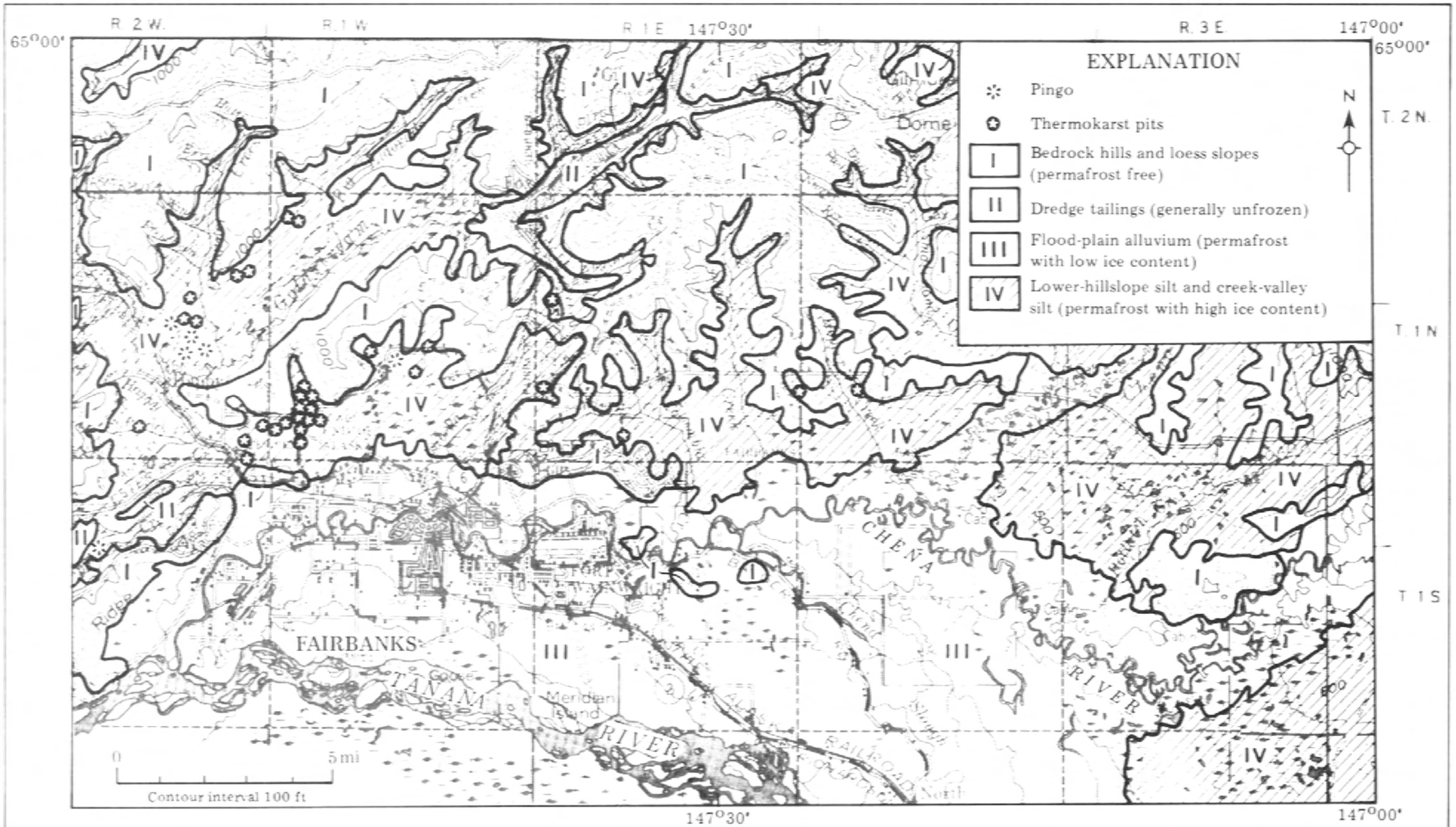

Figure 22. Permafrost map of the Fairbanks area (modified from Péwé, 1958; Williams, Péwé, and Paige, 1959).

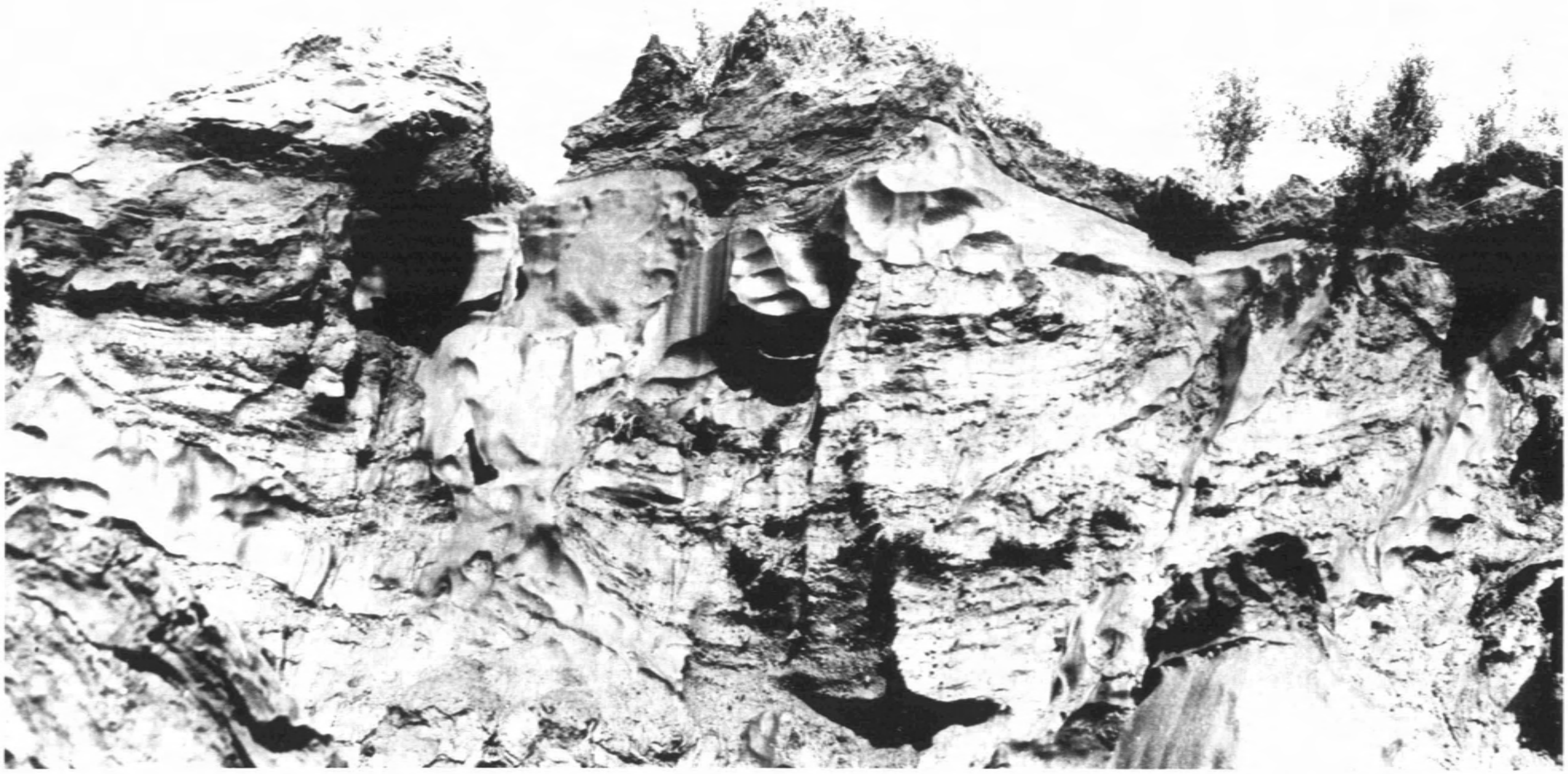

Figure 23. Panoramic view of ice wedges in organic-rich silt along the east wall of a placer gold-mining excavation at Fairbanks Creek, 15 miles northeast of Fairbanks. Photographs 277-278, by T.L. Péwé, July 10, 1948.

The most accurate criteria for determining this boundary are temperature measurements and well-log data, which readily indicate the presence of permafrost at depth. Permafrost can generally be recognized in wells without taking temperature measurements. Drillers' records of wells along Farmers Loop Road permit delineation of the permafrost boundary in that area.

Less reliable indicators of permafrost are thermokarst features and vegetation. Although thermokarst mounds or pits in cleared fields help define the permafrost boundary, the absence of thermokarst phenomena does not necessarily indicate the absence of permafrost. This is especially true when undisturbed ice masses lie below the depth of seasonal thawing, or when frozen ground does not contain massive ice.

Ground temperatures of 30°F to 31°F have been measured in permafrost in the Fairbanks area. This permafrost is 'warm' and particularly sensitive to disturbance by man.

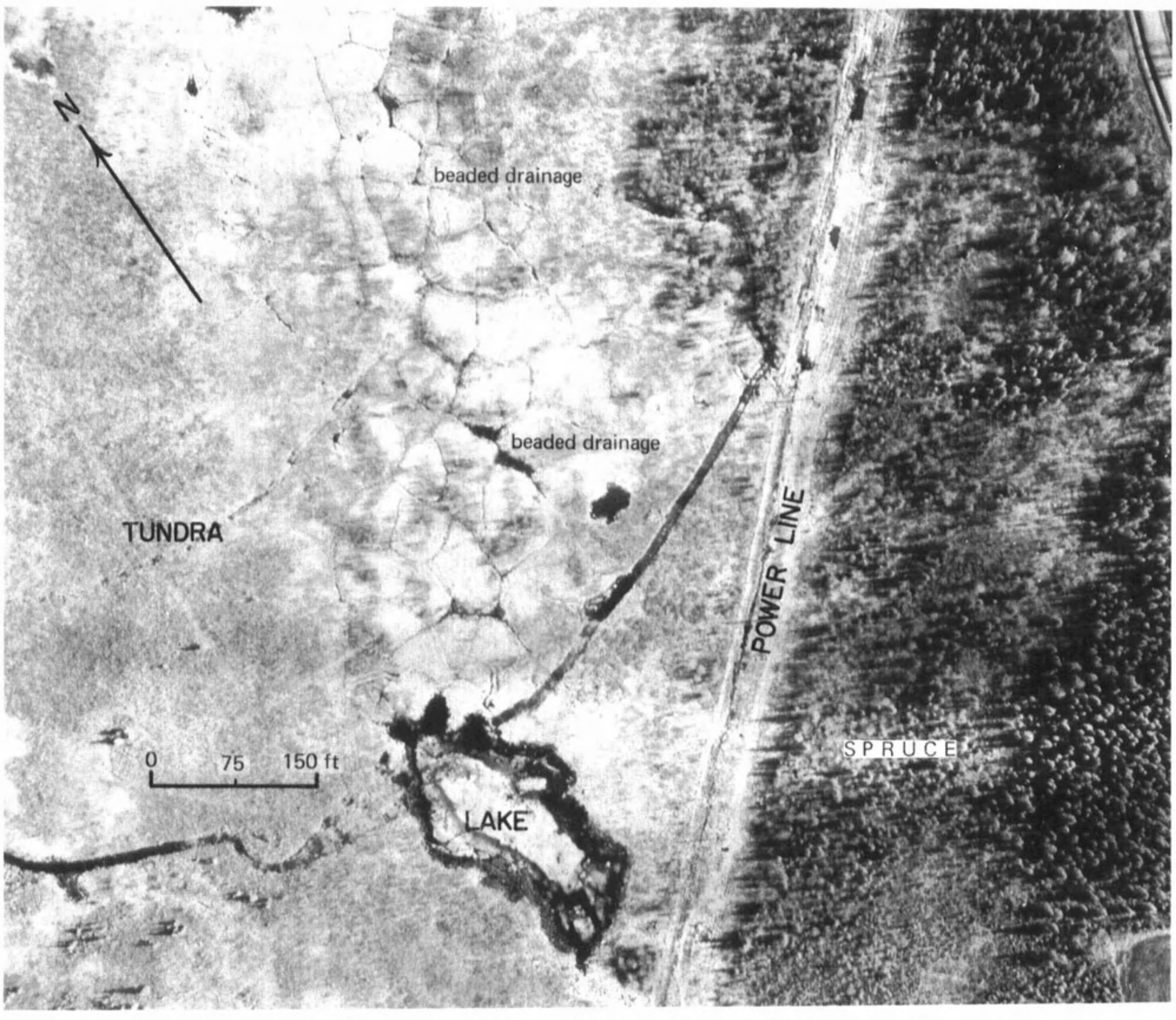

Figure 24. Aerial view of polygonal-ground pattern in silt lowland near the junction of Farmers Loop Road and Steese Highway about 1 mile northeast of Fairbanks. A polygonal network of ground ice is responsible for these surface polygons, which are 40 to 60 feet in diameter. Small lakes have developed at the junction of the polygons and formed beaded drainage. Vegetation on the right is mostly scrub birch-spruce forest with some larch; on the left is cotton-grass-shrub tundra. Black, 8-foot-wide strips that trend diagonally across the photograph are water-filled caterpillar-tractor tracks. The entire area is underlain by ice-rich permafrost. Photograph by U.S. Army Air Corps, May 9, 1947.

The boundary between slopes underlain by permafrost and slopes that are permafrost-free is usually marked by a noticeable change in vegetation. A stunted forest of black spruce with knee-high shrubs of dwarf birch, Labrador tea, and blueberry, and a thick, moist carpet of cranberry, cottongrass, moss, and caribou lichen grow on poorly drained, gentle slopes underlain by shallow (2 to 4 feet below ground surface) permafrost. Willows and alders follow faint water courses.

White spruce, birch, quaking aspen, and alder are found on better drained, slightly steeper slopes where permafrost is absent or present at a depth of more than 4 feet. The boundary between black spruce - scrub forest and white spruce - birch - aspen forest is distinct and readily recognizable (fig. 25). Generally permafrost, with or without ice masses, extends a short distance upslope into the white spruce - birch - aspen forest. This boundary between permafrost and permafrost-free areas is higher on north-facing slopes that receive less solar heat than on sunnier south-facing slopes.

CHARACTER OF GROUND ICE

The ice content of permafrost probably has the most important effect on land use in the north. Ground ice may occur as pore ice, segregated or Taber ice, foliated or ice-wedge ice, pingo ice, and buried ice. Sizes and shapes vary, but each type has definite distribution characteristics.

Figure 25. Aerial view of the central Fairbanks area showing typical landforms: (FP) flood plain underlain by permafrost containing no massive ice; (OSL) organic-silt lowland, and (LHS) lower-hillslopes and alluvial fans, both underlain by permafrost containing ice masses; and (BH) bedrock hills. View toward west from elevation of 10,000 feet. Photograph by U.S. Army Air Corps, 1946.

Pore ice forms when the water filling small voids between soil grains freezes; there is no addition of water. Segregated, or Taber ice, forms films, seams, lenses, pods, or layers that grow by drawing water from adjacent areas as the ground freezes. Although these small ice segregations---which may vary from 1/2 to 12 inches--are not spectacular, they are one of the most extensive types of ground ice. Foliated ground ice, or wedge ice, refers to large masses of ice that grow in thermal contraction cracks in permafrost (figs. 23, 26). Pingo ice is clear or relatively clear and originates from ground water under hydrostatic pressure. Buried ice in permafrost includes buried glacier, sea, lake, and river ice and recrystallized snow.

World estimates of the amount of ice in permafrost range from 48,000 to 120,000 mi^3, or less than 1 percent of the total volume of the Earth. Information was extrapolated from borehole data taken near Barrow, Alaska, and used in conjunction with aerial photographs and geologic maps to estimate that 10 percent of the upper 10 feet of permafrost on the North Slope is composed of ice wedges. Taber ice is the most extensive type of ground ice on the North Slope; in some places it represents 75 percent of the ground volume. The pore- and Taber-ice content between depths of 2 and 6 feet is 61 percent, and between 10 and 30 feet, 41 percent by volume. The upper 2 feet of the ground thaws seasonally. The total amount of perennial ice on the North Slope is estimated at 360 mi^3; most of the ice below 25 feet is pore ice. Similar concentrations of ground ice occur in silt lowlands and creek-valley bottoms in the Fairbanks area.

The most conspicuous type of ground ice is the large ice wedges or masses characterized by parallel or subparallel foliation structures (fig. 26). Most foliated ice masses occur as wedge-shaped, vertical or inclined sheets or dikes, 1/4 inch to 10 feet wide and 10 to 30 feet high in transverse cross section. On the face of frozen cliffs, these ice masses may appear as horizontal bodies (fig. 27).

The generally accepted theory for the origin of ice wedges is the thermal contraction theory, which states that during winter polygonal thermal contraction cracks about 1/2 inch wide and 6 to 10 feet deep form in the frozen ground (fig. 28). In early spring, water from melting snow enters the open tension cracks; when it freezes, it produces a vertical vein of ice that penetrates the permafrost. The following summer the permafrost warms and expands, and horizontal compression bends the adjacent frozen sediments upward by plastic deformation. During subsequent winters, renewed thermal tension reopens the vertical ice-filled crack because it is a zone of relative weakness. Another increment of ice is added in the spring when meltwater enters and freezes. Over the years, this cycle produces a wedge-shaped mass of ice.

Ice-wedge formation requires a rigorous climate, because the ground at the level of the permafrost table must be chilled to -40°F to -50°F for contraction cracks to form. Ice wedges are common in a climate where the mean annual air temperature is colder than 29°F. Although they actively grow in the continuous permafrost of northern Alaska (fig. 29), ice wedges are generally inactive in the discontinuous-permafrost zone of central Alaska. South of the zone of inactive ice wedges, ice wedges are generally absent.

PRINCIPLES OF LAND USE IN PERMAFROST AREAS

A thorough study of frozen ground should be included in the planning of any project in the North. Except in cases of very thin permafrost where thawing is a possibility, it is generally best to disturb frozen ground as little as possible to maintain a stable foundation for engineering structures. Construction techniques which preserve permafrost are referred to as the passive method; those which destroy permafrost are termed the active method.

As stated by Simon W. Muller, who coined the word permafrost, "Once the frozen ground problems are understood and correctly evaluated, a successful solution is, for the most part, a matter of common sense, whereby the frost forces are utilized to play the hand of the engineer and not against it." With few exceptions, all building, railroad, and highway construction in Alaska has involved installation of a pad or gravel fill before construction. Dry gravel is generally a better conductor of heat than the underlying silt or vegetation. In the cooler parts of northern Alaska, it is possible to install a layer of gravel thick enough (about 5 feet) to contain seasonal freezing and thawing of the ground. In these instances, there is no thawing of the underlying permafrost, and in some cases the permafrost table moves into the pad. However, the deep active layer in the Fairbanks area precludes containment of seasonal freezing and thawing in a gravel fill. Alternate procedures are necessary, including placement of insulating materials under fill.

Four fundamental types of permafrost-related, land-use problems are: a) thawing of ice-rich permafrost with subsequent surface subsidence under unheated structures such as roads, airfields, agricultural fields, and parks; b) ground subsidence under heated structures; c) frost action, generally intensified by poor drainage caused by permafrost; and d) freezing of buried sewer, water, and oil lines.

GROUND SUBSIDENCE CAUSED BY THAWING OF ICE-RICH PERMAFROST

PRELIMINARY STATEMENT

The most ubiquitous and unique geologic hazard of arctic and subarctic regions results from the thawing of ice-rich permafrost. This thawing promotes a loss of

Figure 26. Foliated ice wedge exposed in permafrost tunnel excavated by U.S. Army Cold Regions Research and Engineering Laboratory near Fox, Alaska. Photograph by C.J. Romberg, 1973.

Figure 27. Large mass of foliated ground ice exposed in silt during placer-gold-mining operations at Dome, 10 miles north of Fairbanks. Photograph 1038, by T.L. Péwé, August 16, 1954.

bearing strength, high moisture content, and subsidence of the ground. Melting of large ground-ice masses produces dramatic differential settlement and can result from man's disturbance of the thermal equilibrium of the ground or from climatic change.

THERMOKARST PHENOMENA

GENERAL FEATURES

Thermokarst topography is created by the thawing of ice-rich permafrost and is characterized by a complex, uneven ground surface that includes mounds, sink holes, tunnels, caverns, and short ravines. Removal of the insulating vegetation blanket by forest fire or man allows the ground to absorb more solar heat; as ground ice melts, the ground surface settles or caves.

Because cultivation removes the vegetation annually, it is probably more responsible for rapid and extensive thawing of the ground than forest fires, which allow revegetation. Thus, thawing and caving proceed most rapidly, deeply, and continuously in artificially cleared areas.

The removal of vegetation is one of several factors that influences the development of thermokarst features. Because thermokarst features require differential distribution of large ground-ice masses near the surface, they seldom form where ground ice occurs only as cement between sediment grains. The abundant loess in the Fairbanks area is capable of standing in steep banks and, upon thawing, is probably the best sediment in which to form extensive thermokarst topography.

On gentle slopes, ground-water circulation thaws ice masses and hydraulically enlarges the resulting cavities. Surface water is often diverted underground where it contributes to thawing and subterranean erosion. On horizontal surfaces this water forms ponds and lakes in depressions; the borders of these depressions cave and

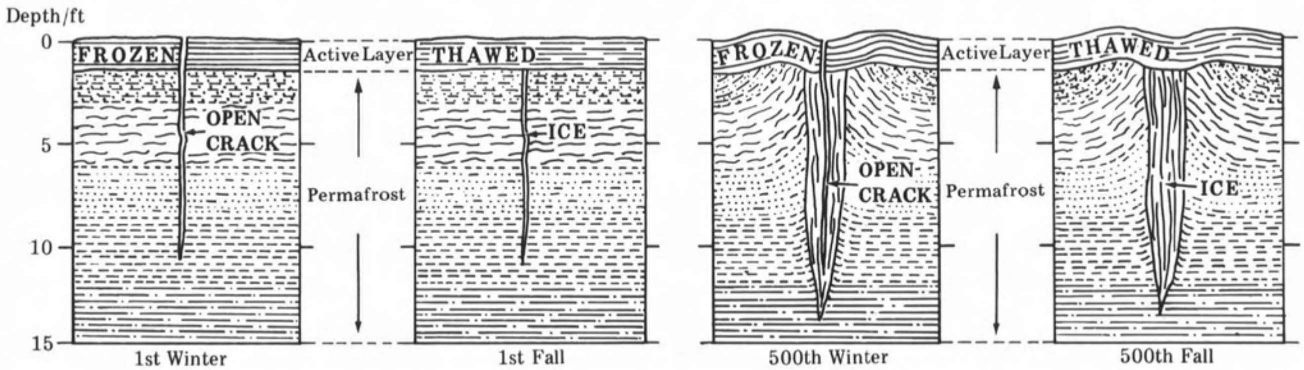

Figure 28. Schematic representation of the evolution of an ice wedge according to the contraction-crack theory--the width of the crack is exaggerated for illustrative purposes (modified from Lachenbruch, 1962, p. 5).

retreat under the thawing effects of water and waves (fig. 30).

Thermokarst phenomena in the Fairbanks area occur in the lower hillslope and creek-valley silt (fig. 22) characteristic of alluvial fans, colluvial slopes, and lowlands underlain by silt. Only in these areas does permafrost contain large ground-ice masses. Cave-in lakes are the most conspicuous thermokarst features in the silt lowlands, and thermokarst mounds and pits dominate silt fans and colluvial slopes that lie at slightly higher elevations.

THERMOKARST MOUNDS

Thermokarst mounds in the Fairbanks area are polygonal or circular hummocks of loess and retransported silt 10 to 50 feet in diameter (fig. 31) and 1 to 8 feet high (fig. 32). They are most common in cultivated fields, but a few are found in abandoned reforested fields, front yards, roadways, and other cleared areas. In some fields, thermokarst mounds are separated by trenches 1 to 5 feet wide, but elsewhere trenches are poorly developed and mounds are not completely separated (fig. 33).

Trenches form where melting polygonal ground-ice causes differential settlement of the ground surface. Local, unconnected depressions first appear; surface water collects in the depressions and speeds thawing and, after entering cavities left by melting ice, enlarges them. If the underlying ice is distributed in a polygonal pattern, the center of each polygon will eventually stand out in relief. The fact that the silt in the mounds is not deformed is evidence that the mounds do not originate by frost heaving.

Thermokarst mounds begin forming 2 or 3 years after an area is cleared. Mound formation ceases only after the ice is completely melted, or after the thawed layer becomes thick enough to insulate against further melting, and after subterranean water erosion ceases.

The most well-developed mounds (with the best documented history in the Fairbanks area) are located in a field on a gentle, north-facing slope at the University of Alaska Experimental Farm (fig. 31). The smooth-surfaced field was cleared in 1908, but by 1922 pronounced individual and connected depressions that interfered with the operation of farm machinery had formed. The field was then seeded to pasture. By 1938 the mounds were 3 to 8 feet high and 20 to 50 feet in diameter (fig. 34). In November 1938 a bulldozer removed the upper part of every hummock and filled each pit until the land surface was approximately uniform. The smooth surface persisted for nearly a year; by July 1939--nearly a year later---irregularities in the smooth surface began to form. During succeeding years, polygonal mounds formed as the ground surface subsided over melting ice. By 1947 mounds in the area that

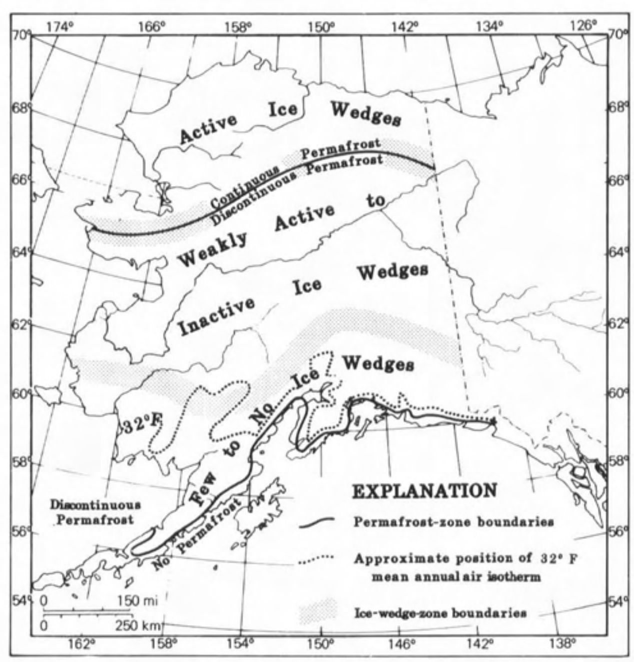

Figure 29. Distribution of ice wedges and permafrost in Alaska.

Figure 30. A cave-in lake in the silt lowland near Fairbanks, the result of thawing ice-rich permafrost. Note the spruce tilting toward the lake as the bank retreats. Photograph 321 by T.L. Péwé, July 25, 1948.

Figure 31. Low-angle, oblique aerial view of thermokarst mounds in an abandoned agricultural field at the U.S. Department of Agriculture Experimental Farm at the University of Alaska, Fairbanks. These mounds are located on the north-facing side of College Hill and are 10 to 30 feet in diameter. Photograph by R.F. Black and T.L. Péwé, September 10, 1948.

was graded in 1938 were as large and as high as those in the field that was not graded. Maximum mound height was 8 feet. Comparisons of 1938 and 1948 aerial photographs (figs. 34, 35) reveal a similar size, shape, and position for the mounds. A soil-auger probe on July 14, 1948, revealed no ice or frozen ground 9 feet below the surface.

THERMOKARST PITS

Thermokarst pits are generally 5 to 20 feet deep and 3 to 30 feet in diameter. They are steep walled and commonly bottle shaped (fig. 36). Pits initiated by melting of massive ground ice are commonly enlarged and modified by surface water that is diverted into small cracks and subterranean passageways and flows 6 to 20 feet beneath the surface. The well-sorted, fine-grained silt of the Fairbanks area is readily eroded and carried in suspension by small quantities of water moving over low gradients.

By headward erosion, running water often enlarges the surface opening of a pit along a rut in a road or a furrow in a cultivated field; the result is a linear thermokarst pit. Although pits may not appear for 3 to 30 years after clearing of vegetation, most openings become apparent within 8 to 10 years.

All known thermokarst pits in the Fairbanks area are in cultivated or formerly cultivated fields or other clearings on alluvial fans and colluvial slopes near the boundary between permafrost-free slopes and slopes underlain by large ice masses (fig. 22). The distribution of permafrost in thin, isolated masses and a 15-to-100-foot-deep water table provide conditions favorable for pit formation. Water from melting ice and surface water can circulate freely through the thawed passageways as it progresses down to the water table. Because the water

Figure 32. Closeup view of thermokarst mounds shown in figure 31. Photograph 143 by T.L. Péwé, July 23, 1947.

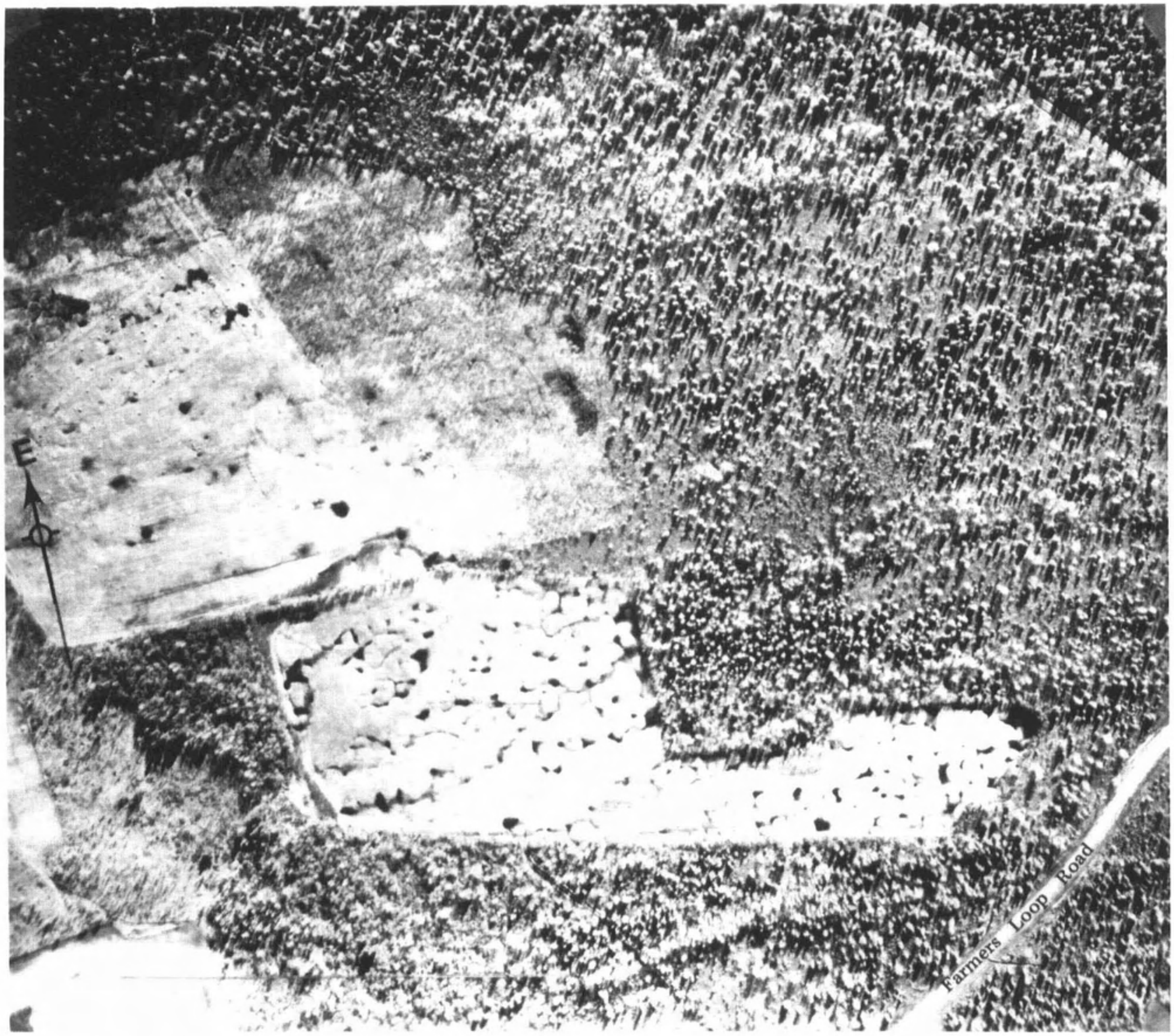

Figure 33. Vertical aerial photograph of formerly cultivated field on lower colluvial slopes in vicinity of Farmers Loop Road near the junction with McGrath Road north of Fairbanks. Well-developed thermokarst mounds about 30 feet in diameter and 6 feet high occur in the L-shaped part of the field. Many mounds are not completely separated because dividing trenches are not fully developed. Black spots in the field are water-filled depressions. Since this photograph was taken, houses have been built in the upper right corner of the photograph; they have subsequently been distorted by thawing of the ice-rich ground. Photograph 62VV46PL-MTM7346RS by U.S. Army Air Corps, May 9, 1947.

table is closer to the surface on lower hill slopes, in the silt lowlands north of College Road, and in Goldstream Valley, the melting ice masses have created cave-in lakes (fig. 30) rather than pits in these areas.

The largest known pit in the Fairbanks area was 8 feet wide, 15 feet long, and 20 feet deep, with horizontal, tube-like passageways 3 feet wide and 2 feet high branching from both ends (fig. 37). Current markings and water-deposited silt on the floors of the passageways indicate intermittent subterranean flow (fig. 38). Many pits have formed in the Fairbanks Golf Course on Farmers Loop Road over the last 30 years (fig. 39). Consequently, this is probably the only links in the world with thermokarst pits as a natural hazard.

EFFECTS ON AGRICULTURAL DEVELOPMENT

Permafrost has adversely affected agricultural development in many parts of Alaska by influencing water supply, soil drainage, the stability of roads and buildings, and especially the topography of cultivated land. The destructive effects of permafrost on cultivated fields result primarily from the thawing of large ground-ice masses. Care must be used in selecting areas for cultivation, because thawing permafrost may force abandonment or modification to pasturage only a few years after clearing. Fields containing thermokarst mounds and pits can be utilized with repeated grading, but excess time, money, and soil are expended in the struggle.

Agriculture in the Fairbanks area is seriously affected by permafrost, and several fields have been abandoned or used for pasture because they were affected by the thawing of large ice masses. R.D. Rayburn of the SCS (written commun., December 15, 1977) estimated that resmoothing bumpy fields in the Fairbanks area cost $175 per acre in 1977. In 1948, 32 of 37 fields that were cleared on alluvial fans, colluvial slopes, and silt lowlands in the Fairbanks area showed evidence of thermokarst modification. Thermokarst pits are still forming in fields cleared more than 50 years ago, as shown by the 1977 appearance of another large pit in the hayfield north of the University of Alaska.

The influence of permafrost on agricultural development varies according to permafrost zone in the Fairbanks area (fig. 22). Most agricultural development is unaffected on south-facing middle and upper hillslopes where permafrost is nonexistent. Unfortunately, much land has been cleared on the gently sloping alluvial fans and colluvial slopes (lower hillslope silt and creek-valley silts in fig. 22) extending from the hills to the flood plain. Permafrost containing large ground-ice masses underlies 40 percent of the area in figure 22; fields located in these areas are likely to develop thermokarst mounds and pits. Although mounds develop less dramatically and suddenly than pits, they constitute a more ubiquitous obstacle to cultivation.

Farms have existed for many years near Fairbanks, and areas of the Chena and Tanana River flood plains are being cleared for agricultural use. Drainage is poor on large parts of the uncleared flood plain, but after the insulating vegetation cover is removed the permafrost table will drop, and in most places, drainage will improve so that farming may be successful. Because large ground-ice masses are absent, cultivated fields will not become pitted or bumpy due to thermokarst development.

EFFECTS ON RAILROADS

Serious construction and maintenance problems created by thawing of ice-rich permafrost affect railroads in the USSR, Canada, China, and Alaska. From Dunbar (40 miles west of Fairbanks) to near Happy (7 miles west of Fairbanks), the Alaska Railroad is underlain by perennially frozen silt containing large masses of ground-ice (fig. 22). Differential settlement of the roadbed is extreme when the sensitive permafrost thaws (fig. 40). In the 1960's the annual maintenance cost of railroad grade in this section averaged about $200,000. Because of permafrost thawing, an exceptionally wide roadbed constructed on a thick layer of gravel over frozen silt has not prevented track settlement of up to 2 feet per year, even 50 years after construction, according to R.M. Moore of the Alaska Railroad.

Moore also estimated the 1970 annual maintenance cost for each length of rail at $87. Gravel backfill must be used to raise the track about 2 feet each year and widen the shoulders as the fill sloughs. Raising the grade 4 feet and widening it 8 feet costs $40 per rail and lasts 10 years. A 2-inch thickness of rigid or foam insulation placed under the gravel roadbed and shoulders costs $53 per rail and has a 10-year life. If track settling is not corrected annually, the track will continue to deform and soon become unserviceable.

EFFECTS ON ROADS AND HIGHWAYS

Roads and highways in the Fairbanks area are especially susceptible to deterioration and eventual destruction by thawing of ice-rich permafrost. This is particularly true of those sections of roadway that lie on the silt-covered lower hillslopes and organic-rich silt lowlands (fig. 22), where the soils contain 30 to 500 percent (dry weight) ice and large ice wedges (fig. 23). Thawing of such ground, which may be 50 to 300 feet thick, results in noticeable differential subsidence. In fact, subsidence is still occurring in areas that were cleared 50 to 60 years ago.

Almost all of Farmers Loop Road lies on ice-rich permafrost (fig. 22), and constant upkeep is necessary to maintain grade. In 1974 Farmers Loop Road was rerouted across ice-rich peat and organic silt between College Road and the east entrance to the University of Alaska (fig. 22). This one-third mile reroute cost $170,000 (Woodrow Johanson, Alaska Department of Transportation and Public Facilities, written commun., October 3, 1977). Shortly after the subgrade was paved, differential settlement 300 feet south of the entrance to the University resulted in rebuilding and refinishing the surface (fig. 41). In 1977 leveling of the road shoulders cost $5,000, and similar annual maintenance, including leveling with asphalt, has been necessary since 1974.

One of the most interesting and persistent highway problems occurred in the vicinity of the peat bog where College Road paralleled the north bank of Noyes Slough. The underlying ice-rich silt and peat thawed dramatically after establishment of the road, necessitating expensive

Figure 34. Vertical aerial photograph of thermokarst mounds in the University of Alaska Experimental Farm fields north of College Hill, summer 1938. In November 1938, the field was graded by a bulldozer. Compare mound development in this photograph with that in figure 35, which was taken in 1948. Photograph by Pacific Aerial Surveys, July 22, 1938.

maintenance, even before the road was paved; constant resurfacing was necessary after paving. The problem became so acute that the road was relocated southward in 1968 and 1969 at a cost of $300,000. This realignment required diversion of Noyes Slough at a cost of approximately $85,000. How much of this cost can be attributed to the existence of frozen ground is debatable, but Alaska Department of Transportation and Public Facilities officials attribute at least $25,000 of the relocation costs to thawing of ice-rich permafrost; others suggest the entire project was necessitated by the poor foundation qualities of the perennially frozen peat. Even the relocated section of highway west of the intersection of Alaska Way and College Road has subsided significantly, and numerous leveling courses of asphalt have been applied. The last major repair was performed in 1975 at a cost of $11,000. An estimated $15,000 has been spent on maintenance since construction at this location.

Some local subsidence occurs in sinuous courses of former creeks and sloughs that wind across the flood plains of the Chena and Tanana Rivers (fig. 8). These sinuous channel fillings consist of 1 to 30 feet of silt and silty clay rich in small ice segregations. Melting of these ice segregations produces bumpy, irregular paved surfaces such as those encountered along the Richardson Highway as it traverses the Tanana River flood plain from Fairbanks to 7 miles south of Eielson Air Force Base.

In 1957 a new housing area was constructed at Eighth and Balsam Streets in the western part of Ladd Field (now Fort Wainwright). Located on the flood plain south of the Chena River, the subdivision included paved roads, concrete sidewalks, and buried utilidors. By the

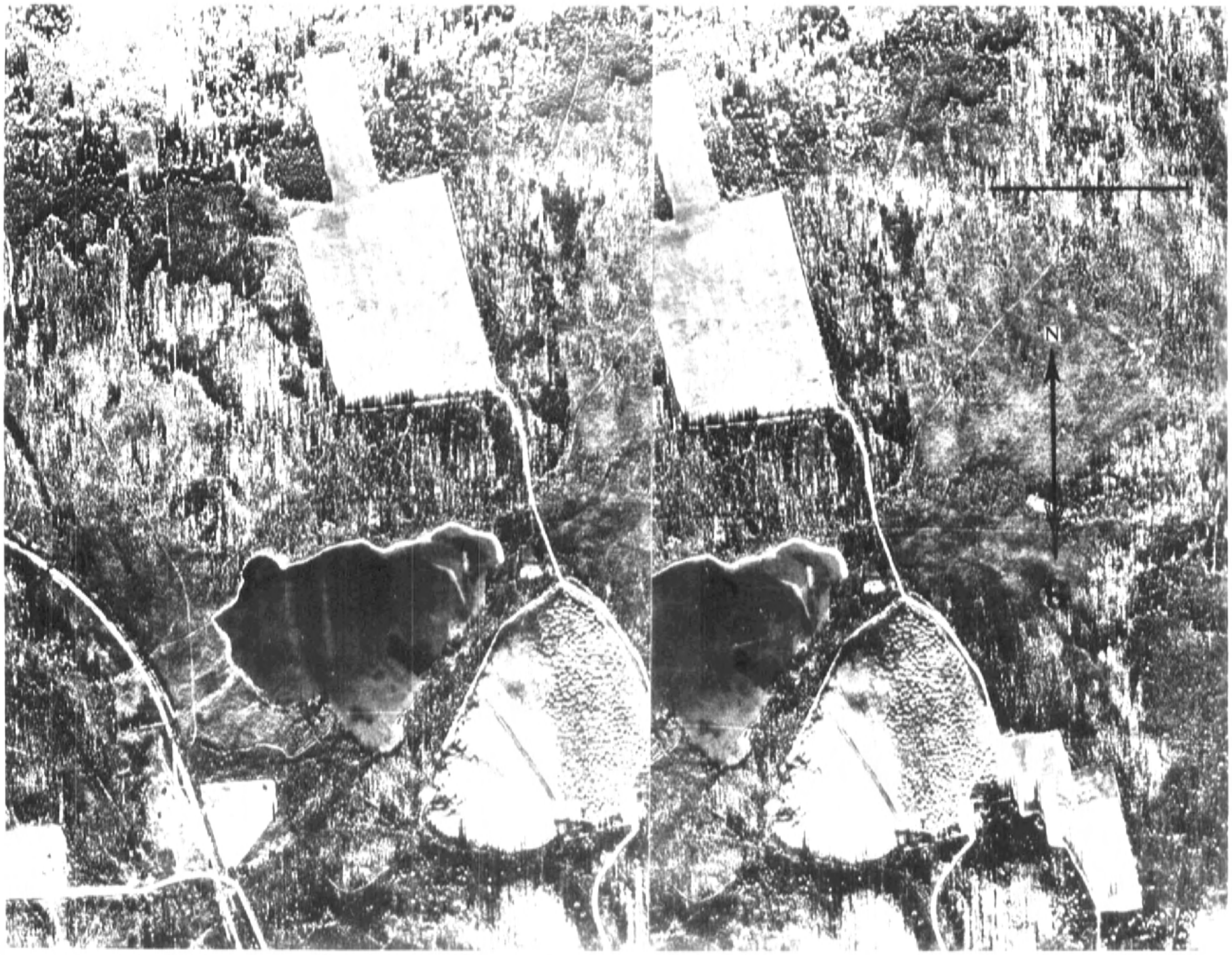

Figure 35. Stereopair of thermokarst mounds in the University of Alaska Experimental Farm fields on north slope of College Hill. Mounds shown in figures 31 and 32 are in the center of the field. Parts of the three largest fields have been abandoned. Photographs by U.S. Army Air Corps, 1948.

summer of 1958, ground subsidence due to the thawing of ice-rich permafrost had caused serious damage to paved streets (fig. 42), sidewalks (fig. 43), and curbs, especially near buried, heated utilidors. Houses and utilidors were not seriously damaged. A study revealed that most, if not all, subsidence was in ice-rich silt fillings of former channels (fig. 8). Summer warming of paved areas and watering of nearby lawns caused the permafrost to thaw, resulting in subsequent damage to many structures. One might ask why most of the subsidence affected unheated structures rather than heated utilidors and homes. Construction records show that the 27-foot-deep excavations for utilidors were backfilled with gravel. Deep excavations were also made under houses to provide a thick thermal insulating blanket for the underlying permafrost. However, excavation for the streets was only 2 to 6 feet. If the silt-filled channels were only 20 to 25 feet thick, then most, if not all, of the ice-rich material was removed in the excavations beneath utilidors and houses (fig. 44). The thawing of ice-rich permafrost then, affected only those areas of shallow excavation.

A definite pattern of settling relative to heated underground utilidors was evident in the vicinity of Balsam Street. Because settling was most pronounced within 3 to 5 feet of the sides of utilidors, it is possible that the ice-rich ground beneath the structures was completely removed during excavation, and thawing therefore proceeded laterally into the remaining ice-rich frozen ground. Heat radiating from houses probably produced similar results.

The use of thermal stabilizing berms is a new method of providing a uniform highway surface across areas of ice-rich permafrost. First used in the Fairbanks area in 1974 along one section of the Parks Highway, these berms are placed at the base of embankments to prevent thaw along the roadbed edge from affecting the roadway. At a minimum, they are constructed of an

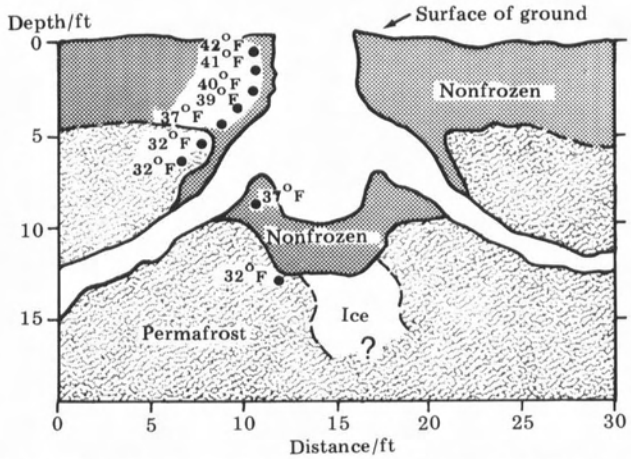

Figure 36. Cross section of thermokarst pit at Fairbanks Golf Course across Farmers Loop Road from KFAR-transmitter station. Note that the opening simulates the shape of the irregular ice mass shown in figure 23. Temperature measurements by Ansel Gooding, September 4, 1948.

8-foot-thick layer of silt and other fine-grained waste materials that is at least 15 feet wide. Such dimensions are necessary to prevent long-term thaw from adversely affecting the toe of the main embankment. Thermocouple readings indicate that thaw is slowed, thus reducing maintenance costs over the life of a project.

Construction of highways on ice-rich permafrost will continue to be a serious problem in Alaska. The best defense against this geologic hazard is relocation of roads to nonfrozen areas or areas of sand and gravel containing scant ground ice. If these alternatives are not practical or economical, the placement of insulation between the gravel overlay and the subgrade may reduce the problem, but continued maintenance may be necessary.

EFFECTS ON AIRFIELDS

Major airfields in the Fairbanks area are limited to level ground on the flood plains of the Tanana and Chena Rivers. Because permafrost containing large ice masses does not exist beneath the flood plains, the

Figure 37. Thermokarst pit in thawed silt 2 miles northwest of College on the old Yankovich Homestead. The semicircular dark area at the base of the wall on far side of pit is opening to passageway. Photograph 269 by T.L. Péwé, July 7, 1948.

Figure 38. Current markings in underground passage leading from thermokarst pit in figure 37. Passageway is about 1 foot high and 2 1/2 feet wide and partly filled with water-deposited silt. Photograph 258 by T.L. Péwé, June 24, 1948.

airfields are subject to minor subsidence caused by thawing of ice-rich permafrost. Some slough and swale deposits contain considerable segregated ice, but these deposits are restricted in extent and easily removable.

EFFECTS ON HEATED BUILDINGS

As one might expect, a heated building introduces more heat into the ground and causes more thawing of ice-rich permafrost in a shorter time than a highway, railroad, cleared field, or other area where the natural surface has been disturbed. Instead of gradual subsidence over a large area, there may be local differential lowering of the ground surface 5 to 10 inches or more a year, which is enough to seriously distort most structures.

Such distortion and destruction of structures are generally spectacular and emphasize the hazards of thawing permafrost and its effect on one's pocketbook. Most people are only vaguely aware of the maintenance or replacement costs of deformed highways and airfields. However, the cost and importance of the ice-rich permafrost hazard are dramatically realized when one observes tilted homes, abandoned cabins, and ill-placed split-level homes.

It is disheartening to notice the deformation and destruction of homes in the Fairbanks area because of improper construction on ice-rich permafrost. Even though detailed information about local permafrost has

Figure 39. Thermokarst pit in loess; pits form and are filled, only to have more pits develop nearby the following year. Thermokarst pits are a unique golf hazard---and a dangerous hazard in agricultural fields. Photograph 1037 by T.L. Péwé, August 15, 1954.

Figure 40. Differential subsidence of the Alaska Railroad bed (Mile 457, 12 miles northwest of Fairbanks in Goldstream Valley) caused by thawing of ice-rich permafrost. Photograph 946 by T.L. Péwé, June 1954.

been available from federal agencies since 1948---and earlier from some mining companies---lots continue to be sold and buildings continue to be constructed in a manner that will result in deformation, increased maintenance costs, and perhaps abandonment. Such construction is continuing (fig. 45) along Farmers Loop, McGrath, and Steel Creek Roads and in other areas where "the ground is good because large spruce trees are present." Real-estate signs proclaiming the joys of building in areas that are obviously underlain with ice-rich permafrost are only too common near Fairbanks.

Prior to World War II, most buildings constructed on the ice-rich permafrost beneath lower south-facing slopes, middle north-facing slopes, colluvial slopes, and creek-valley bottoms were simple frame structures without basements. Shifting of these buildings was corrected by annual shimming; that is, jacking up one or more corners and adding a small block or two to level the structure.

One notable exception is the former KFAR-transmitter building constructed in 1939 near Farmers Loop Road. Because this reinforced concrete building settled as a block (fig. 46a-b), it was not seriously deformed as the underlying permafrost melted. Ground subsidence became evident when the well in the building began to 'rise.' The casing of the well is frozen into 120 feet of permafrost, but the pump, which is set on top of the casing, continued to 'rise' above the floor (fig. 46c). When it was 1 or 2 feet above the floor, the well casing was cut off and reset at floor level. Contrary to popular opinion, the casing was not rising out of the ground; rather, the ground and building were sinking around the stable casing. Because the KFAR-transmitter building was constructed solidly (and expensively even by modern standards), the building is generally intact, except for cracks and broken buried utility connections. It has not been used as a transmitter station for several years, but stands partially subsided in the middle of the golf course surrounded by well-developed thermokarst pits (fig. 39) and mounds.

No report about the thawing of ice-rich permafrost by a heated building is complete without the story of Bert and Mary's Roadhouse 80 miles southeast of Fairbanks on the Richardson Highway. A large log cabin with a full concrete basement was built in 1949 on the same type of ice-rich retransported silt that exists in the Fairbanks area. A furnace was placed in the basement

Figure 41. Irregular surface of Farmers Loop Road near the east entrance to the University of Alaska, Fairbanks. Road is constructed on a perennially frozen, silty, slough filling containing large masses of ground ice. The 4-foot-deep-gravel layer and black pavement induce deep thawing of permafrost, and consequent unequal subsidence of the road in summer. As the subgrade subsides, maintenance crews relevel the surface. During the summer of 1981, the road surface nearby was painted white to combat absorption of solar rays. Note the irregular guard rail and tilting of the light standards. Photograph 3958 by T.L. Péwé, July 14, 1977.

near the front of the building. The attached front porch and rear service building were not heated. Figures 47a-f present a pictorial record of the sinking of the roadhouse from 1954 to 1964, when the entire structure was razed. The front of the heated structure, where the furnace was located, subsided most rapidly. The unheated porch and utility buildings did not sink immediately, but were dragged downward as the rest of the building settled.

Another striking example of the fate of a heated building constructed on ice-rich permafrost is the destruction of the former church-school building of the University Presbyterian Church in College. The sanctuary of the church was built on flood-plain sand and gravel in 1949. In 1955 a church-school building was constructed 30 feet from the sanctuary (fig. 48) north of the contact between flood-plain sand and gravel and ice-rich silt (fig. 49). The one-story, heated, block school building with its concrete floor was soon deformed and destroyed as the underlying ice melted; the building was condemned in 1961 and removed. Construction and removal costs (1981) constituted a loss of about $150,000. In 1962 a new church school was built on the flood plain west of the manse at a cost of approximately $150,000. At current prices, this unfortunate experience with ice-rich permafrost cost more than $300,000.

Figure 42. Ground subsidence near and under streets due to thawing of ice-rich permafrost. Damaged pavement and sidewalks have been removed where the ground has subsided, and the area has been brought to grade with additional gravel fill. View west on Balsam Street, Fort Wainwright. Photograph 1780 by T.L. Péwé, July 27, 1958.

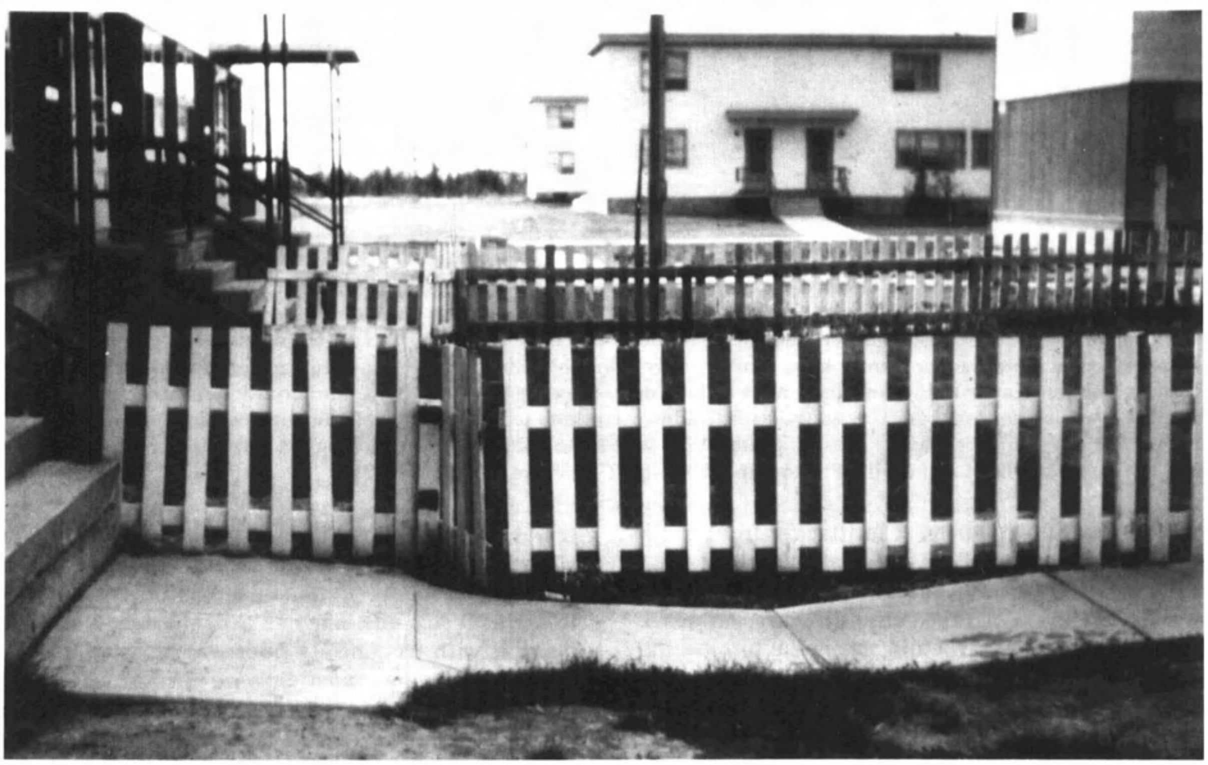

Figure 43. At Building 4106 Fort Wainwright this concrete crosswalk settled about 8 inches near the porch and several more inches in center because of thawing of ice-rich permafrost. Photograph by S.W. Muller, July 27, 1958.

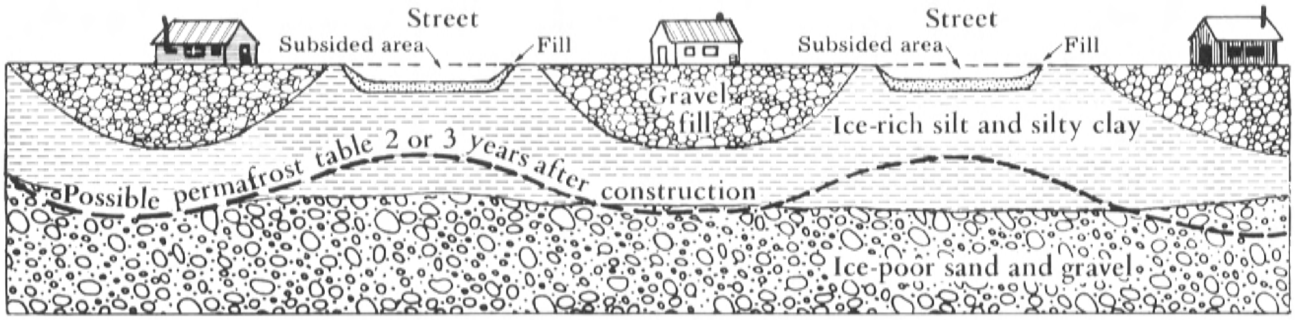

Figure 44. Diagrammatic sketch of housing area between Eighth and Ninth Streets on Balsam Street, Fort Wainwright, showing subsidence of ground near and under streets caused by thawing of ice-rich permafrost (fig. 42). Much of the housing development was built on up to 20 feet of ice-rich slough and swale alluvium overlying flood-plain gravel. Areas under houses did not subside significantly because most silt was removed and replaced with gravel backfill.

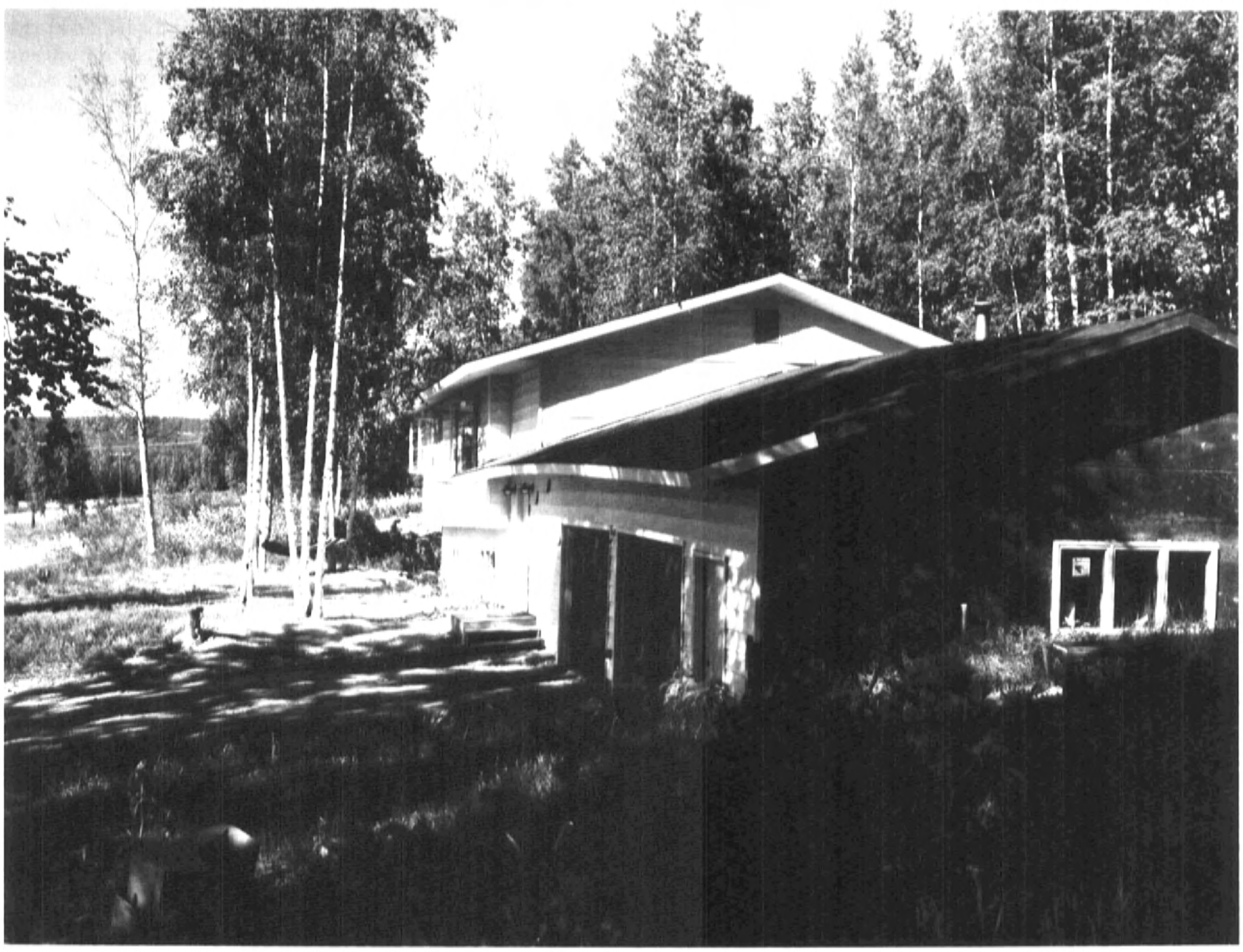

Figure 45. This house was constructed in about 1974 on ice-rich permafrost near the contact with the permafrost-free, west-facing slope on Birch Hill (Péwé, 1958; Péwé and Bell, 1975a). The heated basement under the main part of the house is subsiding but the unheated garage is not. Resulting stresses are bending and stretching the structure, causing breaking, pulling, and buckling of the siding and frame, especially where the garage joins the heated section of the house. The far end of the house appears to have subsided 1 to 2 feet. Photograph 3993 by T.L. Péwé, July 17, 1977.

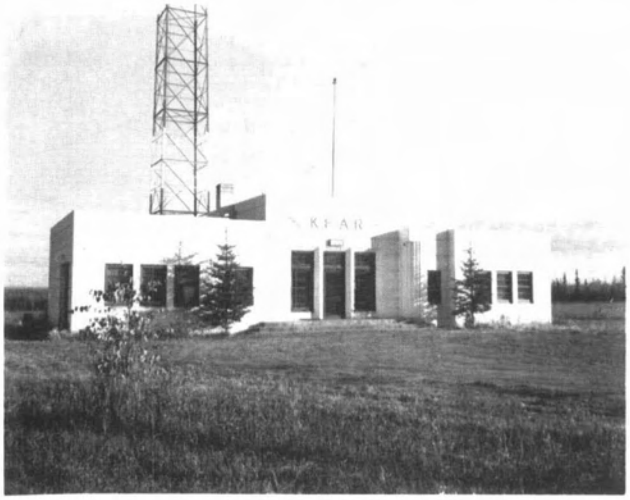

Figure 46a. The KFAR-transmitter station constructed in 1939 had settled 2 or 3 feet by 1948. Only two of the original front-door steps are visible. Although slight cracks had formed in the building, the structure was intact. Photograph 363 by T.L. Péwé, September 9, 1948.

Figure 46b. By 1977, the KFAR-transmitter station had subsided 4 to 5 feet; note the ground surface at the base of the windows. Needless to say, the building was abandoned, but it is remarkably intact after subsiding almost 40 years. Photograph 4005 by T.L. Péwé, July 14, 1977.

Figure 46c. By 1948, the top of the well casing and bottom of the pump in the KFAR-transmitter station were 12 inches above the floor because of ground subsidence caused by thawing of ice-rich permafrost. Photograph 296 by T.L. Péwé, July 14, 1948.

There are numerous examples of the distortion and destruction of heated buildings by the thawing of ice-rich permafrost (figs. 50-52). Obviously, the solution is to construct in permafrost-free areas or on permafrost with a relatively low ice content.

If construction must proceed in areas of ice-rich permafrost, special engineering techniques must be employed to keep the permafrost frozen; building heat must not enter the ground. Placement of the building on piles is a common solution. Another method is to provide openings under the building for cold-air circulation and building-heat dispersion (figs. 53, 54). Unfortunately, many heated buildings require constant and expensive adjustment as the foundation sinks; in many instances the building must eventually be abandoned.

Sufficient scientific and engineering expertise is now available for the trouble-free construction of structures on ice-rich permafrost. Unfortunately, frequency and avoidance costs of permafrost problems are higher in areas of 'warm' sensitive permafrost, such as Fairbanks, than in areas where permafrost is colder and less sensitive.

EFFECTS ON NATURAL-GAS AND OIL PIPELINES

GENERAL STATEMENT

The extraction and transportation of commercial quantities of oil and natural gas in the Arctic have introduced a new set of permafrost-related geological, engineering, and environmental problems. Although natural gas and oil have been extracted in the Arctic for many years, production and transportation were relatively limited. Small, temporary pipelines for crude oil and refined products were built in northwestern Canada (Norman Wells) and Alaska (along the Alaska Highway) during World War II and shortly thereafter.

The most favored means of transporting petroleum products is by large-diameter, above- or below-ground pipeline. The basic problems of pipeline construction in

Figure 47a. Bert and Mary's Roadhouse at Mile 275.7, Richardson Highway, central Alaska. This large log building was seriously deformed and eventually destroyed by ground subsidence caused by thawing of ice-rich permafrost. Heat from the furnace located in the front of the building caused that part of the structure to sink most rapidly. Built in 1949, the building showed little deformation until 1952; by the fall of 1953 the building had subsided 2 feet below the level of the unheated porch. Photograph 854 by T.L. Péwé, April 2, 1954.

Figure 47b. By 1957 the building had subsided even more, dragging down the unheated front porch and small utility room (rear). Photograph 1399 by T.L. Péwé, July 15, 1957.

Figure 47c. Further subsidence had occurred by 1959, but the building was still in use. Photograph 1870, T.L. Péwé, June 18, 1959.

Figure 47d. By 1961 the building was abandoned as a roadhouse; the porch windows were broken during deformation. Photograph PK 7073 by T.L. Péwé, August 19, 1961.

Figure 47e. The porch and attached utility room were even more deformed in 1962. Photograph 2072 by T.L. Péwé, May 29, 1962.

Figure 47f . In 1964 the roadhouse was razed, exposing the differentially subsided concrete basement walls. Photograph PK 8631 by T.L. Péwé, June 17, 1964.

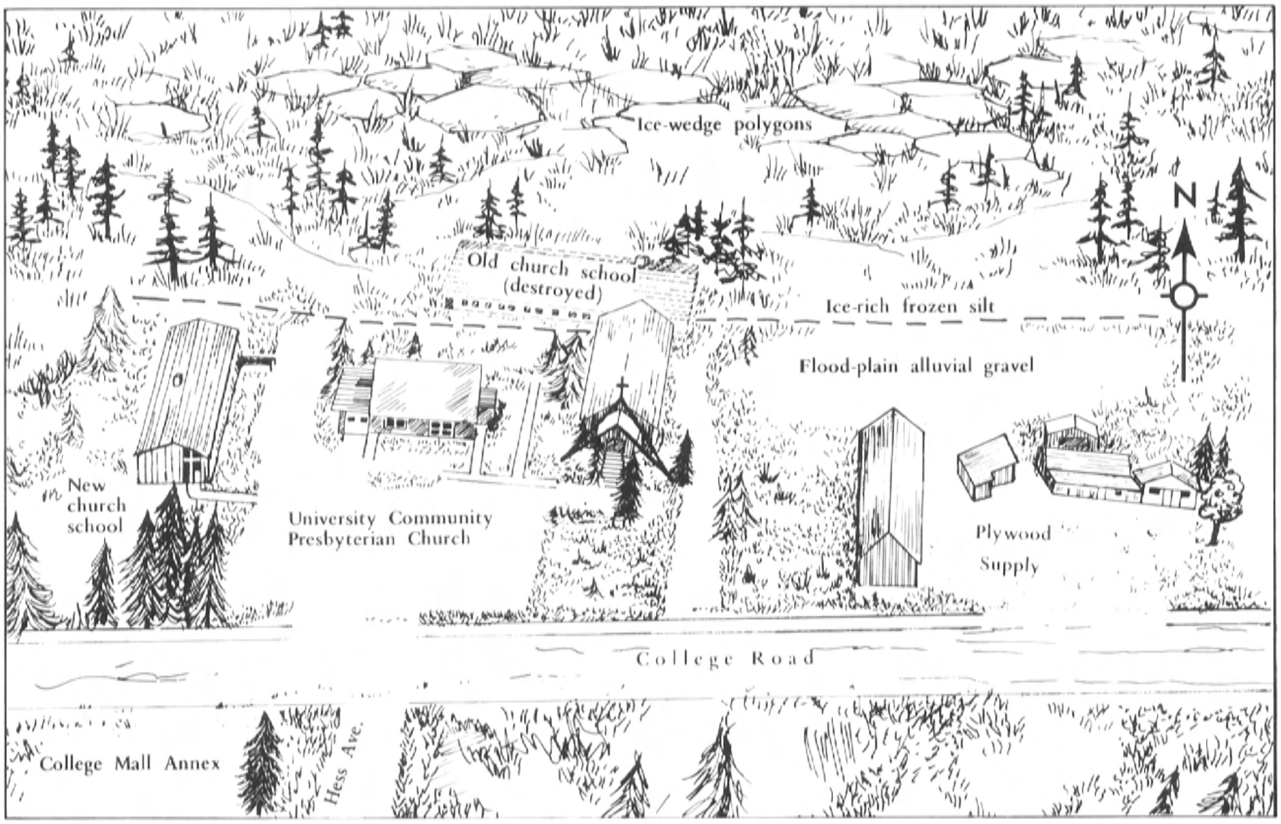

Figure 48. Sketch from 1955 oblique photograph of the University Community Presbyterian Church Manse and old church school in College. Buildings in foreground are on flood-plain alluvial gravel and church school is on ice-rich permafrost. Note the ice wedges diagrammatically expressed as polygonal ground. The old school collapsed several years later as underlying ice melted. The new school building and other modern structures are sketched as of 1981. Photography courtesy of E.H. Beistline.

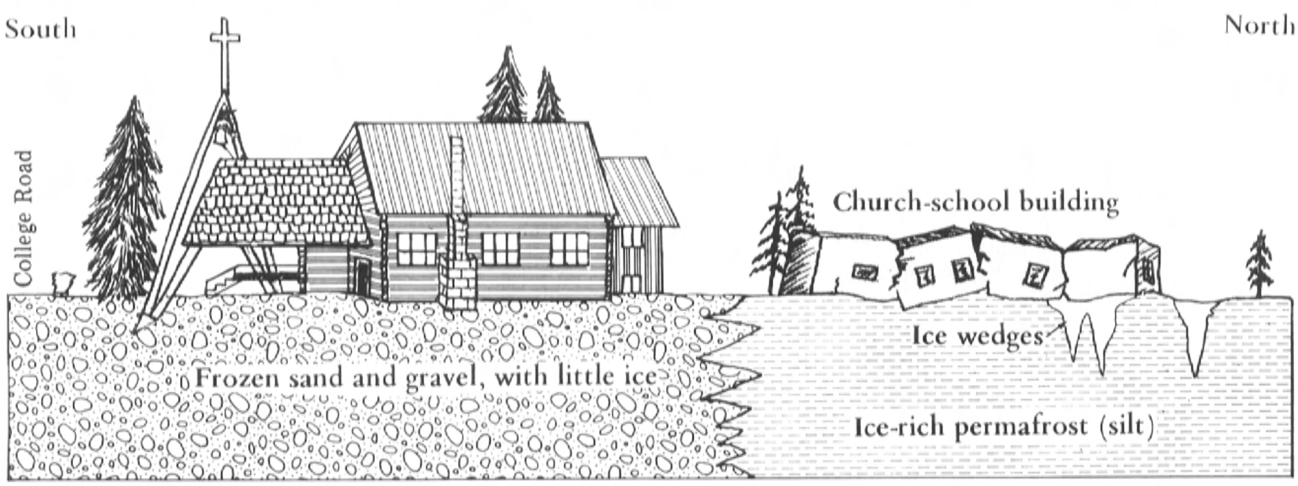

Figure 49. Diagrammatic sketch of sanctuary of the University Community Presbyterian Church and former church-school building in College. The sanctuary was built on perennially frozen flood-plain sand and gravel that contains scant ice. Thus, there has been little subsidence of the building. In 1955, the former church-school building was constructed 30 feet to the north, on ice-rich permafrost, across the boundary between the flood-plain gravel and retransported silt. Permafrost under the heated block building soon thawed, and as the building subsided it was distorted and had to be razed 6 years later.

Figure 50. Tilted, modern log cabin with full, heated concrete basement built on ice-rich permafrost (Péwé, 1954). Location is 3 miles north of Fairbanks near the McGrath-Farmers Loop Roads' junction (see figure 33 for aerial photograph of area). Heat from the 3- to 4-year-old cabin is thawing the permafrost; the greatest subsidence (about 4 feet) is near the furnace and fireplace. The foundation is severely cracked, and distortion of the house has broken windows and drain pipes and jammed doors and windows. Recent repairs entailed breaking up the basement slab, leveling the house with jacks, backfilling with gravel, and repouring the basement slab and wall foundation. Because thaw is not complete, additional settling is expected. Photograph 4001 by T.L. Péwé, July 14, 1977.

permafrost regions involve thawing of permafrost by buried warm-oil pipe and frost heaving of piles that support elevated pipe.

Natural-gas and oil pipelines present different geotechnical problems. Gas may assume the temperature of its surroundings or be chilled and thus cause little thawing of permafrost. However, because pipeline burial and construction of access roads and work pads requires stripping of vegetation, the thermal equilibrium of the frozen ground is disturbed.

High temperatures of flowing oil can cause major disruption of the thermal equilibrium of permafrost. The initial heat of the oil, combined with frictional heating, will thaw surrounding perennially frozen ground unless proper construction methods are used. The rate and amount of thawing are controlled by oil and permafrost temperatures, if other parameters are stable.

GAS PIPELINES

A few large- and small-diameter, short and long gas pipelines exist in permafrost regions, primarily in the USSR. Although cold gas does not significantly thaw permafrost immediately, disturbance of the thermal equilibrium during excavation has favored elevated lines in the North. However, problems of expansion and

Figure 51. Heated concrete basement under frame house subsided 18 inches on south side of building. This World War II era house is located on ice-rich permafrost about 200 yards north of Ballaine Lake near the University of Alaska. Note the wooden, wedge-shaped addition that was added to the foundation in 1946 to level the building. Photograph 187 by T.L. Péwé, August 14, 1947.

contraction, weathering, and damage by human and natural elements, especially wind, must still be addressed.

What promises to be the most expensive private construction job ever undertaken is the proposed large-diameter natural-gas pipeline extending from northern Alaska through the Fairbanks area to the central United States via Canada. Considerable discussion is underway concerning the geologic hazards of permafrost and seasonal frost along the northern part of the route.

TRANS-ALASKA PIPELINE SYSTEM

The first major oil pipeline constructed in the North is the 798-mile-long, 48-inch-diameter, Trans-Alaska Pipeline System (TAPS). A review of the engineering techniques used in that project will summarize our knowledge of warm-oil-pipeline construction in permafrost.

Originally the Trans-Alaska Pipeline System was to be buried along most of the route; the oil temperature was initially estimated at 158° to 176°F during full production. Obviously such an installation would thaw the surrounding permafrost, but, because such an enterprise had never before been undertaken, there was scant knowledge of the serious problems created by a warm-oil pipeline in frozen ground.

Previous experience indicated that thawing of ice-rich permafrost by a buried warm-oil line could cause liquefication and loss of bearing strength, thus producing mudflows and differential settlement of the line. The greatest differential settlement could occur in areas of

Figure 52. Frame house with heated basement near Farmers Loop Road north of the University of Alaska, Fairbanks. Note separation of the building and distortion of doors caused by melting of underlying ice-rich permafrost. Photograph 3326 by T.L. Péwé, June 19, 1972.

Figure 53. Building constructed with air vents in foundation to facilitate removal of structural heat. To prevent thawing of underlying permafrost, heated buildings may be constructed with such passageways to allow air circulation under the structure. The 4-inch-high vents in the foundation of this building were insufficient to dispose of building heat and the permafrost thawed, resulting in building subsidence. Location is the Cold Regions Research and Engineering Laboratory Permafrost Experimental Station, U.S. Army Corps of Engineers, Farmers Loop Road, Fairbanks. Photograph 1782 by T.L. Péwé, July 26, 1958.

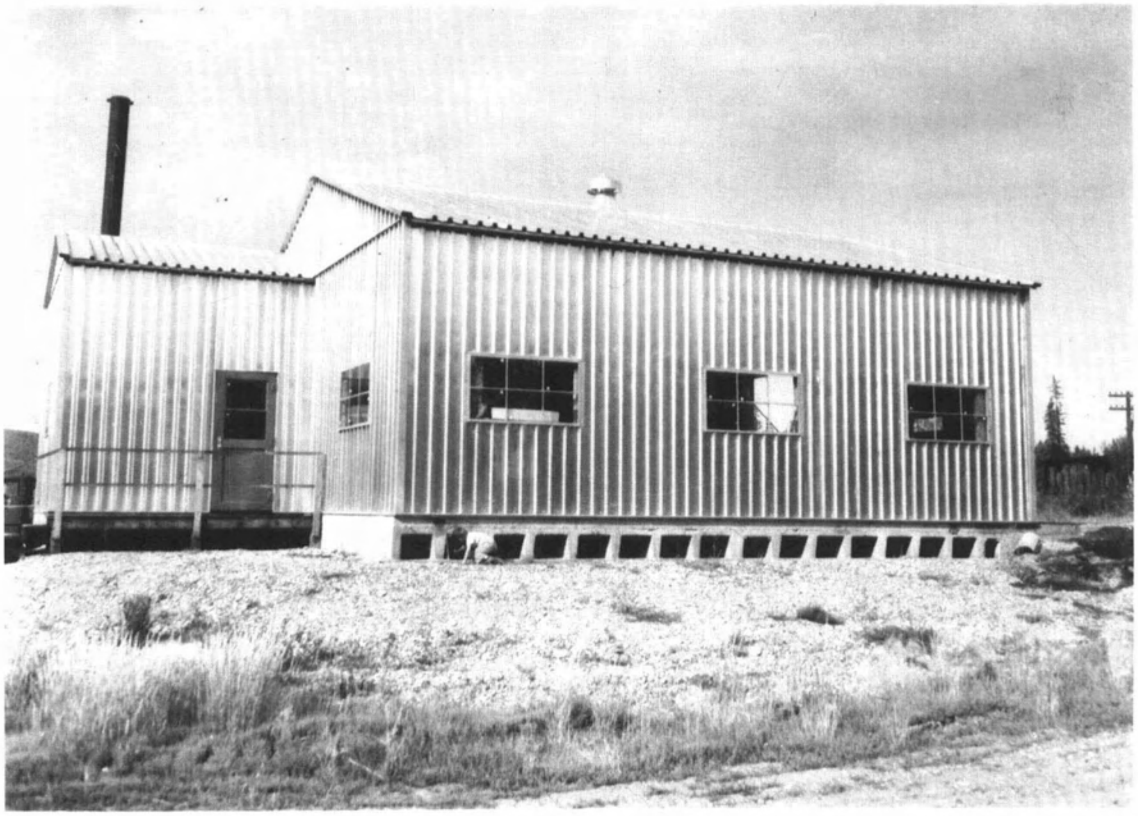

Figure 54. Twelve-inch-high air vents in the concrete foundation of this building prevent thawing of underlying permafrost. Location is Cold Regions Research and Engineering Laboratory Permafrost Experimental Station, U.S. Army Corps of Engineers, Farmers Loop Road, Fairbanks. Photograph 1783 by T.L. Péwé, July 26, 1958.

ice wedges, where polygonal troughs could deflect surface water into erosional trenches and cause additional erosion and thawing.

Pipeline engineers studied potential permafrost-related problems in detail. A monumental effort was directed to the design and testing of construction modes in and across varying permafrost and nonpermafrost terrains in an effort to build a secure, warm-oil pipeline.

Three modes of construction were used---conventional buried, artificial-refrigerated buried, and above ground---depending upon environment, terrain, and permafrost conditions. All modes were used in the Fairbanks area. Because heat is generated by both pumping and friction with the inside of the pipe, the oil moving through the system at the design flow rate of 2,000,000 barrels per day ranges from 130° to 145°F. Potential effects of this heat on the frozen ground along the route determined the mode of pipe installation.

The pipeline crosses the continuous and discontinuous permafrost zones (fig. 55), as well as an area along the southern segment of the route that contains no permafrost. In areas where permafrost is nearly ice free, or where permafrost is absent, the pipe is buried in the conventional manner. About 409 miles of the pipeline are conventionally buried (fig. 56a).

Seven short sections of the line, totalling about 7 miles, are buried and refrigerated (fig. 56b). In these sections the pipe was insulated with 3 inches of polyurethane foam covered by a resin-reinforced fiberglass jacket. The permafrost is maintained by electrical refrigeration units that pump chilled brine through small pipes buried beneath the pipeline.

Nearly half of the TAPS pipeline (382 miles) is elevated because of the presence of ice-rich permafrost (fig. 11). The above-ground placement of such a large pipeline is a major effort, especially in permafrost terrain. Although the pipeline successfully discharges its heat into the air and does not directly affect the underlying permafrost, other problems must be considered. As indicated in figures 56c and 56d, the pipe is clamped in a saddle assembly placed on a crossbeam installed between steel vertical-support members (VSMs). The VSMs are subject to frost heaving but, as indicated earlier, frost heaving of VSMs is virtually eliminated when they are frozen firmly into the permafrost with a nonmechanical thermal device. To compensate for expansion and contraction of the elevated pipe, the line was built in a flexible zigzag configuration that converts expansion of the pipe into lateral movement. In these sections, the pipe is mounted on a sliding shoe (fig. 56c). As the line expands or contracts, the pipe slides back and forth across the horizontal-support member. To stabilize the pipe on the crossbeams along the line, it is anchored by special platforms at the end of each zigzag configuration (every 800 to 1,800 feet) (fig. 56d). The elevated pipe is insulated with a 4-inch-thick layer of resin-impregnated fiberglass jacketed with galvanized steel. This insulation keeps the oil warm and in a pumpable state for the period of time necessary to complete any unexpected maintenance, should oil flow cease.

Operation of the pipeline began in the summer of 1977, and to date no serious engineering problems have developed as a result of permafrost or frost action. The basic question that must be asked is what part of the $8 billion spent to construct the TAPS facility was spent to learn about, combat, accommodate, and otherwise work with the perennially and seasonally frozen ground? According to the Alyeska Pipeline Service Company, the elevated mode cost three times more than the buried mode. Although this value is not accepted by all construction and federal officials, all admit that the hazard of frozen ground was an extremely costly aspect of the project. M.J. Turner, acting Authorized Officer of the Trans-Alaska Pipeline Office of the Department of Interior, conservatively ventured (written commun., October 5, 1977) that 10 percent of the $8 billion cost of the TAPS project, or $800 million, was spent to accommodate frozen-ground conditions. I suggest a figure of $1 billion for the cost of combating the frozen-ground hazard in construction of the Trans-Alaska Pipeline System.

EFFECTS ON BURIED UTILITY LINES

Water, steam, gas, sewer, and utility lines are commonly buried in the Fairbanks area. To prevent freezing, water, sewer, and other lines are usually placed in underground boxes, called utilidors, which may be from 1 foot to more than 5 feet across (figs. 57, 58). In areas where permafrost is absent or ice-poor, such as the flood plain of the Chena and Tanana Rivers (fig. 3) on which Fairbanks and Fort Wainwright are located, there is little problem with distortion and destruction of utility lines. However, construction of buried utilidors in ice-rich permafrost generally creates problems similar to those of a heated building---thawing of permafrost and subsidence of the utilidor causing pipe breakage and the eventual destruction of the system (fig. 59).

INDICATORS OF PERMAFROST

RECOGNITION OF THE PROBLEM

From the above discussion, it is readily apparent that it is absolutely necessary to recognize areas of

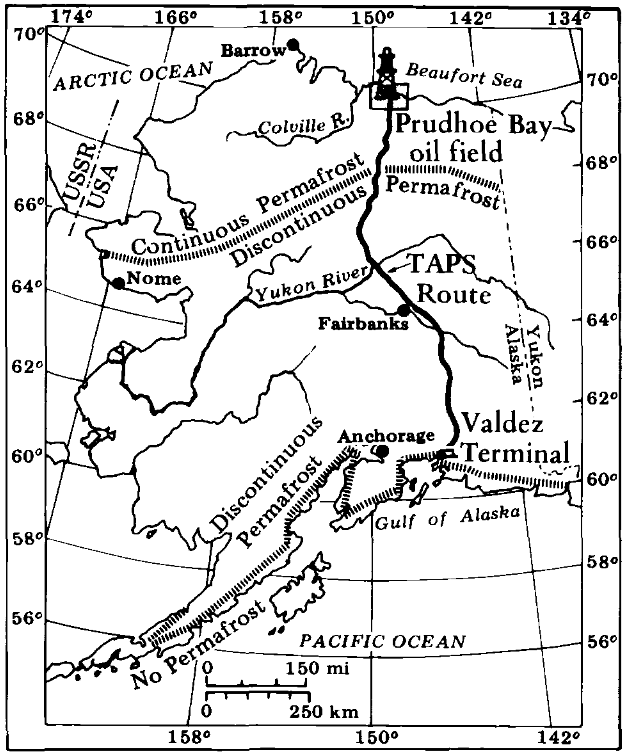

Figure 55. Route of the Trans-Alaska Pipeline System through three permafrost zones.

ice-rich permafrost. As mentioned earlier, there are several ways to infer the presence of permafrost. The most accurate methods of detection, even at depths of 20 to 25 feet below a thawed layer, are ground-temperature measurements and well-log data. So what can an individual do to avoid the hazards of permafrost?

The best method is to study a geologic hazards or permafrost map of the area, either independently or with an experienced consulting geologist or engineer. Unfortunately, few geologists and engineers have extensive experience in permafrost detection. However, with a geologic map as a guide, a preliminary examination can be made.

If a map showing ground temperatures and well information is not available (and many are available for the Fairbanks area), experienced geologists and geobotanists can still make fairly reliable inferences concerning permafrost in the area, especially if they have local experience. What do they look for? One of the guides is the distribution and type of natural vegetation.

VEGETATION

The distribution of trees and tall shrubs may contribute indirectly to the interpretation of permafrost conditions when the age of the land surface, the climate, and the character of the underlying material are taken

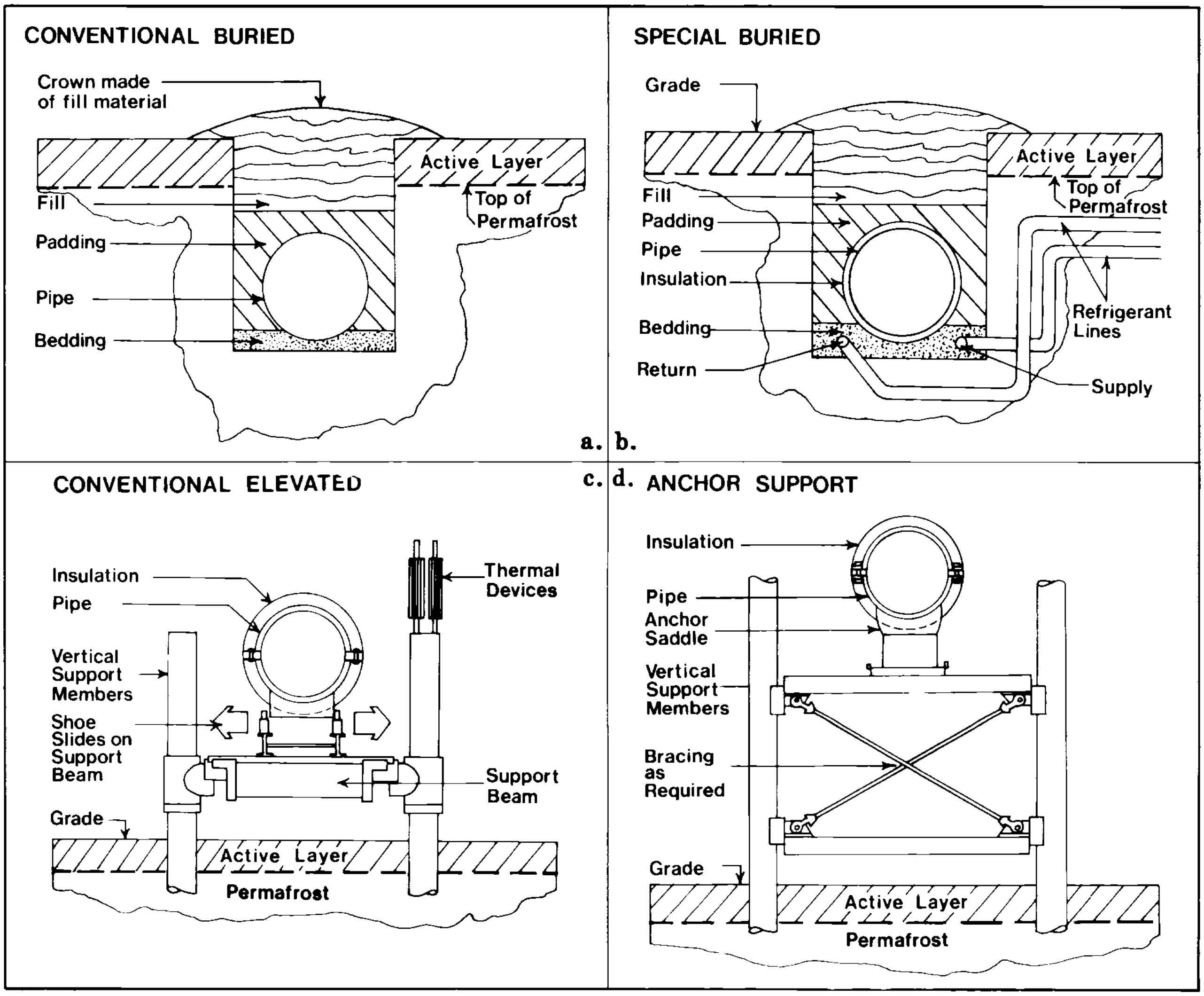

Figure 56a-d. Various construction modes used during construction of the Trans-Alaska Pipeline System. Conventional burial was used in permafrost-free areas and areas of low-ice-content permafrost. Special burial was used for short sections requiring a permanently frozen state. The conventional elevated mode was used in areas of ice-rich permafrost; movement of the pipe is allowed to compensate for expansion caused by warm oil. The anchor-support mode was used above ground in ice-rich permafrost but no movement of the pipe is allowed. Diagram courtesy of Alyeska Pipeline Service Company.

into consideration. Observations of the kinds of trees and shrubs and their growth forms also permit inferences concerning local depth to permafrost. The exact significance of these vegetation phenomena varies from region to region and must be used with caution. Distribution of trees and shrubs is a function of many variables, and permafrost is an influencing factor only where it occurs at a depth shallow enough to influence subsurface drainage, soil stability, and soil temperatures in the root zone.

When permafrost is close to the ground surface on gently sloping or flat areas, drainage is poor and soil temperatures are cold. This situation generally results in boggy conditions. Some trees, such as larch and black spruce, have shallow root systems and manage to grow in wet areas where permafrost is shallow. In the Fairbanks area, open uniform stands of black spruce growing on flat or gently sloping, moss-covered ground occur in silty or peaty soils with shallow permafrost (fig. 24). However, it is very important to note that elsewhere, as in the Anchorage area, permafrost is generally absent beneath similar forests, even though seasonal frost frequently persists through most of the summer.

South-facing, permafrost-free slopes in the Fairbanks area are generally covered with white spruce - birch forests containing interspersed aspen. Such forests

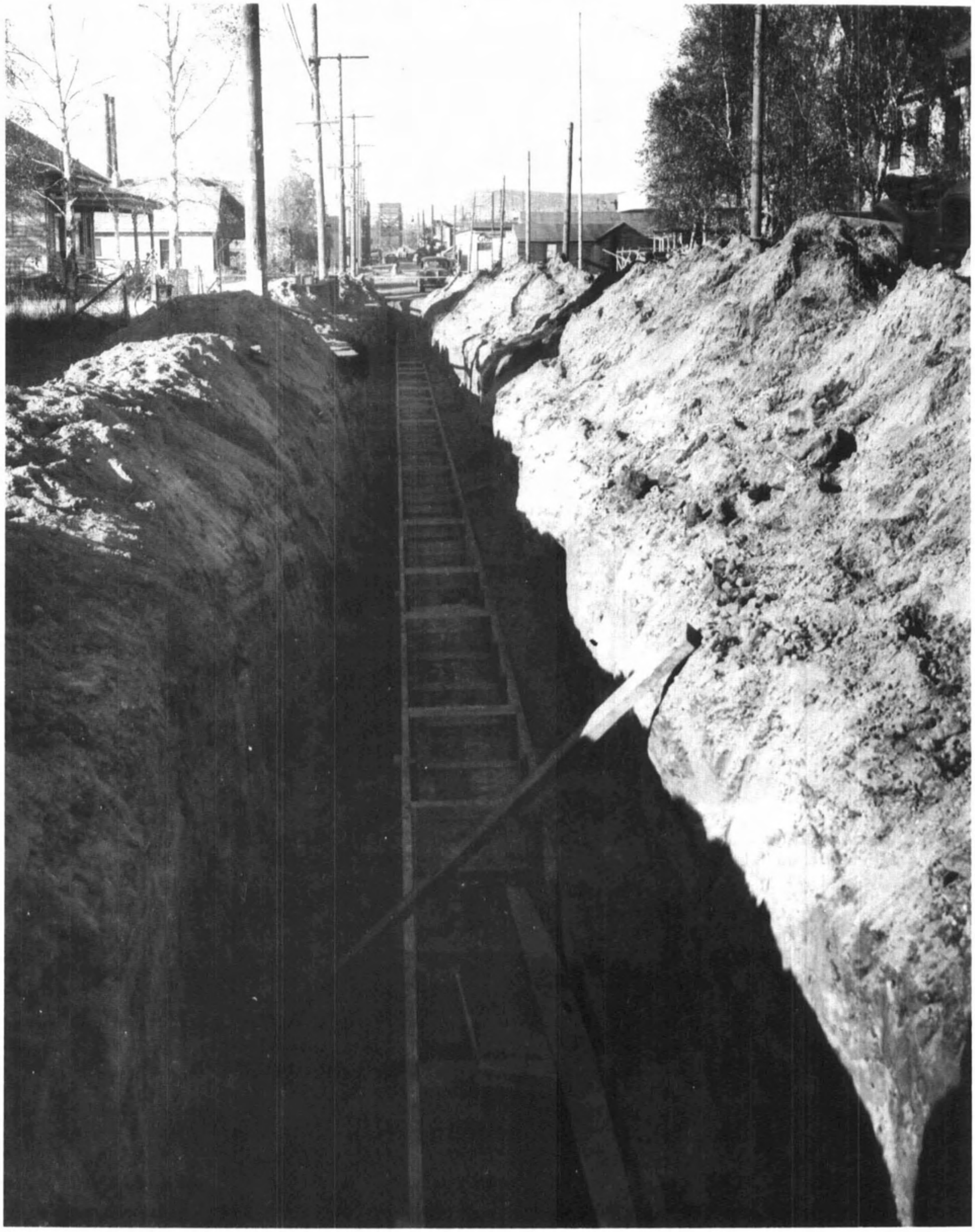

Figure 57. Early-day utilidors along Cushman Street in Fairbanks were simple wood boxes used to prevent the enclosed utility lines from freezing in seasonal frost and permafrost. Note former Cushman Street bridge over the Chena River in the distance. Photograph 127 by T.L. Péwé, September 11, 1946.

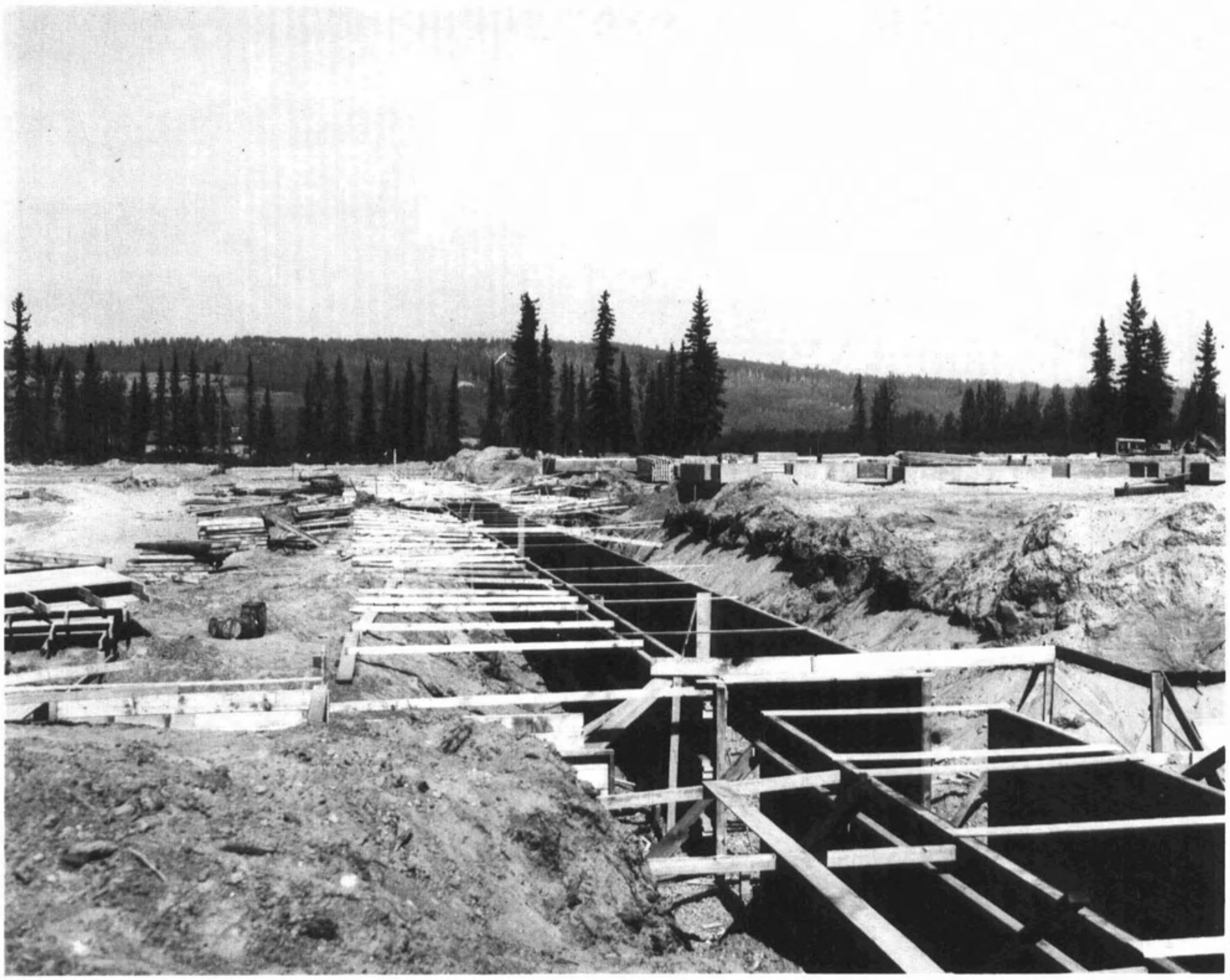

Figure 58. Concrete utilidor under construction at Fort Wainwright near Fairbanks. This area is on the Chena River flood plain and is underlain by perennially frozen sand and gravel with a low ice content. Photograph 139 by T.L. Péwé, July 16, 1947.

grow best in relatively well-drained areas where the ground thaws at least several feet by mid-summer. However, one of the greatest misconceptions in central Alaska is that the presence of such a forest unequivocally indicates the absence of permafrost. As mentioned earlier, on lower slopes a well-developed growth of large birch and spruce trees may extend a short distance into areas underlain by ice-rich, perennially frozen ground. Thus, even though the boundary between the black spruce - scrub forest and the white spruce - birch - aspen forest is distinct and easily recognized (figs. 24, 25), permafrost, with or without ice masses, generally extends a short distance upslope from the boundary between these two vegetation types.

SMALL LANDFORMS AND NATURAL SURFACE PATTERNS

A surprising amount of information on the distribution and type of permafrost can be obtained on the ground and from aerial photographs by studying small landforms and ground patterns, especially in areas of large ground-ice masses (fig. 24). In the Fairbanks area, these permafrost indicators can be divided into natural features and features formed by human influence. Natural landforms and patterns indicative of ice-rich permafrost are thaw lakes, large-scale polygonal patterns, beaded drainage, and pingos. Human influence may result in thermokarst pits and mounds and distorted buildings.

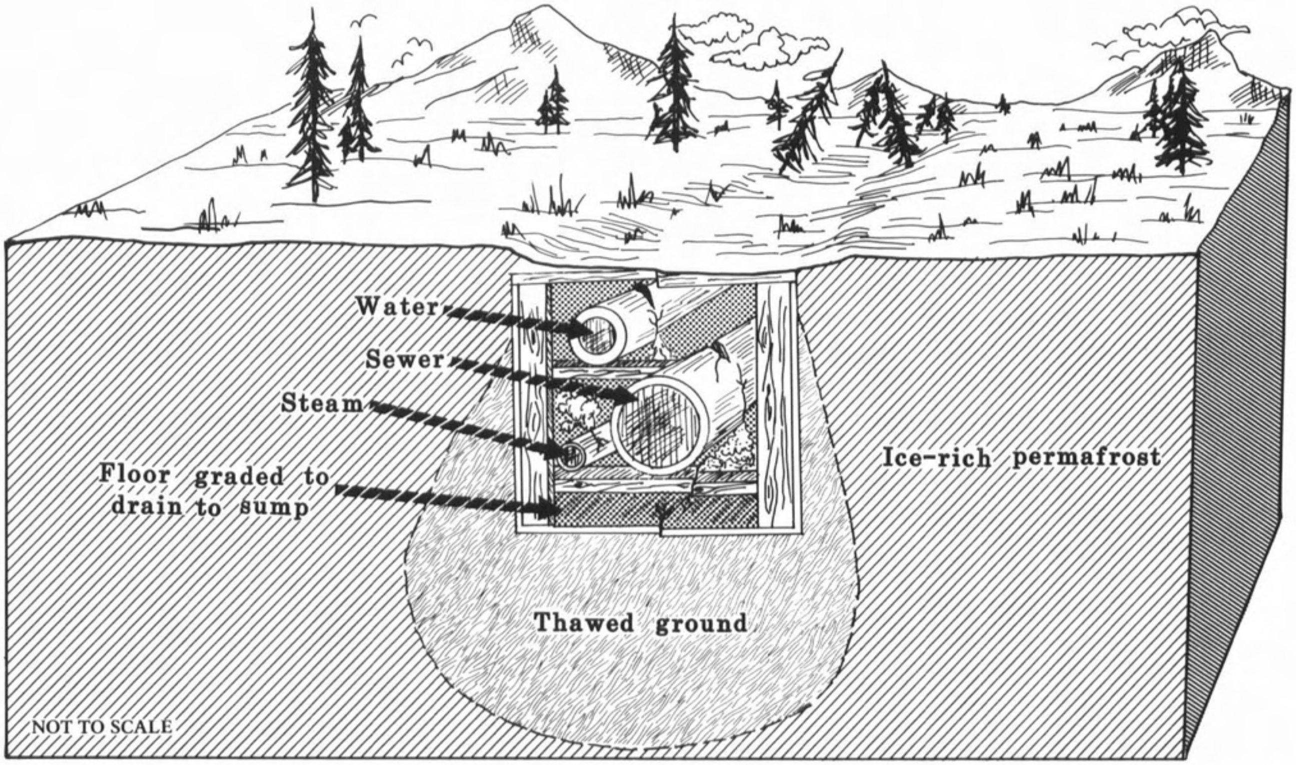

Figure 59. Diagrammatic sketch (exaggerated) of a utilidor buried in ice-rich permafrost. Heat from the utilidor has thawed the ground, and allowed the irregular subsidence of the utilidor that resulted in broken pipes. This is not an uncommon occurrence in permafrost areas, especially where the ice content is not uniformly distributed.

Thaw lakes, also called cave-in or thermokarst lakes, occupy shallow depressions formed by local thawing of ice-rich, perennially frozen ground on flat surfaces and gentle slopes underlain by at least 10 feet of peat and silt. Thaw lakes assume various shapes, are generally shallow, and may be as much as 100 to 1,000 feet in diameter. Actively caving banks are ragged and steep or overhanging; tilted trees often lean over the water along the banks (fig. 60) and dead trees with submerged bases protrude above the water surface close to the banks. Lake size increases by thawing and wave erosion along banks, and lakes eventually drain when retreating banks intersect a stream valley or other lower ground. Thawing generally proceeds most rapidly along ice wedges that form reentrants in the lake banks.

Thaw lakes are common in the Fairbanks area, especially in silt-filled creek valleys, silt lowlands, and on lower, silt-covered hillslopes. Examples of thaw lakes in the Fairbanks area include Paul, Reindeer, Middlestar, and Caribou Lakes just south of Farmers Loop Road. Ballaine and Smith Lakes are thermokarst in origin, as are lakes and ponds in the Ace and St. Patrick Creek drainages.

The ground surface in areas of ice wedges commonly exhibits a large-scale polygonal microrelief pattern. Such patterns are well-known in central Alaska. Surface polygons reflect underlying polygonal ice wedges and measure from 10 to 100 feet in diameter. Although they are among the most dependable indicators of ice-rich permafrost, permafrost is also present in many areas without polygonal ground. Water often collects in trenches over a partially thawed ice wedge. In the Fairbanks area most polygonal patterns are outlined by a series of these interconnecting, shallow, water-filled troughs that may be 2 feet wide and 10 to 50 feet long (fig. 24).

It should be noted that in other areas---for example, near Delta Junction---similar polygonal patterns also exist, but they are relic and indicate ice wedges that have melted. These patterns are now outlined by surface troughs and vegetation. The patterns in the Delta Junction area occur on gravel and are not associated with thaw lakes, beaded drainage, or pingos.

Polygonal ground is common in the organic-rich silt lowland south of Farmers Loop Road and north of College Road (fig. 3). Alluvial fans of silt washing down

Figure 60. Trees tilting into Paul Lake, a cave-in lake near Farmers Loop Road north of Fairbanks. As the warm lake water thaws ice-rich permafrost along the lake's banks, the ground subsides and trees slowly tilt into the lake. Photograph 320 by T.L. Péwé, July 25, 1948.

from the hills during the last 500 to 1,000 years have masked the polygonal surface pattern of ice wedges in the Fairbanks area.

The term 'beaded drainage' is applied to a characteristic pattern of small streams that develops in areas underlain by ice wedges. The pattern consists of a series of small pools connected by short watercourses. These pools, which generally result from the thawing of large ice masses, are particularly common at the junction of ice wedges. Connecting water-courses are commonly straight or sharply angular because they follow ice wedges. Beaded drainage is also common in areas of pingos and thaw lakes (fig. 24).

Pingos are reliable indicators of permafrost. They are isolated, steepsided hills, generally circular to oval in plan, that range from 10 to more than 100 feet in height and from 50 to 1,000 feet in diameter. Summit craters occupied by ponds are common. Pingos are cored by massive ice lenses overlain by a few feet of silt, sand, or peat. In the Fairbanks area pingos that occur in permafrost at the base of hills indicate the presence of silty sediments and ground water. Most pingos occur where the permafrost table is close to the ground surface. Vegetation is generally stunted or consists of low bushes. Because pingos stand above the landscape and have a well-drained surface, they support healthy stands of birch, aspen, and white-spruce trees, which contrast sharply with surrounding vegetation (fig. 61).

SELECTED REFERENCES

Beskow, Gunnar, 1947, Tjalbildningen och tjallyftningen [soil freezing and frost heaving with special application to roads and railroads]: Swedish Geological Society, no. 375, 145 p. (English translation by Osterberg, J.Q., Northwestern University).

Black, R.F., 1969, Thaw depressions and thaw lakes, a review: Biuletyn Peryglacjalny, v. 19, p. 131-150.

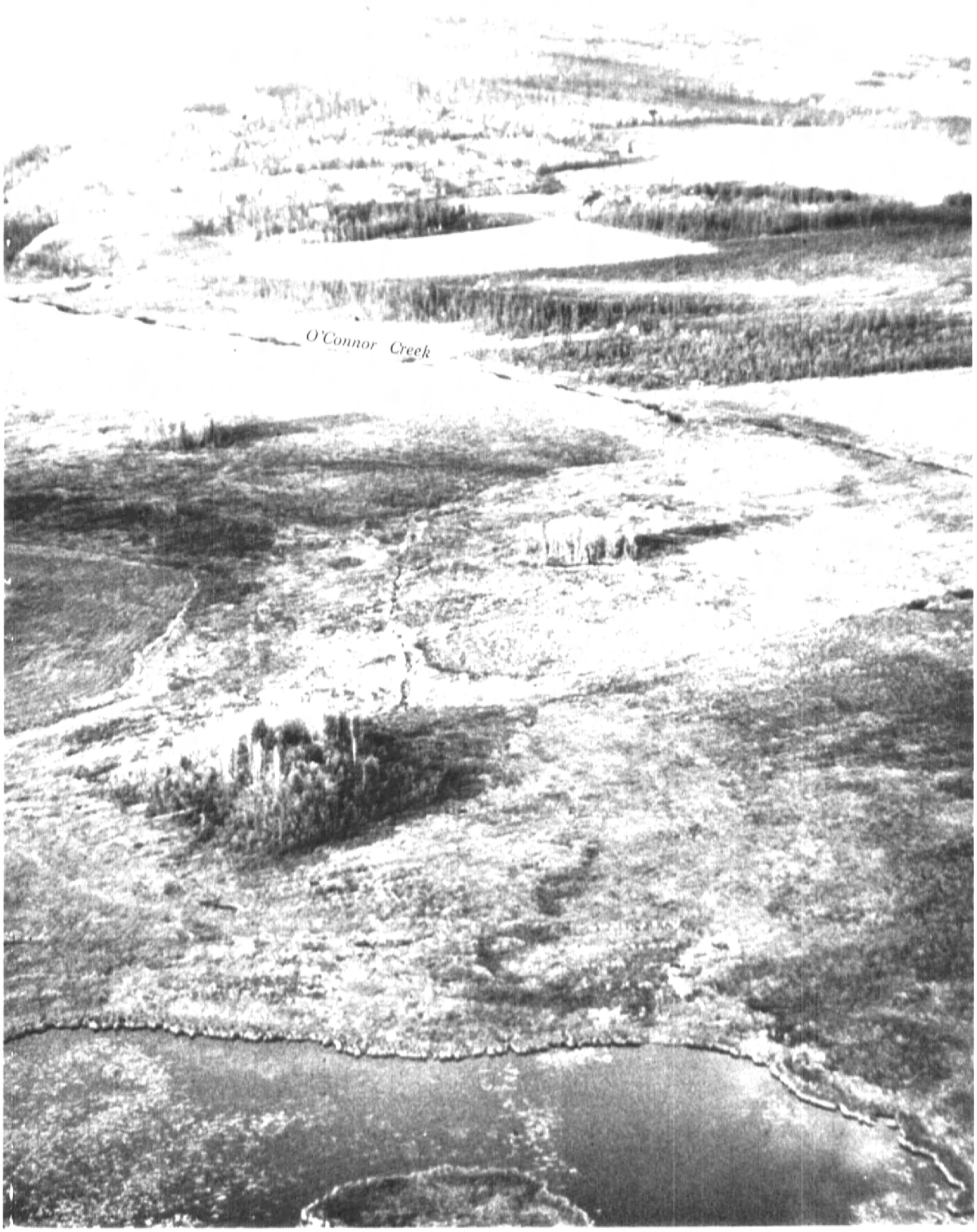

Figure 61. Aerial view toward north of three ice-cored pingos in perennially frozen silt in Goldstream valley. The well-drained conditions on the surface of the pingos allow spruce, aspen, and birch to thrive. Large pingo at lower left is 30 feet high and 300 feet in diameter. Photograph by Florence Weber, September 23, 1964.

Brown, Jerry, 1966, Massive underground ice in northern regions: U.S. Army Conference Proceedings, v. 1, p. 89-102.

_______, 1967, An estimation of the volume of ground ice, coastal plain, northern Alaska: U.S. Army Materiel Command Cold Regions Research and Engineering Laboratory Technical Note, 22 p.

Brown, Jerry, Gray, Sheldon, and Webster, William, 1967, Chemical and related properties of a permafrost section from Fairbanks, Alaska: U.S. Army Materiel Command Cold Regions Research and Engineering Laboratory Technical Note, 18 p.

Brown, R.J.E., 1966, Influence of vegetation on permafrost, *in* International Conference on Permafrost, Lafayette, Ind., 1963, Proceedings: Washington, National Academy of Science, National Research Council Publication 1287, p. 20-25.

_______, 1969, Factors influencing discontinuous permafrost in Canada, *in* Péwé, T.L., ed., The periglacial environment; past and present: Montreal, McGill-Queens University Press, p. 11-53.

_______, 1970, Permafrost in Canada: University of Toronto Press, 234 p.

Brown, R.J.E., and Kupsch, W.D., 1974, Permafrost terminology: Ottawa, National Research Council of Canada, no. 14274, 62 p.

Brown, R.J.E., and Péwé, T.L., 1973, Distribution of permafrost in North America and its relationship to the environment, 1963 to 1973 - a review, *in* Permafrost, the North American contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, National Academy of Sciences, p. 71-100.

Chellis, R.D., 1951, Pile foundations: New York, McGraw-Hill, 665 p.

Ferrians, O.J., Jr., 1965, Permafrost map of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-445, scale 1:2,500,000.

Ferrians, O.J., Jr., Kachadoorian, Reuben, and Greene, G.W., 1969, Permafrost and related engineering problems in Alaska: U.S. Geological Survey Professional Paper 678, 37 p.

Fujii, Y. and Higuchi, K., 1978, Distribution of alpine permafrost in the northern hemisphere and its relation to air temperature, *in* Third International Conference on Permafrost, 1978, Proceedings, Edmonton, Alberta: National Research Council of Canada, v. 1, p. 366-371.

Gorbunov, A.P., 1978a, Permafrost investigations in high-mountain regions: Arctic and Alpine Research, v. 10, p. 283-294.

_______, 1978b, Permafrost in the mountains of central Asia, *in* Third International Conference on Permafrost, 1978, Proceedings, Edmonton, Alberta: National Research Council of Canada, v. 1, p. 372-377.

Gravis, G.F., Zabolotnik, S.I., Lisun, A.M., and Sukhodrovskii, V.L., 1973, The geocryological characteristics of the Mongolian Peoples' Republic and some characteristics of permafrost development in the past, *in* Permafrost, USSR contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, National Academy of Science, p. 81-85.

Hamelin, L.E., and Cook, F.A., 1967, Illustrated glossary of periglacial phenomenon: Montreal, Laval Press, 237 p.

Hennion, Frank, 1955, Frost and permafrost definitions: Washington, Highway Research Board Bulletin 111, p. 107-110.

Higashi, Akira, 1958, Experimental study of frost heaving: U.S. Army Corps of Engineers Snow, Ice, and Permafrost Research Establishment Research Report 45, 20 p.

Highway Research Board, 1952, Frost action in the soils, a symposium: Washington, Highway Research Board Publication 213, 383 p.

Hopkins, D.M., Barnes, P.W., Biswas, Niren, Cannon, Jan, Chamberlain, Edward, Dygas, Joe, Harrison, William, Naidu, A.S., Nummedal, Dag, Rogers, James, Sellman, Paul, Vigdorchik, Michael, Wiseman, William, Osterkamp, Tom, 1977, Earth science studies, *in* Beaufort Sea synthesis report; Arctic Project Special Bulletin 15, National Oceanic and Atmospheric Administration: Fairbanks, University of Alaska, p. 43-72.

Hopkins, D.M., Karlstrom, T.N.V., Black, R.F., Williams, J.R., Péwé, T.L., Fernald, A.T., and Muller, E.H., 1955, Permafrost and ground water in Alaska: U.S. Geological Survey Professional Paper 264-F, p. 113-146.

Hopkins, D.M., and Sigafoos, R.S., 1951, Frost action and vegetation patterns on Seward Peninsula, Alaska: U.S. Geological Survey Bulletin 974-C, p. 51-101.

Hunter, J.A.M., Judge, A.S., MacAulay, H.A., Good, R.L., Gagne, R.M., and Burns, R.A., 1976, Permafrost and frozen sub-sea bottom materials in the southern Beaufort Sea: Canada, Department of the Environment, Beaufort Sea Project report 22, 174 p.

Ives, J.D., and Bovis, M.J., 1978, Natural hazards for land-use planning, San Juan Mountains, Colorado, USA: Arctic and Alpine Research, v. 10, no. 2, p. 185-212.

Johnson, A.W., 1952, Frost action in roads and airfields: A review of the literature, 1765-1951: Washington, Highway Research Board Special Report 1, 287 p.

Jumikis, A.R., 1955, The frost penetration problem in highway engineering: New Brunswick, N.J., Rutgers University Press, 162 p.

Kachadoorian, Reuben, Hopkins, D.M., and Nichols, D.R., 1954, A preliminary report of geologic factors affecting highway construction in the area between the Susitna and Maclaren Rivers, Alaska: U.S. Geological Survey Open-file Report 54-137, 74 p.

Karpov, V.M., and Puzanov, I.I., 1970, Construction and permafrost, *in* Popular Science series: Leningrad, Publisher for literature on construction, 94 p.

King, von Lorenz, 1977, Detection of permafrost occurrence by means of a hammer seismograph at Tarsala, Swedish Lapland: Zeitschrift fur Gletscherkunde und Glazialgeologie, v. 12, p. 187-204.

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

______________, 1966, Contraction theory of ice-wedge polygons - a qualitative discussion, *in* International Conference on Permafrost, Lafayette, Ind., 1963, Proceedings: Washington, National Academy of Science, National Research Council Publication 1287, p. 63-71.

______________, 1968, Permafrost, *in* Fairbridge, R.W., ed., The encyclopedia of geomorphology: New York, Reinhold, p. 833-839.

______________, 1970, Some estimates of the thermal effects of a heated pipeline in permafrost: U.S. Geological Survey Circular 632, 23 p.

Leffingwell, E. de K., 1915, Ground-ice wedges, the dominant form of ground-ice on the north coast of Alaska: Journal of Geology, v. 23, p. 635-654.

Liestøl, Olav, 1977, Pingos, springs and permafrost in Spitsbergen: Oslo, Norsk Polarinstitutt Arbok, 1975, p. 7-29.

Mackay, J.R., 1972, The world of underground ice: Annals of the Association of American Geographers, v. 62, no. 1, p. 1-22.

Moore, R.M., 1970, Permafrost problems on the Alaska Railroad - an economic study: Fairbanks, University of Alaska Department of Civil Engineering report, 73 p.

Muller, S.W., 1945, Permafrost or permanently frozen ground and related engineering problems: U.S. Engineers Office, Strategic Engineering Study Special Report 62, 136 p., reprinted in 1947, Ann Arbor, Mich., J.W. Edwards, Inc.

______________, 1958, Report on permafrost and related problems at Ladd Field, Fairbanks, Galena, Kotzebue, and Pt. Barrow: Boston, U.S. Air Force Cambridge Research Laboratories unpublished report, 21 p.

National Academy of Sciences, 1966, International Conference on Permafrost, 1963, Proceedings, Lafayette, Ind.: Washington, National Research Council Publication 1287, 563 p.

National Academy of Sciences, 1973, Permafrost, the North American contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, 783 p.

______________, 1973, Permafrost, the USSR contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, 866 p.

National Research Council of Canada, 1978, Third International Conference on Permafrost, 1978, Proceedings, Edmonton, Alberta: National Research Council of Canada, v. 1, 947 p.

Nichols, D.R., and Yehle, L.A., 1961, Highway construction and maintenance problems in permafrost regions, *in* Symposium on geology as applied to highway engineering, 12th, Knoxville, 1961: Tennessee University Engineering Experimental Station Bulletin 24, p. 19-29.

Nikiforoff, C.C., 1912, On certain dynamic processes in the soils of the permafrost region: Pochvovedenie, no. 2.

Péwé, T.L., 1949, Preliminary report of permafrost investigations in the Dunbar area, Alaska: U.S. Geological Survey Circular 42, 3 p.

______________, 1954, Effect of permafrost on cultivated fields, Fairbanks area, Alaska: U.S. Geological Survey Bulletin 989-F, p. 315-351.

______________, 1958, Geology of the Fairbanks D-2 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-110, scale 1:63,360.

______________, 1962, Ice wedges in permafrost, lower Yukon River area near Galena, Alaska: Biuletyn Peryglacjalny, no. 3, p. 65-76.

______________, 1966a, Paleoclimatic significance of fossil ice wedges: Biuletyn Peryglacjalny, no. 15, p. 65-72.

______________, 1966b, Ice wedges in Alaska - classification, distribution and climatic significance, *in* International Conference on Permafrost, Lafayette, Ind., 1963, Proceedings: Washington, National Academy of Sciences, National Research Council Publication 1287, p. 76-81.

______________, 1970, Permafrost and vegetation on floodplains of subarctic rivers (Alaska), a summary, *in* Ecology of the subarctic regions, proceedings of the Helsinki symposium: New York, UNESCO, p. 141-142.

______________, 1975, Permafrost, challenge of the Arctic, *in* 1976 yearbook of science and the future: Encyclopedia Britannica, Inc., p. 89-105.

Péwé, T.L., and Bell, J.W., 1974, Map showing distribution of permafrost in the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-829B, scale 1:24,000.

______________, 1975a, Map showing distribution of permafrost in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668A, scale 1:24,000.

______________, 1975b, Map showing foundation conditions in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668D, scale 1:24,000.

______________, 1975c, Map showing distribution of permafrost in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669A, scale 1:24,000.

______________, 1975d, Map showing foundation conditions in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669D, scale 1:24,000.

______________, 1975e, Map showing distribution of permafrost in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-670A, scale 1:24,000.

______________, 1975f, Map showing foundation conditions in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-670D, scale 1:24,000.

______________, 1975g, Map showing distribution of permafrost in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671A, scale 1:24,000.

______________, 1975h, Map showing foundation conditions in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671D, scale 1:24,000.

Péwé, T.L., Church, R.E., and Andresen, J.J., 1969, Origin and paleoclimatic significance of large-scale polygons in the Donnelly Dome area, Alaska: Geological Society of America Special Paper 109, 87 p.

Péwé, T.L., and Paige, R.A., 1963, Frost heaving of piles with an example from the Fairbanks area, Alaska: U.S. Geological Survey Bulletin 1111-I, p. 333-407.

Péwé, T.L., and Sellman, P.V., 1973, Geochemistry of permafrost and Quaternary stratigraphy, *in* Permafrost, the North American contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, National Academy of Sciences, p. 166-170.

Priesnitz, K., and Schunke, E., 1978, An approach to the ecology of permafrost in central Iceland, *in* Third International Conference on Permafrost, 1978, Proceedings, Edmonton, Alberta: National Research Council of Canada, v. 1, p. 473-479.

Rapp, Anders, and Annersten, Lennart, 1969, Permafrost and tundra polygons in northern Sweden, *in* Péwé, T.L., ed., The periglacial environment, past and present: Montreal, McGill University Press, p. 65-91.

Rockie, W.A., 1942, Pitting on Alaskan farm lands; new erosion problem: Geographical Review, v. 32, p. 128-134.

Scott, R.F., 1959, Freezing of slurry around piles in permafrost: American Society of Civil Engineers Proceedings, v. 85, no. SM-4, pt. 1, p. 1-10.

Sellman, P.V., 1967, Geology of the U.S. Army Cold Regions Research and Engineering Laboratory permafrost tunnel, Fairbanks, Alaska: U.S. Army Materiel Command Cold Regions Research and Engineering Laboratory Technical Report 199,

______________, 1972, Geology and properties of materials exposed in the U.S. Army Cold Regions Research and Engineering Laboratory permafrost tunnel: U.S. Army Material Command Cold Regions Research and Engineering Laboratory Special Report 177, 14 p.

Taber, Stephen, 1929, Frost heaving: Journal of Geology, v. 37, p. 428-461.

______________, 1930, The mechanics of frost heaving: Journal of Geology, v. 38, p. 303-317.

U.S. Army Corps of Engineers, 1946, Airfield pavement design---frost conditions, *in* An interim engineering manual for War Department construction: U.S. Army Crops of Engineers, pt. 12, ch. 4.

______________, 1947, Report on frost investigation, 1944-1945: U.S. Army Corps of Engineers, 66 p.

______________, 1949, Addendum 1, 1945-1947, report on frost investigation, 1944-1945: U.S. Army Crops of Engineers, 50 p.

______________, 1954, Arctic and subarctic construction of building foundations, *in* Engineering manual for War Department construction: U.S. Army Corps of Engineers, pt. 15, ch. 4, 14 p.

______________, 1956, Engineering problems and construction in permafrost regions, *in* The dynamic north: U.S. Office of Naval Operations, Polar Projects, Book 2, OPNAY P03-17, 53 p.

U.S. Geological Survey, 1972, Permafrost: Information Pamphlet 72-25 (R2).

Wallace, R.E., 1948, Cave-in lakes in the Nabesna, Chisana, and Tanana River valleys, eastern Alaska: Journal of Geology, v. 56, p. 171-181.

Washburn, A.L., 1956, Classification of patterned ground and review of suggested origins: Geological Society of America Bulletin, v. 67, no. 7, p. 823-866.

Weidick, Anker, 1968, Observations on some Holocene glacier fluctuations in west Greenland: Meddelelser om Gronland, v. 165, no. 6, p. 1-202.

Williams, J.R., 1959, Geology of the western part of the Big Delta D-6 Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-297, scale 1:63,360.

Williams, J.R., Péwé, T.L., and Paige, R.A., 1959, Geology of the Fairbanks D-1 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-124, scale 1:63,360.

GROUND WATER

PRELIMINARY STATEMENT

Hazards associated with ground-water movement are complicated by the presence of permafrost and by the severe northern climate. Such complications include the creation of pingos, ice or frost blisters, seasonal icings (aufeis), and the uncontrolled flow of artesian wells. Ground-water movement may also affect permafrost near structural foundations.

Because permafrost acts as an impermeable barrier to ground-water movement, recharge and discharge in permafrost areas are limited to unfrozen zones that perforate the frozen ground. In areas of thick permafrost, few shallow wells exist. Ground-water temperatures range from 32° to 35°F, and as a result, ground water is slightly more viscous and moves more slowly than in temperate regions.

GROUND WATER IN THE FAIRBANKS AREA

PRELIMINARY STATEMENT

Most commercial and domestic wells in the Fairbanks area are less than 100 feet deep but some extend to a depth of 400 to 500 feet. Until 1953, no extensive, central, year-round water-distribution system existed, and water was entirely supplied by individual wells. Since 1953, parts of Fairbanks have been supplied by a circulating water supply. Outside of Fairbanks and Fort Wainwright, individual wells are still the prime source of water, although College Utilities now supplies sewer and water service to much of the College area west of Fairbanks.

In small-diameter wells that penetrate thick permafrost, water tends to freeze as easily in July as in January, especially if the wells are not used for several weeks. Because the temperature of the steel pipe in these wells is at or below the freezing point of water, ideal conditions exist for the freezing of stationary or slow-moving water. The more often the well is used, the less likely the water is to freeze. Wells that become frozen, or begin to freeze, were previously thawed with steam (fig. 62), but today many wells are kept open with electrical heating tapes.

General areas of uniform ground-water conditions are the flood plains of the Tanana and Chena Rivers, the bedrock hills, and the lower hillslopes and creek-valley bottoms. The latter include organic-rich silt lowlands at the base of the hills (fig. 63). Topographic position, water-bearing properties of the rocks and sediments, and distribution of permafrost are prime factors controlling ground-water distribution.

TANANA AND CHENA RIVER FLOOD PLAINS

The alluvial fill of the Tanana and Chena River valleys is a tremendously large ground-water reservoir that has been extensively exploited in the Fairbanks area. Alluvial deposits consist of several hundred feet of interbedded layers of silt, sand, and gravel. Although the aquifer is generally very permeable, ground-water distribution is controlled by the discontinuous occurrence of permafrost (fig. 3), which, when coupled with the lenticular nature of the alluvium, accounts for differences in water quantity and quality in proximate wells. Perennially frozen alluvium is generally absent beneath younger sloughs and modern rivers and on the inside of river meanders. The water table is normally 10 to 15 feet below the surface in unfrozen alluvium.

Water is supplied to many residents in the Fairbanks area by hundreds of small-diameter (2-inch) private wells (fig. 64). Some 2-inch wells yield as much as 40 gallons per minute and records indicate that yields as high as 3,000 to 3,400 gallons per minute with a drawdown of 10 to 15 feet are available through large-diameter wells less than 100 feet deep. Many wells are only 15 to 30 feet deep and draw water from above permafrost or from unfrozen zones within permafrost. Other 100- to 250-foot-deep wells draw water from unfrozen sediments below the frozen layer. Large yields are available in gravel layers above and below permafrost.

The quality of water from wells on the flood plain ranges from very good to very poor. Most wells yield a rather hard water rich in calcium bicarbonate and high in iron content. The iron may be detected by taste; it also stains plumbing fixtures, utensils, and clothing.

UPLAND HILLS

Bedrock hills adjacent to the flood plains of the Tanana and Chena Rivers are covered by 3 to 200 feet of loess. As a result of topographic relief and its fair to good vertical permeability, the unfrozen loess is well drained; thus no productive wells have been reported in this sediment. Most hillside wells tap water from the underlying bedrock, where the reservoirs are primarily controlled by fractures, joints, and fractured quartz veins whose location and frequency are very poorly known.

In general, the water table in the upland hills is deep because of the great relief relative to the valley bottoms. In most places the water table is generally 100 to 200 feet above the adjacent valley floor and wells are 300 to 500 feet deep. In some hill locations, more shallow perched water zones occur along fracture zones or above

Figure 62. Portable steam boiler for thawing wells and sewers, Lacy and Fifth Streets, Fairbanks. This city-operated steam boiler was regularly used to thaw wells and sewers prior to the establishment of a city water system. It was equipped with wheels in summer and runners in winter. Freezing of wells and sewers is not uncommon in the Fairbanks area today. Photograph 329 by T.L. Péwé, June 30, 1948.

local permafrost. The yield from bedrock is very low, normally less than 10 gallons per minute. The quality of water from bedrock is generally good with a low iron content; locally the arsenic content may be high.

Recent research indicates that arsenic concentrations in ground water in the Fairbanks area range from 0 to 10,000 micrograms per liter. Although ground water exceeding the State of Alaska and Environmental Protection Agency levels for safe drinking water (one ounce in about 148,600 gallons) has not been found in the flood plains, many wells in the uplands north of town yield dangerously high concentrations of arsenic. The primary source of arsenic and the mechanisms by which it enters the ground water are not completely known, but mineralized bedrock in the Fairbanks area commonly contains arsenopyrite, an arsenic-bearing mineral. This mineral is probably the source of the arsenic, because all wells with arsenic concentrations higher than the U.S. Public Health Service standards are in bedrock. Homeowners with wells in bedrock should be aware of the sporadic distribution of the arsenic-contaminated waters and realize the potential health hazard of this element. Arsenic dissolved in water is colorless and odorless and is not removed by commonly used water-treatment systems.

LOWER HILLSLOPES AND CREEK-VALLEY BOTTOMS

The organic silt that has accumulated in up to 360-foot thicknesses in upland valleys is a very poor water-bearing formation. Because of its high organic content and low permeability, ground water obtained from the silt is undesirably high in iron, hardness, and

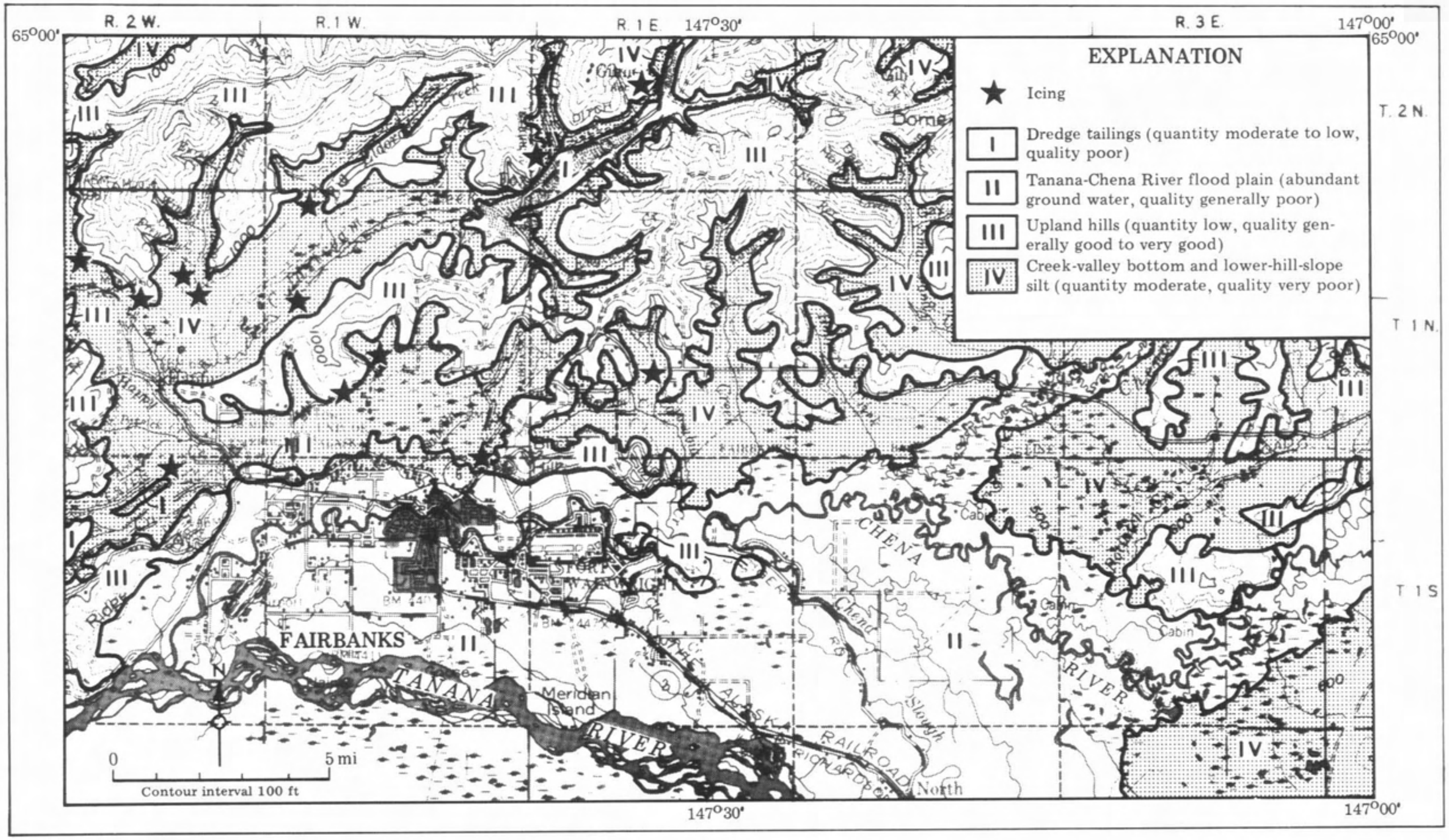

Figure 63. Ground-water map of the Fairbanks area, Alaska (modified from Péwé, 1958; Williams, Péwé, and Paige, 1959).

Figure 64. Driving a 2-inch-diameter well at 819 Seventh Street, Fairbanks. Before World War II, and until about the 1950's, it was common to develop a well on the flood plain (fig. 2) by driving a perforated pipe 20 to 40 feet into the alluvium. Today this technique is used on the flood plain in outlying areas, but a municipal water system provides water within the city limits. Water from shallow wells is often contaminated. Photograph 314 by T.L. Péwé, July 17, 1948.

organic taste.

Ground water in areas of lower hillslopes and creek-valley bottoms is primarily controlled by permafrost distribution. Nearly all valley-bottom silt is continuously frozen to a maximum known depth of more than 360 feet; depth to permafrost is generally 1 1/2 to 3 feet below ground surface but may be as much as 25 feet under cleared areas. Ground water can be found above, below, and occasionally within the permafrost.

In many of the large upland creek valleys, the valley-bottom muck (silt washed down from the hillslopes) is underlain by as much as 100 feet of creek gravel. This gravel, which usually lies beneath 30 to 300 feet of valley-bottom silt, can provide abundant quantities of water if not perennially frozen (fig. 65). However, permafrost commonly extends through the gravel into bedrock, and thus prevents the gravel from serving as an aquifer.

Whether the gravel is frozen or unfrozen is of great importance to miners interested in underground workings. If frozen, the ground may be excavated without fear of mine flooding. Figure 66 illustrates how the geologist may indicate the distribution and thickness of permafrost and shows, in detail, information about ground water and sediment type. Scientists and engineers use this type of map when advising individual homeowners, highway and pipeline planners, and contractors, miners, and farmers.

GEOLOGIC HAZARDS ASSOCIATED WITH GROUND-WATER MOVEMENT IN PERMAFROST REGIONS

PRELIMINARY STATEMENT

Alexander Alexandervitch Tihonrovov was showering in a heated bathhouse one winter day in a northern valley in Siberia. As he washed, he noted cold water welling up between the floor boards and covering the floor. He rushed outside into the subzero weather and watched as water poured from the windows. The water quickly froze, and soon the building was filled with ice; ice 'waterfalls' draped from the windows to the ground (fig. 67). This is not an unusual story, and examples are known from Siberia and North America.

But what destroyed the house? As illustrated in figure 67, this type of icing results from ground-water movement in a permafrost terrain. In this instance, as winter progressed, shallow ground water under hydrostatic head percolated downhill above the permafrost table, and was trapped between the underlying permafrost and the ever-thickening seasonal-frost layer. The only place the pressurized water could escape was beneath the heated house.

Other hazards from moving ground water include the uncontrolled flow of artesian water, the formation of ice sheets (icings) on roads, under bridges, and on rivers, and the development of ice blisters and pingos. The Fairbanks area, unfortunately, is well situated for the formation of these geologic hazards, and if careful geologic and engineering investigation and maintenance are not undertaken, hundreds of thousands of dollars can be lost.

ARTESIAN WELLS

In hilly areas precipitation is absorbed and percolates downslope as ground water. In areas of discontinuous permafrost, ground water on lower slopes flows beneath and is confined by the frozen layer. Several borings through permafrost in the Fairbanks area have produced artesian-water flow.

Artesian wells occur on lower slopes just a short distance below the boundary between permafrost and nonpermafrost areas (fig. 68). At least a dozen such artesian wells are known north of Fairbanks and in outlying creek valleys; eight artesian wells have been reported in the upper Isabella Creek area near Steese, McGrath, and Farmers Loop Roads (fig. 65). Artesian water occurs in sandy gravel, bedrock, or less often, in silty sand.

Several artesian wells that flowed without control for some time created serious problems. The most well-documented artesian well in the Fairbanks area was drilled in May 1946 to a depth of 108 feet at the U.S. Army Cold Regions Research and Engineering Laboratory Experimental Station on Farmers Loop Road (fig. 65). Two dry wells, each 165 feet deep, were drilled that year. The third hole encountered water under such high hydrostatic pressure that it gushed about 4 feet above the ground surface, carrying gravel particles as large as 2 inches in diameter. Later measurements indicated that the water pressure was equivalent to a ground level 28 feet above the existing ground surface (fig. 69). The hole was immediately cased, but water flow outside the casing thawed the surrounding permafrost.

After a slurry of 40 bags of cement was pumped down the casing to seal the well, a 40,000-gallons-per-hour pump was used to remove the water, and a 10-foot-square, 12-inch-thick, concrete slab was placed around the main casing (fig. 69). By mid-June 1946 the well was sealed. Later, it froze shut, was reopened, and again froze a number of times. In 1947 the well was thawed and was used that summer and during part of 1948. In August 1948 the final loss of control occurred. Water began escaping from beneath the 10-foot-square, concrete slab, and during the summer of 1949 the slab collapsed into an enormous, water-filled thermokarst cavity. Eventually the slab sank as much as 25 to 50 feet below the surface. Much of the unrestrained artesian water flowed downhill, underneath the surface, but above the permafrost table. Subsequent thawing of permafrost caused the overlying ground to subside

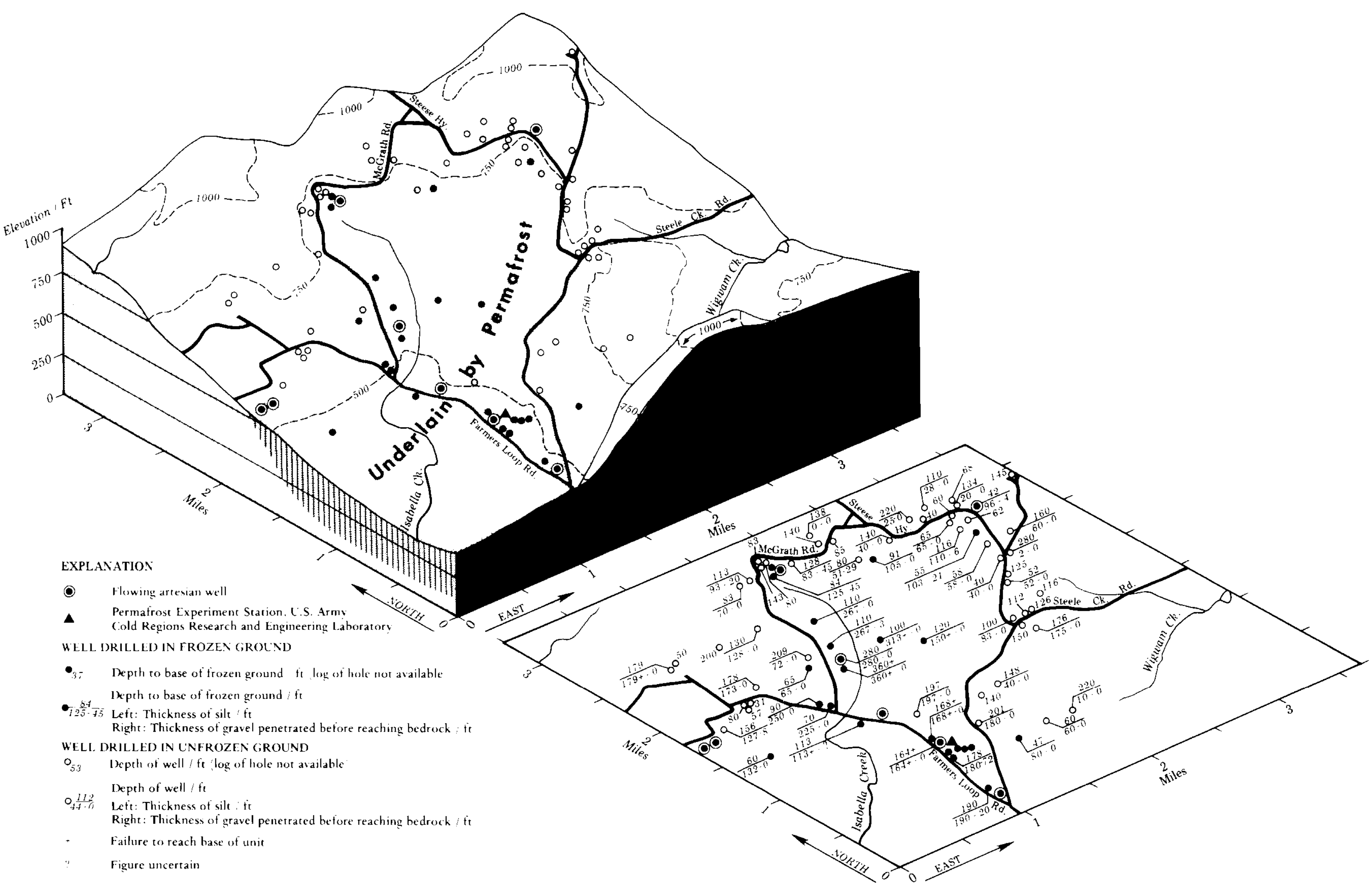

Figure 65. Map of upper Isabella Creek valley in the Farmers Loop Road, McGrath Road, and Steese Highway area 2 miles north of Fairbanks, showing location and thickness of permafrost and location and depth of wells.

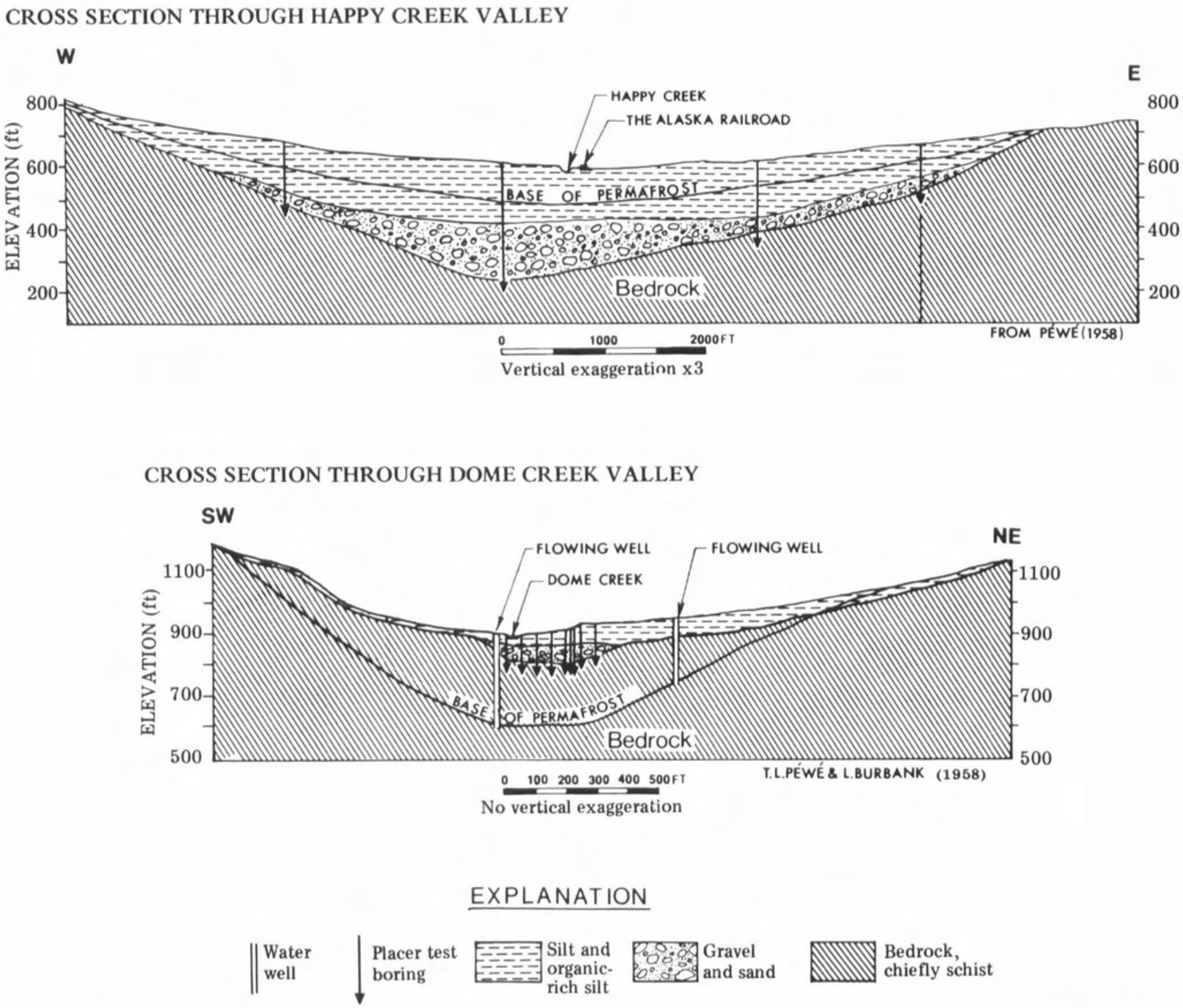

Figure 66. Geologic cross sections through Happy Creek valley 5 miles northwest of Fairbanks and through Dome Creek valley 20 miles north of Fairbanks, showing distribution of permafrost and ground water. In the Happy Creek area, ground water occurs in unfrozen gravel beneath the permafrost. In Dome Creek valley, the base of the permafrost is in the underlying bedrock; wells draw their water from below the perennially frozen zone in this bedrock. Because unfrozen recharge areas exist uphill from the creek valley, and because the overlying permafrost acts as a confining layer, artesian water conditions exist and flowing wells are present (modified from Williams, 1970).

and the permafrost table was lowered 12 feet in some affected locations. Permafrost supporting adjacent structures was warmed and threatened to thaw, and silt washed from underneath Farmers Loop Road caused the road to subside.

One of the most serious hazards resulting from this uncontrolled artesian well was the formation of an icing, which will be discussed in the next section. Dense ice fog also developed as relatively warm water vapor reacted with cold winter air. Problems connected with the well continued into 1950, when control was finally re-established by using freeze probes and mechanical refrigeration to refreeze the ground around the well. The well was then abandoned.

K.A. Linell (written commun., June 1, 1978) of the U.S. Army Cold Regions Research and Engineering Laboratory estimated that about $5,000 ($15,000 in 1980-equivalent dollars) in federal and state funds were spent attempting to control water flow and repair the damages created by erosion, icings, subsidence, and flooding. Records of the cost of the final refreezing are no longer available.

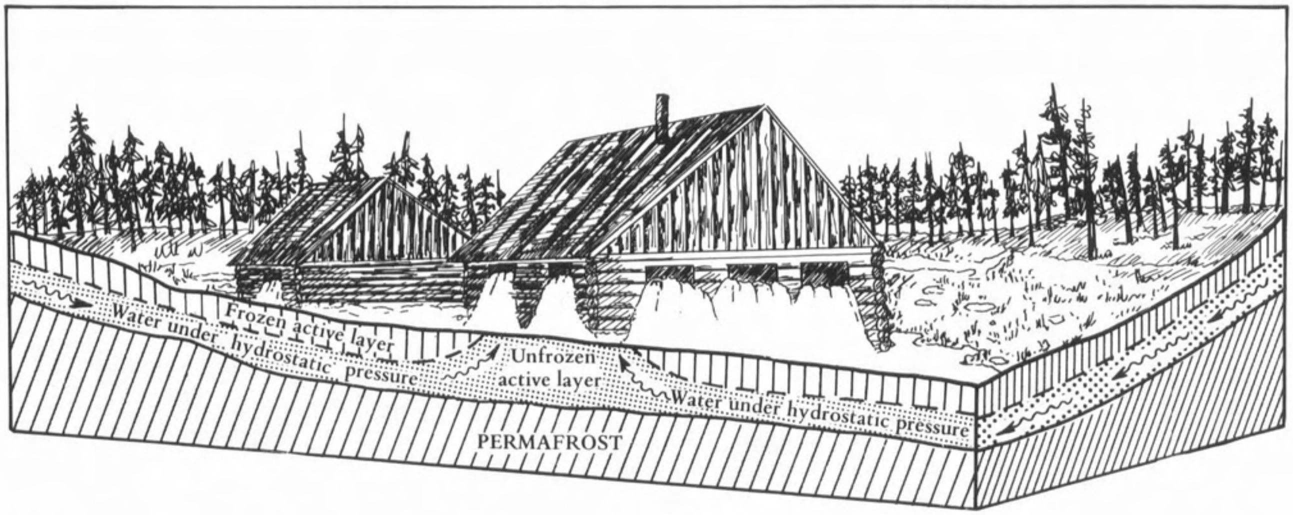

Figure 67. Water moving downslope under hydrostatic pressure is trapped between the thickening seasonal-frost layer and underlying permafrost table. The unfrozen ground beneath the heated building provides an exit for the water, and it bursts through the floor, filling the building and pouring out the windows into the subzero weather. As the water freezes, the building is filled with ice (modified from Muller, 1945).

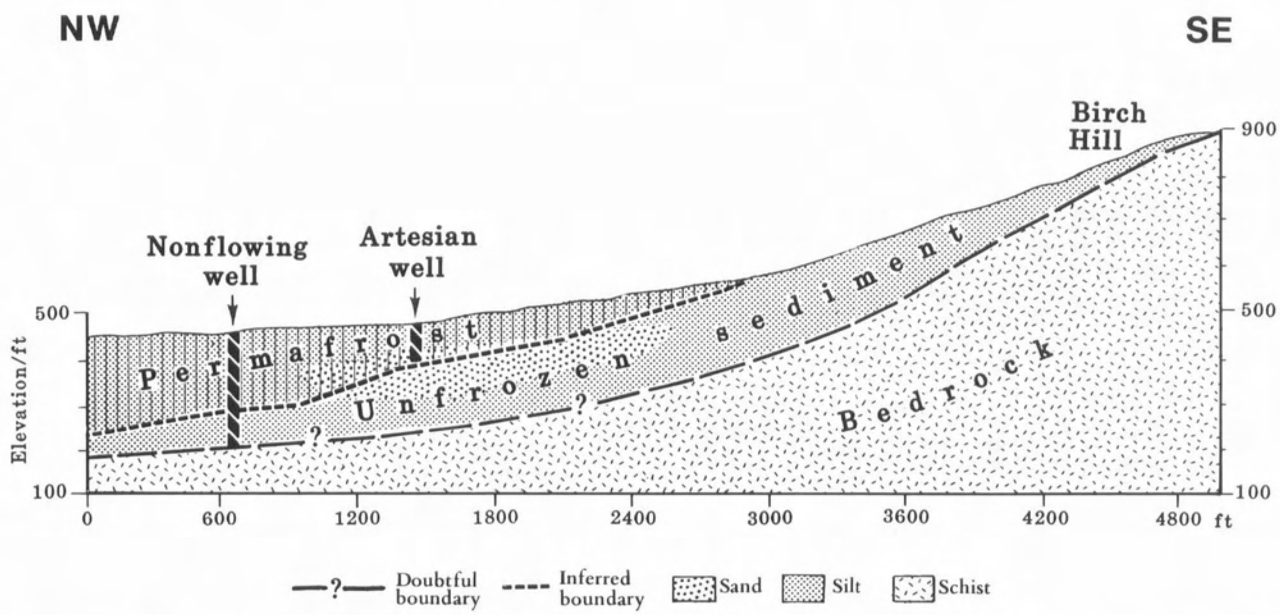

Figure 68. Diagrammatic sketch of geology and ground-water conditions at site of artesian well at U.S. Army Cold Regions Research and Engineering Laboratory Experimental Station on Farmers Loop Road north of Fairbanks. The permafrost acts as a confining layer for ground water that originates as precipitation falling on the unfrozen upper slopes of Birch Hill.

ICINGS

In arctic and subarctic regions, water reaching the ground surface each winter from a river, spring, or well may freeze in successive sheets until the ice is several feet thick and covers a large area. These ice sheets are a serious hazard in the Fairbanks area where they have been the cause of great losses of property and have created dangerous conditions. Termed icings, these irregular sheets, mounds, or encrustations of ice form on slopes and in valleys. Icings have been called naledi in the USSR, and aufeis in the German literature; unfortunately, in Alaska they have been informally called glaciers, which is technically incorrect. Actually, an icing

Figure 69. Hose held up to show flowing artesian water from well drilled in 1946 at the U.S. Army Cold Regions Research and Engineering Laboratory Experimental Station on Farmers Loop Road north of Fairbanks. D.G. Cederstrom of the USGS (holding hose) is standing on a 10-foot-square, 1-foot-thick concrete pad that was placed around the casing to contain the well. Eventually, escaping underground artesian water thawed a huge pit; the block cracked, then turned on end and sank out of sight. Photograph PK 655 by T.L. Péwé, July 11, 1947.

is a coating or a crust of ice that is at least superficially similar to the icing on a cake.

Most icings are less than a few hundred yards long, but some, especially in river valleys, may be enormous, covering several square miles. Ice sheets are ordinarily 2 to 3 feet thick, but they may be up to 30 feet thick, and icing mounds may be as high as 50 feet. Some rare icings in Siberia are reported to be as much as several hundred feet thick.

Most icings melt during the summer and form again the following winter. Conditions favorable for the formation of icings are: a) the presence of ground water moving downslope, especially above the permafrost table, b) cold air temperatures and thin snow cover during the early winter, c) a layer of seasonally frozen ground, and d) thick snow cover during the late winter.

For the purpose of this report, icings are separated into two major categories. Seepage icings are ice sheets that form from any source of seepage water on the surface of slopes or flatlands; they are not associated with a creek or river. Stream icings are formed on flood plains or surfaces of low stream terraces by water confined to a small or large stream valley.

SEEPAGE ICINGS

Ground water that seeps or flows onto the ground surface in winter may be a natural phenomenon, or it may result from human activity. Man produces ground-water flows or seeps by drilling wells, intercepting the ground-water table in road cuts, or influencing the rate and depth of seasonal-frost penetration by building roads and railroads.

Uncontrolled artesian wells often result in the formation of disruptive icings. As mentioned earlier, a well drilled in 1946 at the U.S. Army Cold Regions Research and Engineering Laboratory Experimental Station on Farmers Loop Road resulted in icings in 1948 and 1949. The icings were as much as 5 feet thick and covered several acres, including access roads and about backed up and breaks through ice fissures and thin ice sheets form over the existing ice.

On wide streams, icings thousands of acres in extent and many feet thick may occur. As the ice thickens, it inundates the flood-plain surface and may spread over roads and flood adjacent buildings. Prior to construction of high, modern bridges over major streams in central Alaska, annual icings covered highway bridges to depths of from 10 to 15 feet. Each spring, the artificial removal of this ice was a spectacular event.

As icings thaw in the spring, snow melt increases stream flow, and some streams are diverted around the icing beyond the normal flood plain, causing severe erosion of highways and bridges, or undermining buildings.

Stream icings on large flood plains are uncommon in the Fairbanks area, but a serious icing did occur in the winter of 1975-76 where Plack Road crosses Chena Slough just north of Badger Road (fig. 71). The channel of Chena Slough filled with ice and when water escaped beyond the low banks, the icing area was extended. As ice and water invaded the lower level of a home near the south bank of the slough, bicycles, tables, refrigerators and other objects were buried to a depth of about 3 feet (figs. 72-74). Because this icing occurred at least twice, the house probably should be moved. Seventy-thousand dollars is probably a conservative estimate of the damage.

During winter, a common icing form occurs on small streams in the Fairbanks area, especially where they cross highways. Streamwater freezes to the creek bottom, blocking flow and causing the small valley to rapidly fill with ice. Generally, the water freezes at a constriction caused by a culvert or small bridge (figs. 75a,b) and these areas of the stream are soon blocked by ice. The resulting icing inundates the road or

Figure 71. Aerial view of the Chena Slough and Plack Road vicinity on the Chena-Tanana Rivers flood plain in the eastern Fairbanks area. Icings filled the slough until overflow inundated the house in center of photograph. Photograph by Thomas Keever, winter 1975-76.

Figure 72. View of Chena Slough side of home inundated by water and seasonal icing. Photograph by Thomas Keever, winter 1975-76.

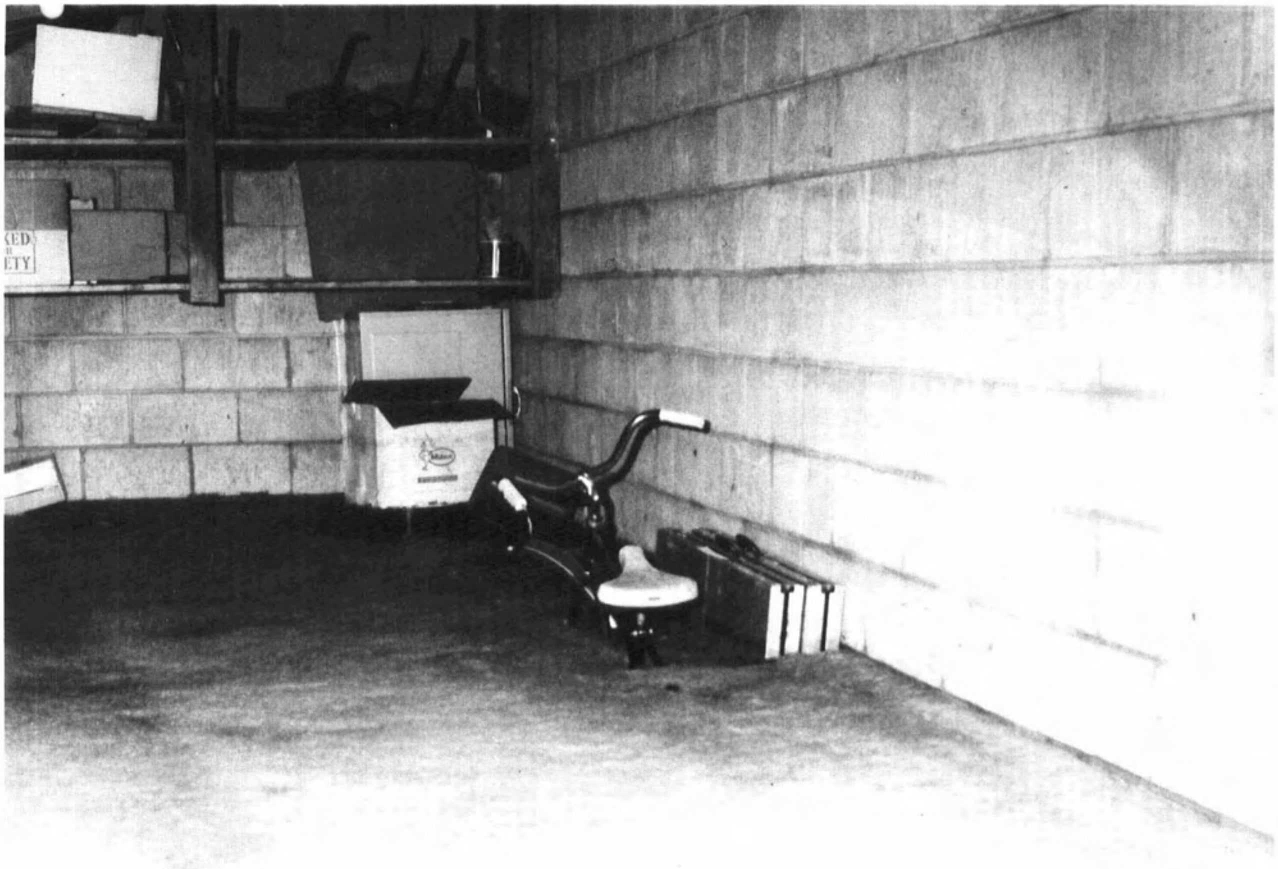

Figure 73. Garage interior of home in figure 72 showing objects buried to a depth of at least 3 feet by a stream icing in the vicinity of Chena Slough and Plack Road. Photograph by Thomas Keever, winter 1975-76.

railroad surface. These icings require constant removal of enough ice to maintain an open channel and prevent ice accumulation.

Icings may also form where stream channels are modified by man. During February 1978, after the natural course of Campbell Creek (near Anchorage) was modified, a mixture of creek water and septic-tank effluent began to freeze into a creeping ice flow similar to a science-fiction green slime. Because such effects are not unusual, stream modifications should be carefully planned with consideration of the potential for winter icing problems.

SUMMARY OF ICINGS

It is readily apparent that icings constitute a serious geologic hazard that must be battled annually by highway and railway engineers in central Alaska. The cost of maintenance and property damage may be reduced in some areas by a careful understanding of the origin of icings and of possible solutions. Whether one is planning a house, a road to one's property, or a multimillion-dollar project, the planning process must involve engineers, geologists, or architects who are aware of this winter hazard.

PINGOS

Pingos form when massive ice lenses grow in permafrost near the ground surface. The two types of pingos include the larger closed-system form, which occurs in regions of continuous permafrost (fig. 76), and smaller open-system pingos.

Closed-system pingos form in nearly level areas, generally in partly filled lake basins, when unfrozen ground water migrates under pressure to a freezing site.

Figure 74. View of garage of home in figures 72-73 after water level of Chena Slough dropped. Photograph by Thomas Keever, spring 1976.

As the permafrost is domed by the ice lens, a mound forms. Open-system pingos generally form on sloping ground where water under intense hydraulic pressure penetrates permafrost and heaves the overlying material to form a mound. These pingos are common in central Alaska and are the only pingos reported in the Fairbanks area. Although more than 700 open-system pingos have been identified in central Alaska, only six have been reported in the Fairbanks area, where they occur in silty sediments. Because open-system pingos have a summit crater enclosing a pond, many have been confused with meteorite-impact craters or thermokarst pits.

Five small open-system pingos occur in Goldstream Valley near the lower end of a low-angle alluvial fan from O'Connor Creek (figs. 25, 63). The largest and southernmost of the pingo group---informally named Alpha pingo---is an elliptical mound about 350 feet long, 220 feet wide, and 34 feet high. A breached 20-foot-deep crater is located on the northwestern side and radial and concentric cracks 1 to 3 inches wide and 10 feet long occur on the flanks. Radial cracks 2 to 150 feet long trend across the surface of the pingo (fig. 77).

The smaller Beta pingo, which has no center depression, is located about 400 feet northeast of Alpha pingo. On its steep and actively slumping south side, growing trees are deformed and several trunks have split. It is not known if the pingo surface is rising, but the south side is slumping because of thawing at the base. The rate of movement is not known.

Three smaller pingos are located north and west of Beta pingo on an alluvial fan of retransported organic-rich silt. Silt in a nearby drill hole is 90 feet thick and overlies 50 feet of creek gravel; permafrost is 140 feet thick. Ground water under the fan feeds the pingos, which undoubtedly have ice cores. A large collapsed pingo containing a shallow pond with numerous mud

Figure 75a. Downstream view of Moose Creek from Murphy Dome Road, 12 miles northwest of Fairbanks in Goldstream Valley, showing typical open, broad, shallow channel during summer and fall. Photograph by H.R. Livingston, October 4, 1966.

Figure 75b. Downstream view of bridge in figure 75a showing stream icing filling channel and forming on roadway. Photograph by H.R. Livingston, March 25, 1971.

springs is located about 1,000 feet northwest of this pingo group and is fed by underground water from the north. The pit is almost surrounded by fresh concentric cracks bordering blocks of silt that are slumping toward the pond as the ice core thaws.

A spruce-covered pingo on the south side of Farmers Loop Road (fig. 22) is in a proposed housing development. An attempt to construct a home on this pingo was abandoned after massive ice was encountered during basement excavation.

Pingos constitute a special permafrost hazard in the Fairbanks area. As with other types of ice-rich permafrost, pingos do not become a problem until the vegetation cover or topography is altered. Highway contractors may unwittingly attempt to dissect a pingo, as was done on the Denali Highway south of the Alaska Range, or perhaps worse, an unwary builder may site a heated building on the crest of a pingo. In addition to the subsidence that results from the melting of the ice core, ground-water flow from summit springs can produce hazardous icings.

SELECTED REFERENCES

Cederstrom, D.J., 1963, Ground-water resources of the Fairbanks area, Alaska: U.S. Geological Survey Water-Supply Paper 1590, 84 p.

Cederstrom, D.J., and Péwé, T.L., 1960, Ground-water data, Fairbanks, Alaska: Alaska Department of Health, Sanitation, and Engineering Section, in cooperation with U.S. Geological Survey, 28 p.

Cederstrom, D.J., and Tibbitts, G.C., Jr., 1961, Jet drilling in the Fairbanks area, Alaska: U.S. Geological Survey Water-Supply Paper 1539-B, 28 p.

Holmes, G.W., Hopkins, D.M., and Foster, H.L., 1968, Pingos in central Alaska: U.S. Geological Survey Bulletin 1241-H, 40 p.

Hopkins, D.M., Karlstrom, T.N.V., Black, R.F., Williams, J.R., Péwé, T.L., Fernald, A.T., and Muller, E.H., 1955, Permafrost and ground water in Alaska: U.S. Geological Survey Professional Paper 264-F, p. 113-146.

Johnson, P.R., Wilcox, D.E., Morgan, W.D., Merto, Josephine, and McFadden, Ruth, 1978, Arsenic, nitrate, iron, and hardness in ground water, Fairbanks area, Alaska: U.S. Geological Survey Open-file Report 78-1034, scale 1:24,000.

Kane, D.L., and Slaughter, C.W., 1973, Recharge of a central Alaska lake by subpermafrost ground waters, *in* Permafrost, the North American contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, National Academy of Sciences, p. 458-461.

Krinsley, D.B., 1965, Birch Creek pingo, Alaska: U.S. Geological Survey Professional Paper 525-C, p. C133-C136.

Krumhardt, A.T., 1979, Arsenic, nitrate, iron, and hardness in ground water, Chena Ridge vicinity, Fairbanks area, Alaska: U.S. Geological Survey Open-file Report 80-49, scale 1:24,000.

Linell, K.A., 1973, Risk of uncontrolled flow from wells

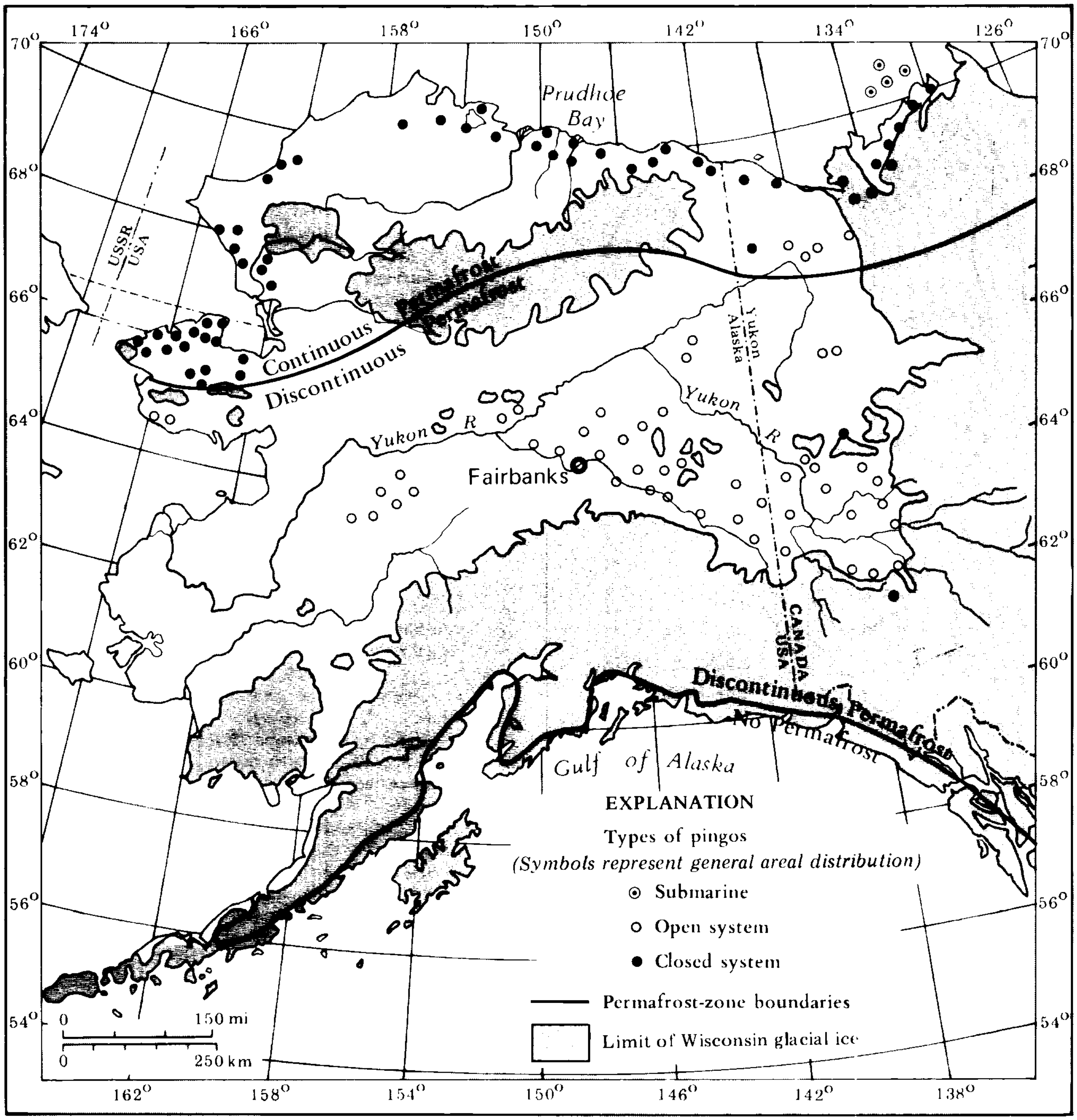

Figure 76. Distribution of open- and closed-system pingos in relation to permafrost zones and areas covered by Wisconsin glacial ice in northwest North America. The origin of pingo-like forms in shallow seas off northwestern Canada is not yet established (oral commun., A.S. Judge, March 3, 1981).

through permafrost, *in* Permafrost, the North American contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, National Academy of Sciences, p. 462-468.

Livingston, Hal, and Johnson, Eric, 1978, Insulated roadway subdrains in the subarctic for prevention of spring icings: Fairbanks, Alaska Department of Transportation and Public Facilities, unpublished report, 9 p.

Mackay, J.R., 1973, The growth of pingos, western arctic coast, Canada: Canadian Journal of Earth Sciences, v. 10, no. 6, p. 979-1004.

Muller, Fritz, 1959, Beobachtung uber pingos [Observations on pingos]: Meddelelser om Grønland, v. 153, p. 1-127, National Research Council of Canada Technical Translation 1073, 117 p.

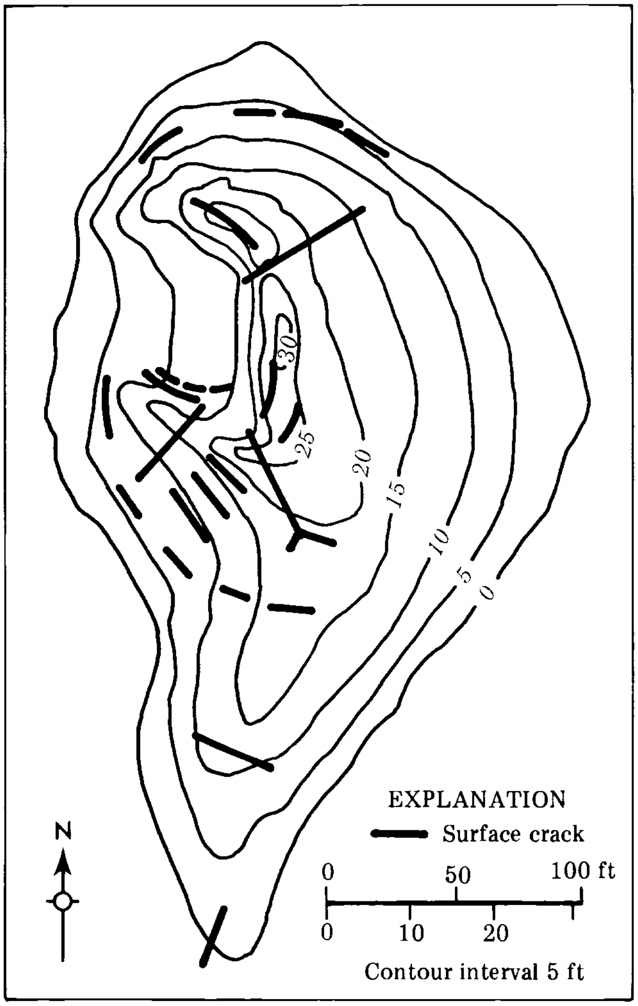

Figure 77. Sketch map of Alpha pingo in Goldstream Valley near junction of Goldstream and O'Connor Creeks northwest of Fairbanks. The pingo is composed of silt; note the breached 'crater' on the northwest flank. The elevation is approximately 600 feet and permafrost is present 3 to 10 feet below the ground surface (modified from Péwé, 1977).

Muller, S.W., 1945, Permafrost or permanently frozen ground and related engineering problems: U.S. Engineers Office, Strategic Engineering Study Special Report 62, 136 p., reprinted in 1947, Ann Arbor, Mich., J.W. Edwards, Inc.

Nelson, G.L., 1978, Hydrologic information for land-use planning, Fairbanks vicinity, Alaska: U.S. Geological Survey Open-file Report 78-959, 47 p.

Nichols, D.R., 1956, Permafrost and ground-water conditions in the Glennallen area, Alaska: U.S. Geological Survey Open-file Report 392, 18 p.

Péwé, T.L., 1948, Permafrost investigations, Fairbanks area, Alaska: U.S. Geological Survey Permafrost Program Report, U.S. Army Engineering Intelligence Division, Office of Chief Engineer, 16 p.

_____________, 1955, Middle Tanana Valley, *in* Hopkins, D.M., Karlstrom, T.N.V., Black, R.F., Williams, J.R., Péwé, T.L., Fernald, A.T., and Muller, E.H., Permafrost and ground water in Alaska: U.S. Geological Survey Professional Paper 264-F, p. 113-144.

_____________, 1958, Geology of the Fairbanks D-2 Quadrangle, Alaska: U.S. Geological Survey Geological Survey Geologic Quadrangle Map GQ-110, scale 1:63,360.

_____________, 1977, Guidebook to the Quaternary geology of central and south-central Alaska: College, Alaska Division of Geological and Geophysical Surveys, 141 p.

Péwé, T.L., and Bell, J.W., 1975a, Map showing ground water conditions in the Fairbanks D-2 NW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-668B, scale 1:24,000.

_____________, 1975b, Map showing ground water conditions in the Fairbanks D-2 SE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-669B, scale 1:24,000.

_____________, 1975c, Map showing ground water conditions in the Fairbanks D-2 NE Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-670B, scale 1:24,000.

_____________, 1975d, Map showing ground water conditions in the Fairbanks D-1 SW Quadrangle, Alaska: U.S. Geological Survey Mineral Investigations Field Studies Map MF-671B, scale 1:24,000.

_____________, 1976, Map showing ground water conditions in the Fairbanks D-2 SW Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-829C, scale 1:24,000.

Porsild, A.E., 1938, Earth mounds in unglaciated Arctic northwestern America: Geographical Review, v. 28, p. 46-58.

Sloan, C.E., Zenone, Chester, and Mayo, L.R., 1976, Icings along the Trans-Alaska Pipeline route: U.S. Geological Survey Professional Paper 979, 31 p.

Williams, J.R., 1953a, Icings in Alaska, 1949-50: U.S. Geological Survey in cooperation with U.S. Army Engineering Intelligence Division, Office of Chief Engineers, Engineering Notes, no. 32, 23 p.

_____________, 1953b, Observation on river-ice conditions near highway bridges in Alaska, winter 1949-50: U.S. Geological Survey in cooperation with U.S. Army Engineering Intelligence Division, Office of Chief Engineers, Engineering Notes, no. 30, 40 p.

_____________, 1965, Ground water in permafrost regions - an annotated bibliography: U.S. Geological Survey Water-Supply Paper 1792, 294 p.

_____________, 1970, Ground water in the permafrost regions of Alaska: U.S. Geological Survey Professional Paper 696, 83 p.

Williams, J.R., Péwé, T.L., and Paige, R.A., 1959, Geology of the Fairbanks D-1 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-124, scale 1:63,360.

Williams, J.R., and van Everdingen, R.O., 1973, Ground water investigations in permafrost regions of North America: A review, *in* Permafrost, the North American contribution to the Second International Conference, Yakutsk, Siberia, USSR: Washington, National Academy of Sciences, p. 435-446.

EARTHQUAKES

INTRODUCTION

As the earthquake shook the city and the chandelier in the dining room swung from side to side, my wife said to herself, "when it hits the ceiling I will put snowsuits on the children and go out into the road before the shaking gets any worse." Soon they were out on the street. This was only one family's reaction in Fairbanks to the 1964 Alaska earthquake---the largest ever recorded on the North American continent---whose epicenter was located 250 miles to the south in Prince William Sound.

Earthquakes are one of our most damaging geologic hazards and, as a result, they account for great loss of life and property. Only a small percentage of the estimated one million earthquakes per year is felt or cause any damage, and on the average only one or two cause catastrophic damage somewhere in the world.

CAUSES AND LOCATIONS OF EARTHQUAKES

The crust of the earth consists of several large and small sections, or plates, that move horizontally at rates of up to several inches per year. As these plates move past each other, tremendous stresses build in the rock. When the stress exceeds the strength of the rocks, they break and an earthquake results.

Most earthquakes are produced by frictional sliding along preexisting breaks. This condition is comparable to two rough-surfaced boards being pressed together while they are pushed past each other. The rough surfaces prevent movement until the shear stresses overcome this resistance and a sudden slip occurs. The sudden slip of rocks along these breaks, called faults, releases energy in the form of seismic waves that are recorded as earthquakes. Some earthquakes are associated with volcanic activity.

Alaska is part of the Circum-Pacific seismic belt, one of three worldwide seismic belts (fig. 78). More than 7 percent of the annual seismic-energy release in the world occurs in the Alaska seismic zone. Approximately 6 percent of the world's large, shallow earthquakes (depth less than 50 miles) occur in continental Alaska and the Aleutian Islands. Parts of Alaska situated within the Circum-Pacific belt are probably more earthquake prone than California with its well-known San Andreas fault. Although interior Alaska is not regarded as particularly earthquake prone, it is in a region that has been periodically shaken by severe shocks; these seismic events will reoccur in the future.

CLASSIFICATION AND TERMINOLOGY OF EARTHQUAKES

I stated that nonvolcanic earthquakes are caused by movements along faults, which are breaks in the earth's crust, or by the initial formation of these faults. Numerous faults are mapped in various parts of the world, and many have not moved or produced earthquakes for millions of years. Therefore, we need only concern ourselves with active faults, which are those faults that have moved in the geologically recent past and are known or suspected to produce earthquakes. Any planning effort in areas of active faults requires special consideration of these features because of their potential threat.

What is an active fault? The former Atomic Energy Commission defined an active fault as one that has moved during the last 10,000 years (Holocene time). Their definition was modified by the Nuclear Regulatory Commission so that an active fault is now defined as a fault along which there has been at least one movement in the last 35,000 years, or more than one movement in the last 500,000 years.

The Denali fault, located in the Alaska Range 80 miles south of Fairbanks, is the longest fault in Alaska; because it has moved in the last 10,000 years, it is generally considered active. Several smaller faults near Fairbanks show evidence of displacement and are also considered active (fig. 79), including a fault near Donnelly Dome south of Delta Junction, two near Blair Lakes in the Tanana Valley, and a small fault near Champion Creek, 52 miles northeast of Fairbanks.

The point or area within the earth where the initial motion along a fault occurs is called the focus of the earthquake and its location is termed the hypocenter. The epicenter is the point on the surface of the earth directly above the hypocenter. When the news media report the location of an earthquake, they usually report the location of the epicenter.

Of paramount importance is how we describe the size of an earthquake. How do we measure the number of people killed, the damage to structures, the amount of energy released, the size of mountains built, or other phenomena? For many years, a qualitative intensity scale was used to measure earthquakes. Intensity is a measure of the amount of damage to manmade structures, of the effects on population, and of related phenomena such as landsliding and ground cracking. The most popular measure of intensity is the Modified Mercalli Scale, which is graduated in Roman numerals from I to XII (table 1).

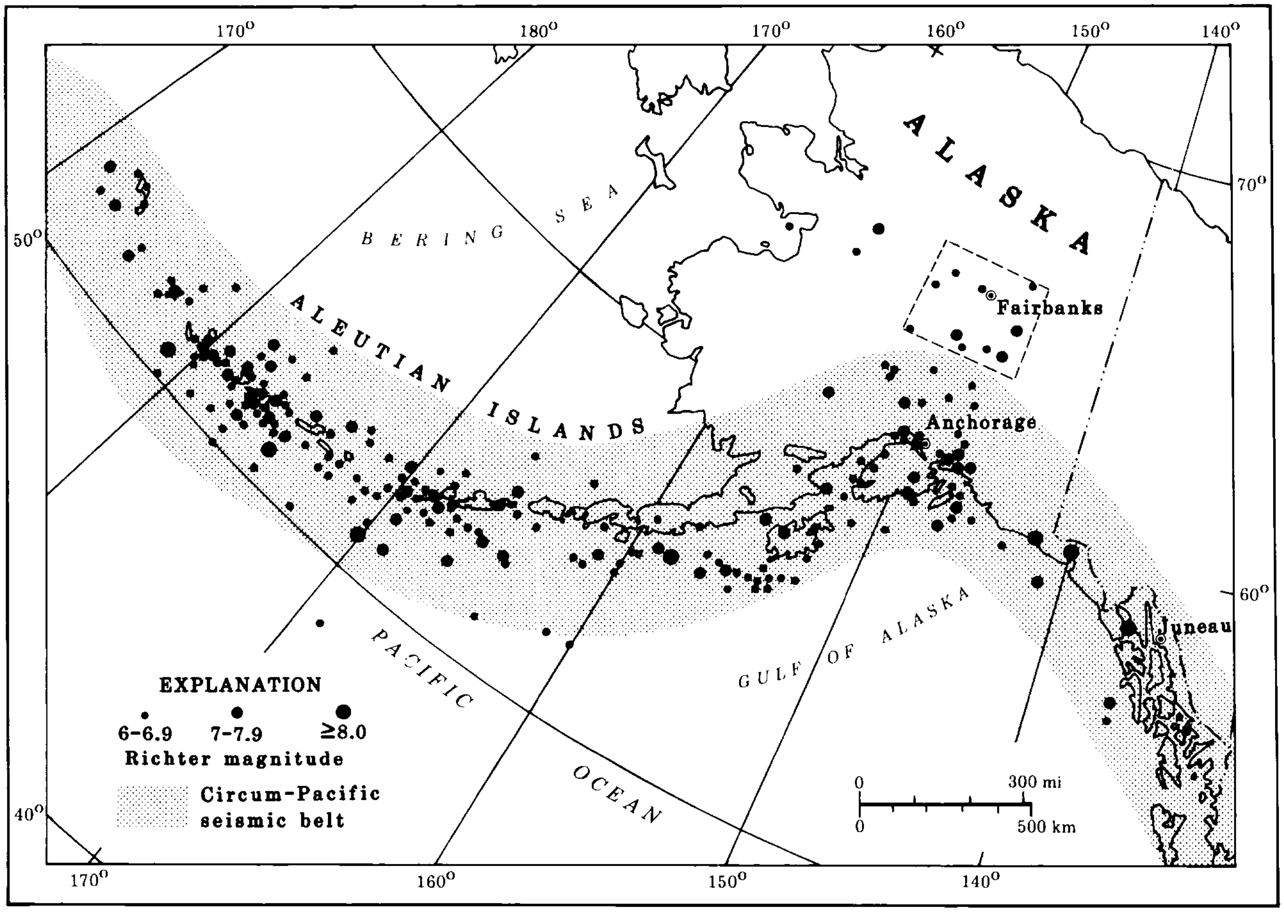

Figure 78. Epicenters of earthquakes with Richter magnitudes 6.0 and larger in Alaska from 1899 to 1967. Shaded area represents the Circum-Pacific seismic belt in Alaska. The dashed rectangle encloses area shown in figure 81 (modified from Jordan and others, 1968).

The most common measure of energy released by an earthquake is the Richter magnitude scale, which is based on the amplitude of seismic waves recorded by a seismograph. The magnitude of an earthquake is given as an Arabic numeral and, commonly, a decimal fraction. Because of the logarithmic character of the scale, an increase of one whole unit, for instance, from 5.5 to 6.5, means that the amplitude has increased 10 times (fig. 80); at the same time, the energy associated with this greater amplitude has increased approximately 31 times. Moderate earthquakes---Richter magnitude 5.5 to 6.0---are on the threshold of causing damage to nearby structures. A seismic event of Richter magnitude 6.1 to 7.8 is a major earthquake and is generally quite destructive. A great earthquake has a magnitude of 7.9 or larger. On this scale, the 1964 Alaska earthquake measured 8.6, the San Francisco earthquake of 1906 measured 8.3, and the 1971 earthquake at San Fernando, California, measured 6.5. According to George Plafker of the USGS (written commun., June 21, 1978), the Richter scale may be an inadequate measure of energy released by earthquakes greater than magnitude 7.9 because such earthquakes commonly involve ruptures longer than 200 miles that cannot be adequately sampled with most seismographs. Dr. Kiro Kanamori of the California Institute of Technology recently extended the Richter scale to sample the energy release of the entire focal region. According to his modification, the 1964 Alaska earthquake was 9.2, the San Francisco earthquake of 1906 was 7.9, and the largest recorded earthquake was the 1960 Chile event at 9.5.

EARTHQUAKE HAZARDS IN THE FAIRBANKS AREA

Large earthquakes with magnitudes up to 7.8 have been recorded in the Fairbanks area since 1904 (fig. 81). The most well-documented large event, magnitude 7.3, occurred near Fairbanks on July 22, 1937. The epicenter of the earthquake was near Salcha Bluff, about 25 miles southeast of the city along the Richardson Highway. A landslide several hundred feet long completely blocked

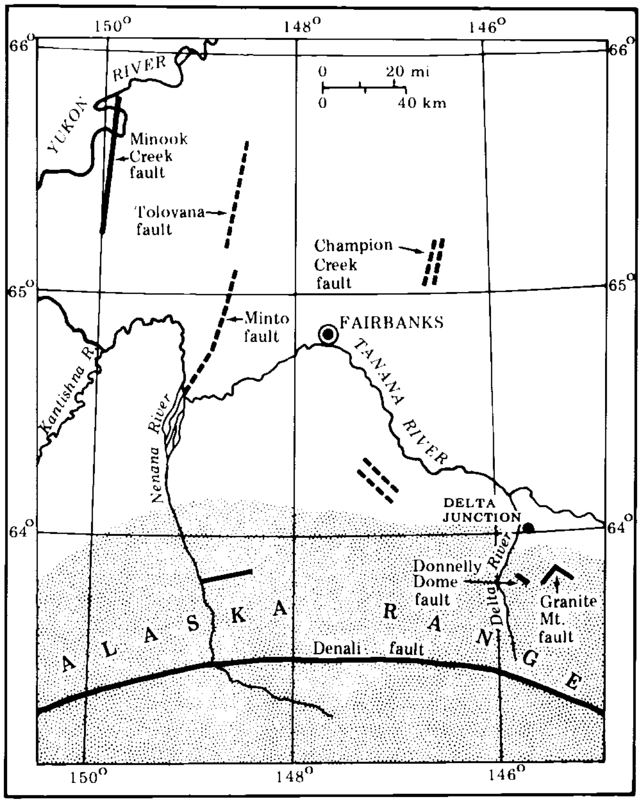

Figure 79. Active faults in central Alaska (Brogan and others, 1975; Gedney and others, 1972; Holmes and Péwé, 1965; Hudson and others, 1977; and Péwé and Holmes, 1964).

the main highway in that vicinity, and mud boils and cracks up to 15 inches wide formed in the highway. A well-built, two-story log structure belonging to the Alaska Road Commission was knocked askew and several windows were broken. Fairbanksans experienced severe shaking and considerable minor damage, and the earthquake was felt over most of central Alaska.

On October 14, 1947, a major earthquake (magnitude 7.0) shook the Fairbanks area. The epicenter was located a few miles south of Nenana near the Alaska Railroad, about 55 miles west of the 1937-event epicenter. Intense cracking of lake ice and frozen ground occurred along the flood plain from Fairbanks to Nenana, and landslides were common along the Richardson Highway. As in 1937, seismic shaking in the Fairbanks area was more intense on flood-plain alluvium than on bedrock hills, and there was heavy damage to shelf-goods at downtown drug, grocery, and liquor establishments. No lives were lost, but almost everyone ran outside. Earthquake experts subsequently recommended that future construction in the Fairbanks area be designed to withstand violent earthquakes, and that whenever possible, construction on alluvium be avoided.

In 1967, one of the most thoroughly documented historic earthquakes occurred in the Fairbanks area.

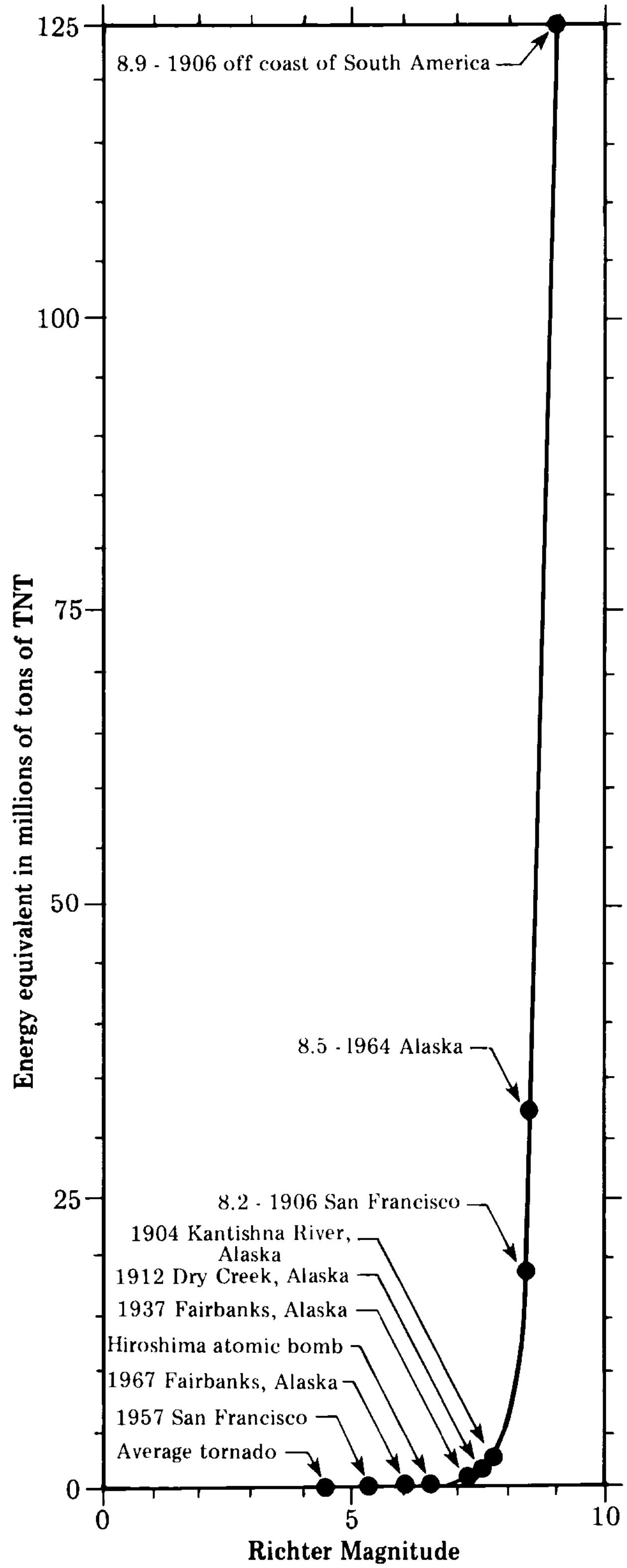

Figure 80. Earthquake energy expressed in terms of millions of tons TNT (modified from Griggs and Gilchrist, 1977).

Table 1. *Modified Mercalli Intensity scale of 1931 (California Geology, 1979)*

Intensity	Damage to man-made structures
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking buildings. Standing motor cars rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved, a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everyone runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Practically all works of construction are greatly damaged or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

On the morning of June 21, four moderately severe shocks shook Fairbanks for about 21 minutes. The largest event measured 6.0 to 6.1 on the Richter scale. The epicenter was located about 9 miles southeast of Fairbanks and, as in the 1937 and 1947 events, there were no visible movements along known surface faults. Considerable damage occurred in downtown Fairbanks, which is built on water-soaked flood-plain sand and gravel. The State Court Building on Barnett Street between Fifth and Sixth Streets reportedly suffered the most extensive damage. Cracks formed on interior and exterior walls, parts of the hanging ceiling and some fixtures fell, cabinets and shelves were overturned, and broken waterlines caused extensive flooding so that the structure was temporarily closed to the public. Damage to merchandise in several stores resulted in losses of thousands of dollars; one store reported at least $5,000 in damage. Some large buildings swayed, and alarmed occupants fled into the streets. As shown on the Modified Mercalli Intensity distribution map of the earthquake (fig. 82), an intensity of VII was assigned to the immediate Fairbanks area.

I was having breakfast at 1114 Galena Street in Fairbanks during the earthquakes and recorded the following notes in my field book.

> Three sharp earthquakes between about 8:04 and 8:20 AM occurred. The jolts were sharp and short. The house shook and some dishes slid toward the edge of the shelves. The quake woke my son, Rick, and the rest of the family. Rick said, "Sure are neat earthquakes." There was no damage to the houses nearby. A good seiche developed in a 19-foot-diameter swimming pool in the rear of the yard at 1114 Galena Street. The swimming pool is above ground and is held in by a metal frame with a plastic liner. It is round and 4 feet deep. The water sloshed back and forth and went up 4 1/2 inches. The amplitude of the waves was 9 inches. The slosh was in a southwest-northeast direction. All three earthquakes caused the seiche to go in the same direction. At Lindy's and other grocery stores, considerable liquor spilled to the floor

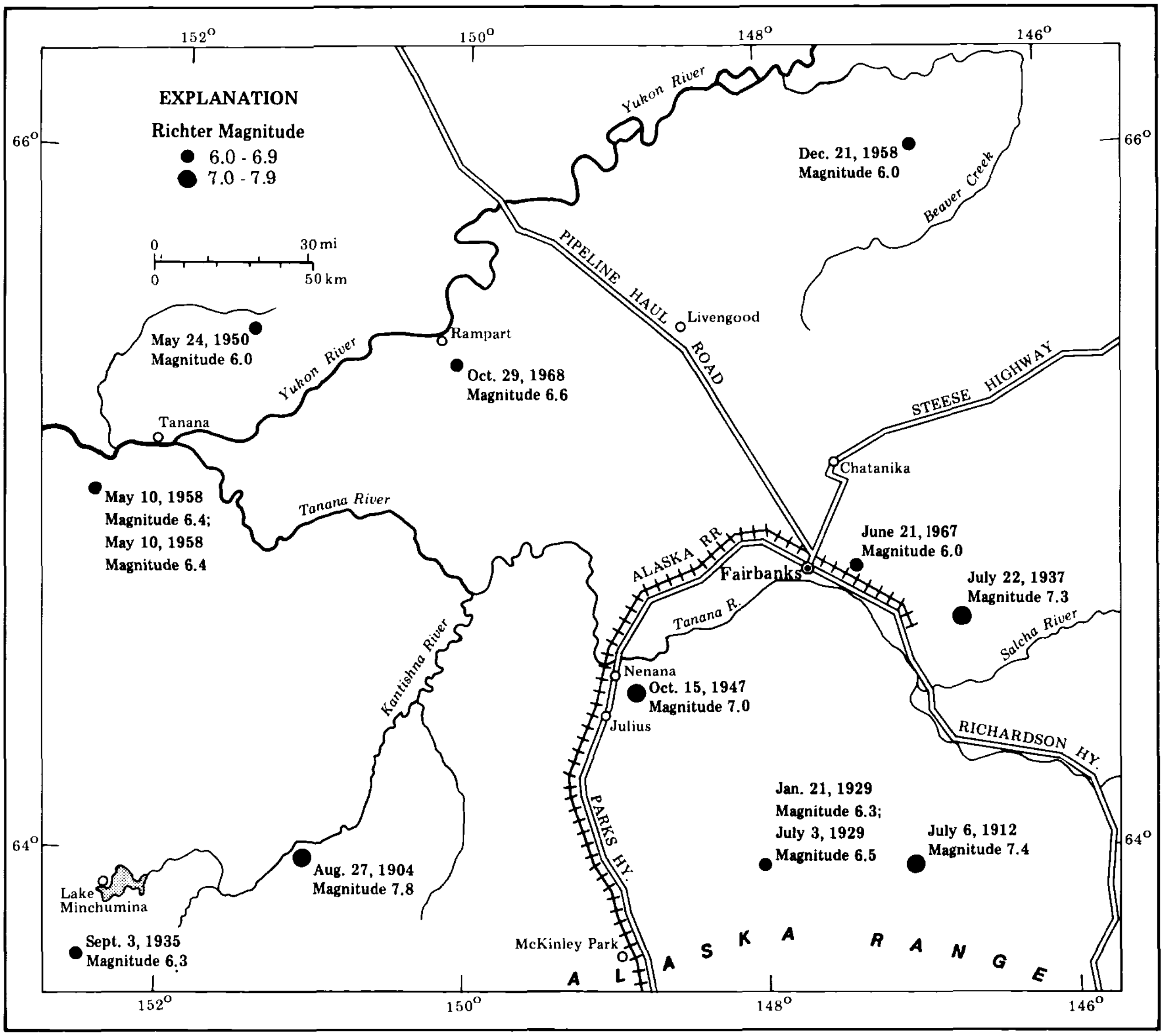

Figure 81. Distribution of earthquakes with Richter magnitudes greater than 6.0 from 1904 to 1968 in central interior Alaska. The center of the 1977 earthquake swarm in the Fairbanks area was in the same locality as the June 21, 1967 earthquakes with Richter magnitudes 6.0 (compiled by J.B. Townshend, USGS).

along with groceries.

Most, if not all, earthquake-induced damage was sustained by buildings located on unconsolidated sediments, that is, on the valley floor or the flood plains of the Tanana and Chena Rivers (fig. 2). Buildings on the bedrock ridge at the University of Alaska sustained no damage. It is well known that damage caused by shaking of structures built on alluvium, especially if it is water saturated, is greater than damage to structures built on bedrock or silt-covered bedrock hills. Differential subsidence caused by liquefaction is also more prevalent on alluvium. For this reason, buildings on natural or artificial fills in the San Francisco area were most severely damaged in the 1906 earthquake.

In the Fairbanks area, serious earthquakes have occurred about every 10 years during the 20th century (fig. 83). Many residents wonder why there was no major earthquake in 1977, and the following explanation is offered. In February and March 1977, there was an anomalous resurgence of seismic activity 9 miles southeast of Fairbanks in the vicinity of the epicenter of the 1967 earthquake. Thousands of small earthquakes---as many as 200 a day---were recorded. Two or three events per day are more characteristic of the area. At least 20 quakes were felt. This earthquake swarm was unusual because it began and ended abruptly. This 1977 swarm may have taken the place of the expected single large earthquake. Although the date of the next large

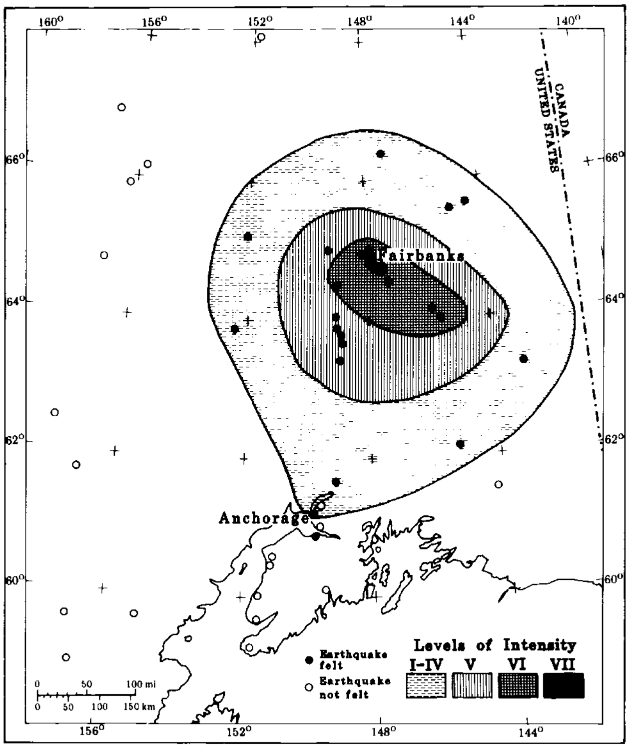

Figure 82. Modified Mercalli intensity distribution of June 21, 1967 Fairbanks earthquake. See Table 1 for definitions of intensity levels. This map was prepared from the results of a questionnaire canvas conducted by J.B. Townshend of the USGS Observatory at College and from press reports (modified from Cloud and Knudson, 1968).

earthquake is questionable, the pattern of activity during the last 40 years leaves little doubt that the Fairbanks area will again be affected by large earthquakes. Prudent planning and construction are the best ways to mitigate consequent damage.

SUMMARY OF THE EARTHQUAKE HAZARD

The earthquake history of the Fairbanks area indicates the existence of a genuine seismic hazard. The U.S. Department of Commerce assigned Fairbanks to seismic risk zone 3, the most earthquake-prone zone in this risk classification used by engineers and architects.

Continued growth of population and industry in the Fairbanks area will result in more construction and larger buildings. Because of rising costs, many new buildings may be less earthquake resistant. Planners, builders, and the city government must be aware of the serious earthquake hazard in the Fairbanks area, especially as it relates to foundation conditions. Structures built on bedrock or loess-covered bedrock hills are less susceptible to damage caused by shaking than structures built on alluvium of the Chena and Tanana Rivers flood plains.

SELECTED REFERENCES

Adkins, J.N., 1940, The Alaskan earthquake of July 22, 1937: Seismological Society of America Bulletin, v. 30, p. 353-376.

Bramhall, E.H., 1938, The central Alaska earthquake of July 22, 1937: Seismological Society of America Bulletin, v. 28, p. 71-75.

Brogan, G.E., Cluff, L.S., Korringa, M.K., and Slemmons, D.B., 1975, Active faults of Alaska: Tectonophysics, v. 29, p. 73-85.

California Geology, 1979, Modified Mercalli Intensity scale of 1931: v. 32, no. 2, p. 36.

Cloud, W.K., and Knudson, C.F., 1968, Preliminary engineering seismological report, *in* The Fairbanks, Alaska earthquakes of June 21, 1967: Washington, Environmental Sciences Service Administration, U.S. Department of Commerce, p. 38-60.

Davis, T.N., and Echols, Carol, 1962, A table of Alaskan earthquakes, 1788-1961: Fairbanks, University of Alaska, Geophysical Institute Report UAG R-131, 44 p.

Eckel, E.B., 1970, The Alaska earthquake, March 27, 1964: Lessons and conclusions: U.S. Geological Survey Professional Paper 546, 57 p.

Estes, Steve, Huang, Paul, Gedney, Larry, and Biswas, Nirendra, 1977, The Fairbanks earthquake swarm of February and March, 1977: Fairbanks, University of Alaska, Geophysical Institute Report UAG R-250, 11 p.

Gedney, Larry, and Berg, Edward, 1969, The Fairbanks earthquakes of June 21, 1967; aftershock distribution, focal mechanisms, and crustal parameters: Seismological Society of America Bulletin, v. 59, p. 73-100.

Gedney, Larry, Shapiro, Lewis, Van Wormer, Douglas, and Weber, F.R., 1972, Correlation of epicenters with mapped faults, east-central Alaska, 1968-1971: U.S. Geological Survey Open-file Report 72-248, 7 p.

Griggs, G.B., and Gilchrist, J.A., 1977, The earth and land-use planning: North Scituate, Mass., Duxbury Press, 492 p.

Holmes, G.W., and Péwé, T.L., 1965, Geology of the Mt. Hayes D-3 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-366, scale 1:63,360.

Hudson, Travis, Foster, H.L., Weber, F.R., 1977, The Shaw Creek fault, east-central Alaska, *in* Blean, K.M., ed., The United States Geological Survey in Alaska: Accomplishments during 1976: U.S. Geological Survey Circular 751-B, p. B33-B34.

Jordan, J.N., Dunphy, G.J., and Harding, S.T., 1968, Preliminary seismological report, *in* The Fairbanks, Alaska earthquakes of June 21, 1967: Washington, Environmental Sciences Service Administration, U.S. Department of Commerce, p. 1-32.

National Academy of Sciences, 1973, The great Alaska earthquake of 1964: Summary and recommendations: Washington, 291 p.

Péwé, T.L., 1964, Good Friday earthquake, Alaska: Geotimes, v. 8, no. 8, p. 9-10, 22-23.

Péwé, T.L., and Holmes, G.S., 1964, Geology of the

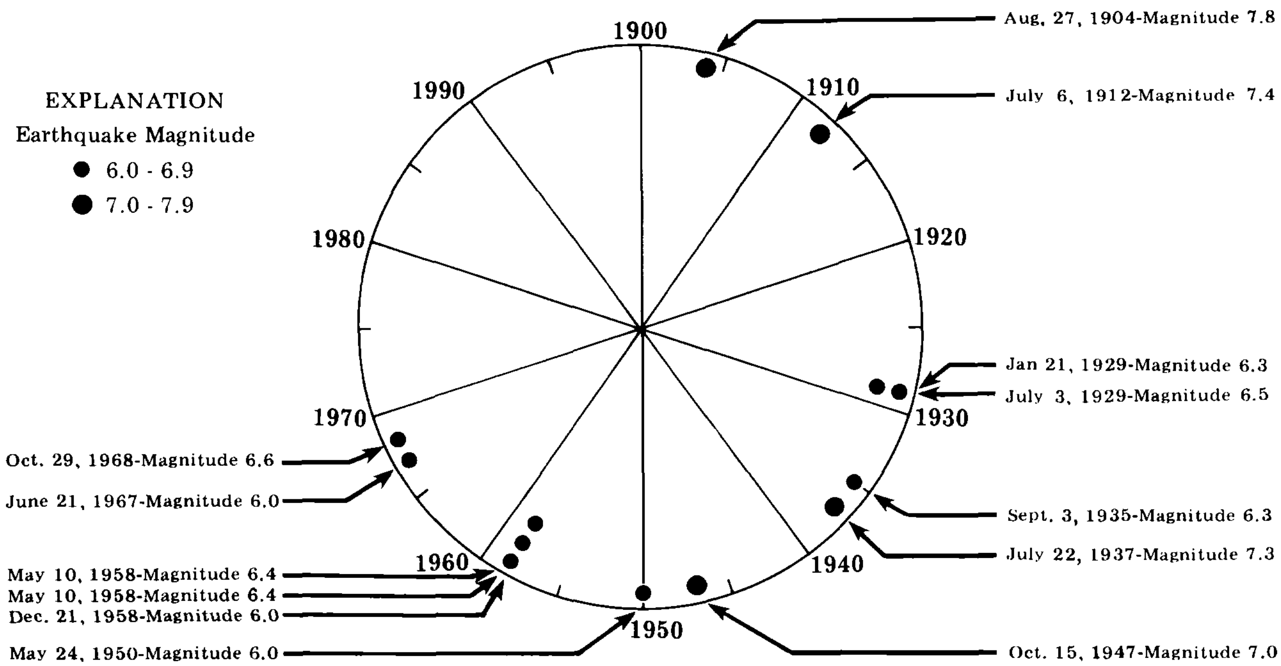

Figure 83. Time distribution of earthquakes of Richter magnitude 6.0 or greater from 1900 to 1978 in central interior Alaska (modified from Townshend, 1971).

Mt. Hayes D-4 Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-394, scale 1:63,360.

Richter, C.F., 1958, Elementary seismology: San Francisco, W.H. Freeman, 68 p.

St. Amand, Pierre, 1948, The central Alaska earthquake swarm of October, 1947: American Geophysical Union Transactions, v. 29, p. 613-623.

Townshend, J.B., 1971, Comments on earthquake predictions: U.S. Geological Survey unpublished report, 1 p.

Yerkes, R.F., Bonilla, M.G., Youd, T.L., and Sims, G.D., 1974, The Van Norman Reservoir area, northern San Fernando Valley, California: Geologic environment of the Van Norman reservoir area: U.S. Geological Survey Circular 691-A, 33 p.

LANDSLIDES

LANDSLIDES IN THE FAIRBANKS AREA

Failure and displacement of near-surface materials are common geologic processes that are often accompanied by sounds of shattering glass panels, snapping lumber, and cries of the homeowner, as masses of rock or loose surface material suddenly move downslope. Landslides are the most widespread geologic hazard in the United States, annually causing hundreds of millions of dollars of damage, with some loss of life. Landslides occur when slope instability leads to gravity-induced downslope movement. Rates of movement vary between less than a few inches per year for soil or rock creep to 250 miles per hour for avalanches. Rock falls, rock slides, mud flows, and earth flows move at rates between these extremes.

All types of landslides and related phenomena occur in Alaska. For example, land and submarine slides and crushing avalanches triggered by the 1964 Alaska earthquake accounted for most of the damage and loss of life during that event. Landslides in the Bootlegger Cove Formation in Anchorage were catastrophic and are now cited in most elementary geology textbooks.

In the Fairbanks area landslides are an uncommon hazard under natural circumstances. Debris flows and slides did occur in the upper Chena River drainage during the intense rains of August 1967. Undercutting of bedrock cliffs by the Tanana River has produced rock falls. As man begins to build on steep hillsides, more landslides will occur.

The most logical places for landslides to develop are on steep bedrock slopes, such as the south side of Birch Hill, and on steep slopes along the Tanana River from just south of Eielson Air Force Base to Shaw Creek Bluff. Landslides are particularly favored where the dip of bedrock is steep and parallels the slope. Most rocks exposed along these steep slopes are schists, which are layered, minutely foliated rocks that can slip along bedding and foliation planes. The schist in these areas contains considerable mica, a mineral with good cleavage planes; thus the rock can slide easily, especially when clay minerals develop along slip surfaces as a result of weathering. If slip planes are undercut or excessively lubricated by precipitation or other sources of water (fig. 84), gliding or slipping are facilitated. This type of movement is called a rockslide.

Several rockslides developed along the Richardson Highway between Miles 298 and 302 southeast of Fairbanks when the road was realigned in 1972 (figs. 85, 86). Large cracks formed at the top of the cut and many tons of rock slid down onto the highway. In addition, large failures were produced by reactivation of ancient, stabilized slides that were masked by thick loess and vegetation. Renewed movement began when the toes of the stabilized slides were removed for the new roadcuts.

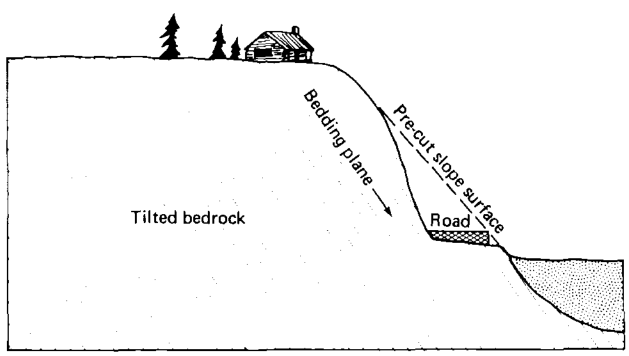

Figure 84. Diagrammatic representation of steeply dipping, bedded rocks that are susceptible to landsliding. As undercutting by road construction steepens the bluff, rocks may easily slide along the well-developed bedding planes, especially if lubricated by excessive precipitation. As a result, the house at the top of the cut could be destroyed.

SELECTED REFERENCES

Eckel, E.B., ed., 1958, Landslides and engineering practice: Highway Research Board Special Report 29, National Academy of Sciences, National Research Council Publication 544, 232 p.

Wahrhaftig, Clyde, and Black, R.F., Quaternary and engineering geology in the central part of the Alaska Range: U.S. Geological Survey Professional Paper 293, 68 p.

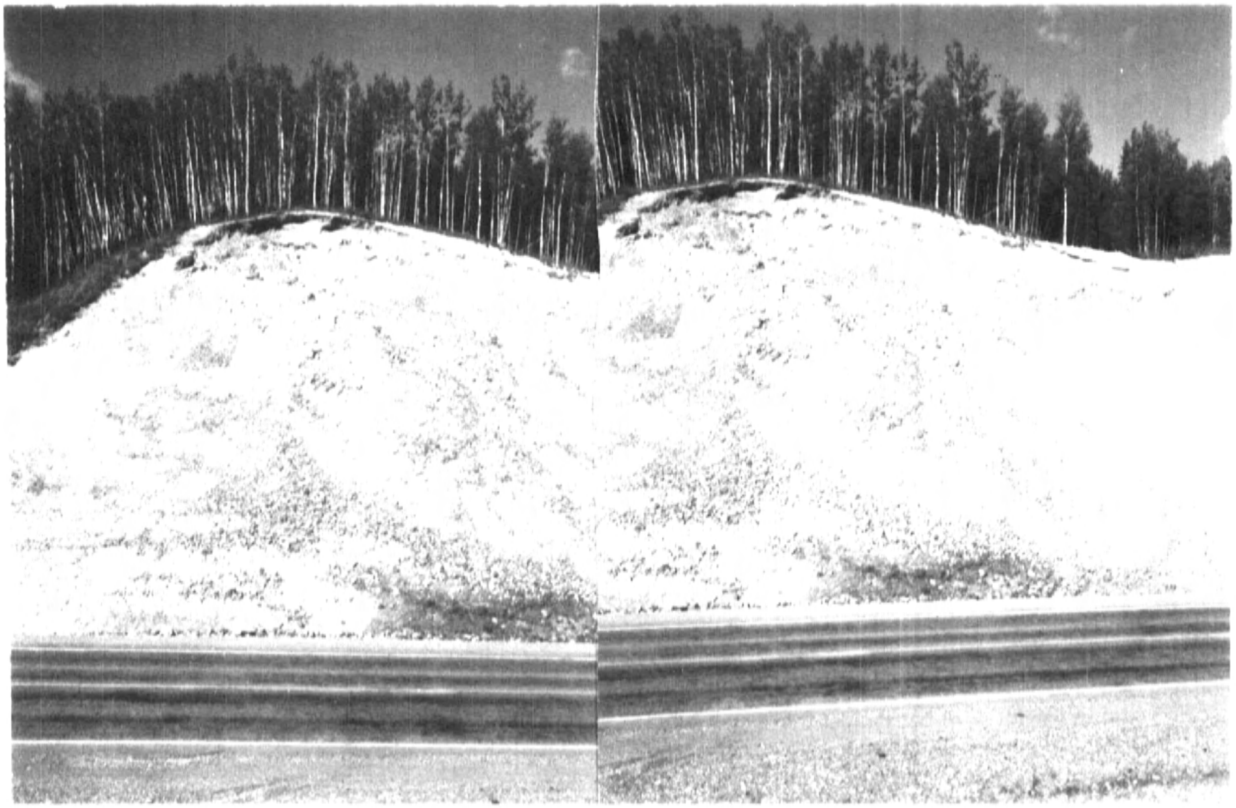

Figure 85. Stereopair of landslide near Mile 300, Richardson Highway. The landslide is in steeply dipping, weathered schist. Excavation for a road realignment undercut the bedrock. Photographs 4019 and 4020 by T.L. Péwé, July 16, 1977.

Figure 86. Head of landslide near Mile 300, Richardson Highway. Photograph 4023 by T.L. Péwé, July 16, 1977.

HILLSIDE EROSION IN LOESS

PRELIMINARY STATEMENT

It is rumored that if one parks a car with a leaky radiator on a hillside underlain by loess, the dribbling water will soon erode a large gully and the car will fall into it. Although this story does illustrate the ready erodibility of loess, it probably should be taken with a grain of salt. Nevertheless, because loess is so easily eroded, it does constitute a considerable geologic hazard. Additionally, it is a factor contributing to damage from other geologic hazards such as landslides and earthquakes. For example, the greatest recorded loss of life in a single earthquake occurred in 1556 when 830,000 persons were crushed and suffocated by the collapse of subterranean homes cut in loess in Shenshi, China. A disasterous 1976 landslide in China killed half a million people in an area underlain by loess. Although the loess, terrain, and earthquake conditions in the Fairbanks area differ from those in China, loess is thick and widespread in central Alaska (fig. 2).

Loess is a fine-grained, wind-deposited sediment, commonly unlayered, unconsolidated, and composed predominantly of silt-sized particles with very few clay-sized constituents. Most particles are about 0.02 millimeter (0.001 inch) in diameter. Fairbanks is the site of the thickest reported loess deposits in the United States. Loess ranges in thickness from less than a foot atop bedrock hills in the northern part of the Fairbanks area to as much as 200 feet atop Gold Hill near Ester. Because the sediment is unbonded and fine grained, it is easily eroded and transported by running water, unless protected by a vegetative cover.

EXAMPLES OF LOESS EROSION

Breaks often developed in the banks of the open ditches---located high on hillsides---that carried water to local placer gold mines. When escaping water rushed downhill from the 6- to 10-foot-wide ditches, the loess cover was immediated trenched, and steepsided gullies 10 to 20 feet deep and up to 1/4 mile long were formed. Scars of these breaks are still visible today.

Breakage of water lines located on the steep, loess-covered slopes is not uncommon today. In 1967, a major water pipeline to the top of the northeast end of Chena Ridge burst, and a 20-foot-deep gully was formed within a day's time.

Loess gullying of roads by ditch water may create a dangerous traffic hazard in the Fairbanks area (fig. 87). Water in ruts of an unimproved road or entryway will quickly cut slashes up to 2 feet wide and 10 feet deep. Water draining away from roads will quickly erode a gully in the loess (fig. 88). In fact, drainage in steep, loess-covered areas must be carefully channeled into vegetated or otherwise erosion-protected drainageways.

Although it is not common for sewage effluent to be discharged on loess-covered slopes, such drainage has and will trench the soft sediment. Even the discharge of water draining from a house roof may gully frozen or unfrozen loess and create a condition hazardous to the house foundation.

Although loess is easily eroded, it has the remarkable ability to stand in vertical cliffs. Most vertical cliffs cut in loess during road building or quarrying have stood for more than 100 years. In 1935, when it was necessary to make a huge excavation for placer gold mining in unfrozen loess at Ester Island 10 miles west of Fairbanks, the mining company artifically froze the loess to impede collapse of the walls. After the gold was dredged, the loess thawed and has been standing in a moderately steep cliff---which in some places is 180 feet high---for the last 33 years. In Mississippi, New Zealand, and Usbekistan, as well as Fairbanks, road cuts in loess are stepped rather than cut to the 2:1 slopes common in other unconsolidated sediments.

SELECTED REFERENCES

Davidson, D.T., and others, 1959, The geology and engineering characteristics of some Alaskan soils: Iowa State University Bulletin 186, 149 p.

Péwé, T.L., 1951, An observation of wind-blown silt: Journal of Geology, v. 59, p. 399-401.

______________, 1955, Origin of the upland silt near Fairbanks, Alaska: Geological Society of America Bulletin 66, p. 699-724.

______________, 1958, Geology of the Fairbanks D-2 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-110, scale 1:63,360.

Figure 87. Deep gully eroded in loess by runoff along edge of old Sheep Creek Road near Goldstream valley northwest of Fairbanks. The gully formed because of inadequate channeling of surface water. Photograph 1170 by T.L. Péwé, July 6, 1955.

Figure 88. Large, 6-foot-deep gully formed in easily erodable loess on the south flank of College Hill, University of Alaska, Fairbanks. Most erosion occurred in a few hours during a summer storm, when upslope water was funneled across this field. Photograph 263 by T.L. Péwé, July 1, 1948.

FLOODING

INTRODUCTION

A river is in flood when the water level reaches a person's pocketbook. Flooding is the most universal geologic hazard and accounts for more annual loss of life than any single hazard. Floods are natural and recurrent events, during which streams periodically overflow their banks to inundate their natural flood plains. Floods become a problem when man competes with rivers for the use of flood plains; this competition has been long and costly.

Flood plains are occupied by man because they are generally accessible and profitable to develop. However, use of the flood plain is limited by man's ability to sustain flood losses or provide flood-control facilities. Full flood control often is not possible or feasible, yet abandonment of the flood plain may not be reasonable because the flood plain is a valuable resource.

Fairbanks is the largest city in Alaska built entirely on a modern flood plain---the compound flood plain of the Tanana and Chena Rivers (figs. 2, 3). Fort Wainwright, North Pole, and Eielson Air Force Base are located on the same surface, which has been flooded periodically for thousands of years. These floods, coupled with normal stream activity, have deposited hundreds of feet of alluvium in the Tanana valley. Innumerable sloughs, swales, and lakes on the modern flood plain are evidence of the constant shifting of the rivers across this surface. The Chena River bisects the City of Fairbanks and Fort Wainwright, and expensive commercial and residential buildings crowd its banks.

HISTORY OF FLOODING IN THE FAIRBANKS AREA

The City of Fairbanks was founded in 1901 on the south bank of the Chena River when Captain E.T. Barnette constructed his trading post. Since then, Fairbanksans have fought spring and summer flooding by the Chena and Tanana Rivers.

Flooding occurs when the volume of water entering the stream channel exceeds the channel's carrying capacity. Hydrologists state that a typical stream will overflow its normal channel and flood low areas of its flood plain about once every 2 or 3 years. Although greater floods occur at less frequent intervals, they generally affect more extensive areas. A flood that submerges all the alluvial deposits in a stream valley occurs once or less per century.

In the early days of Fairbanks, spring-breakup floods were accompanied by the crashing and smashing of huge blocks of river ice that caved in the sides of buildings and destroyed small structures located near the river (fig. 89). Records indicate that in 1905, one of the worst floods of the early part of the century carried swirling water around log cabins and commercial buildings in the city. Floodwaters extended to beyond Sixth Street and it was estimated that bulldozing by large blocks of ice did more than a half a million dollars (1905 value) in damage.

To understand the causes of some of the floods in early Fairbanks, it is necessary to review the geography of the Chena River and Chena Slough (fig. 63). A slough is the distributary of a river and forms where part of the river water is channeled into a smaller passageway that later joins the major channel. In the early days the Chena Slough was used by large boats to circumvent Bate's Rapids on the Tanana River. Because the Chena River formerly emptied into the Chena Slough, Fairbanks was subject to high water from the Chena River, the Little Chena River (which also emptied into the slough), and the Tanana River.

In the mid-1940's, a dike was constructed along the north side of the Tanana River from Moose Creek Bluff downstream for many miles, and that part of the former Chena Slough below the Chena River became an extension of the Chena River. There has been no serious hazard caused by water or ice passing from the Tanana River through the slough since the dike was constructed.

In 1948 flooding of the Chena River submerged much of downtown Fairbanks, and lowlands on the inside of meandering stream channels were inundated. Hundreds of thousands of dollars in losses occurred in the city and at Ladd Field, now Fort Wainwright (fig. 90).

In 1967 the flood of the century submerged all alluvial deposits in the lower Chena River valley. Most damage and threats to survival occurred in Fairbanks. Unique meteorological conditions in early and middle August brought tremendous amounts of moisture to central Alaska from the Bering Sea. Rains began on August 8 and continued until August 20. Northwest of Fairbanks as much as 10 inches of precipitation fell. Fairbanks received 6.15 inches of rain from August 8 to 15. More than half of the average annual precipitation fell in one week and discharge of the Yukon and Tanana Rivers increased about 72 percent; the result was widespread flooding. Southeast of Fairbanks the Little Salcha and Salcha Rivers washed away parts of the Richardson Highway. Runoff in the Chena River was catastrophic; the stream gauge 40 miles upstream from Fairbanks was complete destroyed. Peak discharge measured at the Steese Highway Bridge was 74,400 cubic feet per second (cfs) on August 15, 1967, more than three times the previous maximum discharge of 24,200 cfs recorded on May 21, 1948. Discharge of the

Figure 89. *Circa* 1908 flood in Fairbanks. Large blocks of river ice---accompanied by icy water---shoved against and into houses and constituted a serious hazard. Photograph 58-1026-633, Bunnell Collection, University of Alaska Archives, Fairbanks.

Chena River near Eielson Air Force Base was 105,000 cfs, but bank overflow substantially reduced the volume of water moving downstream. The decrease in peak discharge of the Chena River from above the Little Chena to Fairbanks is attributed to intervening flood-plain storage, which was a common factor affecting larger streams near Fairbanks during the 1967 flood. Indeed, without the broad flood-plain surfaces, all flow would have been more efficiently channeled, and the peak discharge at Fairbanks would undoubtedly have been much greater (J.M. Childers, written commun., Sept. 22, 1978).

The 1967 flooding of the Chena River at Fairbanks is best described as a flowing lake that extended upstream and downstream from the city for several miles (fig. 91). About 95 percent of Fairbanks was flooded; locally water was as deep as 5 feet (figs. 92a,b). Except for a few artificial islands, most notably Fairbanks International Airport, the flood plain was inundated. Flood damage and the reaction of the city and its residents were succinctly summarized by Childers and others (1972, p. A33-A39).

> Because the Chena River rose rapidly and quickly inundated the occupied flood plain to unprecedented depths, unprepared residents were not able to comprehend their plight. Many first concerned themselves with basements. They piled belongings on tables or other furniture, working frantically to save their possessions from the silty floodwater. They soon realized the hopelessness of their efforts and began carrying things up to the main floor of their houses, where they soon watched the floodwater rise rapidly up to windowsill height, floating bureaus, refrigerators, and other objects. Need for evacuation then became urgent, and it was discovered that only boats or helicopters could be used because depths of inundation and current velocities were too great for cars or wading. People moved to rooftops and multistoried buildings to await evacuation.

Data were inadequate to accurately forecast the flood crest. That some people suffered loss because of their reliance on the forecast can be illustrated by the following account. A man and his family lived in a basement apartment in the northeast section of Fairbanks. They helped the landlord build dikes with sandbags and loose dirt. By midnight on August 15, the predicted time of the crest, the water was still confined to the street, and the family peacefully went to bed. Several hours later, they were awakened by the

Figure 90. Oblique aerial view of Fairbanks during maximum flood stage of the Chena River, May 20, 1948. Low areas on slip-off slopes of the meandering river were under several feet of water. On May 21, a maximum flow of 24,200 cubic feet per second was reached. Water levels indicate this was a 25-year flood. Photograph 24-72PL-R-8M112-72RS, U.S. Air Force.

sound of water running down the basement stairway. With a few of their possessions, the family was soon driving through deep water seeking an exit from town, but the exits were blocked by stalled vehicles. The man then tried to find a high spot to park his car, but it also stalled. They waited on top of their car until someone in a boat came by, but only the wife and two children could be taken toward the north side of town. They later found their way to the University of Alaska campus, which stands on a hill about 3 miles northeast of Fairbanks. Later the man was rescued and taken to the south end of town. Several days passed before the family was reunited.

Certainly the large number of private boats in Fairbanks prevented a larger loss of life than the three reported drownings. Fairbanks was fortunate, too, that a large number of tracked vehicles, trucks, and helicopters were available

Figure 91. Oblique aerial view (to the west) of the flooding Chena River, August 15, 1967 at Fairbanks. Water was 3.9 feet deep in the downtown area and inundated the Cushman Street Bridge. Photograph courtesy of the Alaska Railroad.

from nearby Fort Wainwright and Eielson Air Force Base to use in rescue operations. As many as 6,500 people were evacuated to the University of Alaska campus.

Damage-survey teams later found saturated underground electrical installations, silt-clogged sewers, undermined and caved building foundations, imploded basement walls and floor slabs, saturated and warped wood-frame buildings, eroded road subgrades and bridge abutments, well-water pollution, collapsed cesspools, inundated automobiles, saturated business inventory, deposition of silt in yards, and many other kinds of damage.

Foundation failures were the most costly damage related to the higher ground-water table. Most failures were caused by pumping of basements before the ground-water table had dropped sufficiently low to reduce hydrostatic loading on basement walls and floor slabs. Structural damage to some large buildings resulted from settlement caused by loss of bearing capacity of the wet soils.

The Fairbanks municipal water-supply system did not lose its pressure and remained useable during the flood. A determined crowd of refugee volunteers saved the electrical-power and heat-generating plant at the University. This plant, which is located on the flood plain at the toe of University Hill, was protected from floodwaters by diligent handwork, which continued for most of one night. In places the floodwater surface was covered by films of oil and gasoline from leaking fuel tanks, and although fire was a serious threat, only a few small fires occurred.

The Chena River was above flood stage for a week, and some low-lying areas required an additional week or more to be drained of floodwater. Residents then faced the difficult task of cleaning up and preparing for the harsh winter. For weeks the streets were piled with flood-destroyed possessions and business stocks awaiting cleanup truck crews. This was a time of hard work, but universally high spirits characterized the hardy people of Fairbanks. When winter arrived, they were prepared.

The Fairbanks vicinity sustained about $84 million in flood damage during the August 1967 flood and was declared a national disaster area (table 2).

Table 2. *Cost summary of 1967 flood damage in Fairbanks (U.S. Army Corps of Engineers, 1968; Childers and others, 1972).*

Category	Total
Private and commercial sector	$75,230,000
Utilities	1,633,000
Public buildings	1,680,000
Transportation	529,000
Debris cleanup	1,037,000
Miscellaneous	4,000,000
Total	$84,109,000

FREQUENCY OF FLOODING IN THE FAIRBANKS AREA

Fairbanks residents no doubt wonder if there will again be floods in Fairbanks like those of 1948 and 1967, and if so, when? How often do such floods occur?

The objective of a flood-frequency analysis is to determine how often, on the average, we can expect floods of various magnitudes. The probable frequency of floods of various magnitudes is determined by a statistical analysis of annual peak discharges for all the years of record at the site. Peak discharge is the highest rate of flow of the stream and generally coincides with the greatest inundation. The longer the record, the more accurate is the flood-frequency prediction. By obtaining these stream records and applying formulas given in most environmental-geology and hydrology books, one can calculate the flood-frequency probability. Knowledge of average recurrence intervals for a range of floods of various magnitudes is necessary when designing engineering structures or rationally planning floodplain use.

A flood that has a 2 percent (1 in 50) chance, or probability, of being exceeded in any year is called the 50-year flood. A flood that has a 1 percent (1 in 100) chance is the 100-year flood, meaning that such a flood has a probability of occurring on the average once in 100 years. Such a flood may occur more often; for example, it may occur twice in 2 years.

Recurrence intervals for floods of specific magnitudes in the Fairbanks area are difficult to calculate because of the lack of data on annual peak discharges for a sufficient number of years. Generally there is a fair degree of confidence for recurrence intervals up to the 50-year flood, but for greater floods the frequency is doubtful. The peak discharge of the Chena River at Fairbanks for the 25-year flood is estimated at 27,000 cfs and for the 50-year flood at approximately 34,000 cfs. These estimates mean that a flood of the magnitude of the 1948 event probably occurs once in approximately 25 years. The 1967 peak discharge of the Chena River at Fairbanks (74,400 cfs) was 2.2 times the peak discharge estimated for the 50-year flood. In fact, it was greater than the estimated magnitude of the 100-year flood.

Figure 92a. View north along Cushman Street of downtown Fairbanks during the mid-August 1967 Chena River flood. Photograph by Thomas Snapp.

Figure 92b. View of Third Avenue west toward Cushman Street during the mid-August 1967 Chena River flood. Photograph by Thomas Snapp.

SOLUTION TO THE PROBLEM OF FLOODING

INTRODUCTION

People have always lived on flood plains and will continue to utilize these attractive, level, fertile lands. As flood-plain development becomes more extensive and intensive, the natural flood zones of streams are preempted, often without regard to periodic floods that endanger property, health, and life. The result is a continual increase in flood losses. Despite a nationwide federal investment of more than $9 billion in flood protection and preventive measures since 1936, the annual flood loss was estimated at more than $1.7 billion in 1966 and $2 billion in 1972.

To begin reducing the flood-loss potential in Fairbanks, local residents must first appreciate the problem. As incredible as it may sound, many people in Fairbanks are not aware that they live on a flood plain, in spite of the 1967 flood, nor do they understand that the Chena River will flood again. Many believe that because the 100-year flood occurred in 1967, there is little chance of such a flood in the near future.

After the population understands the reality of future flooding in Fairbanks, flooding areas and depth of floodwaters must be delineated. Flood-hazard maps, which show the extent of potential hazards, are prepared as a result of thorough technical studies and are commonly sufficiently detailed to help in developing plans and programs of flood-plain management. These maps generally outline the 100-year-flood level because this flood has been accepted as the reference for flood-hazard evaluation, flood insurance, and flood-plain planning. A flood-inundation map for the Fairbanks area was prepared and published by the U.S. Geological Survey immediately after the 1967 flood.

Structural and nonstructural measures may be taken to reduce potential losses within areas susceptible to flooding. Structural solutions include construction of dams, levees, and other protective structures. Nonstructural solutions include economic and social actions such as flood-plain zoning, regulation, and insurance.

STRUCTURAL MEASURES

Structural methods to reduce flooding include reservoir and levee construction and channel improvements. Except for the dike built along the Tanana River in mid-1940s to prevent Tanana River water from entering Chena Slough, no major structural methods were seriously considered until after the 1967 flood, when the U.S. Army Crops of Engineers outlined an impressive flood-control project (fig. 93). This plan, called the Chena River Lakes Project, includes construction of a levee system along the Tanana River as well as reservoir storage in the Chena River and its tributaries behind an earth-filled dam. This $165-million plan provides protection for Fairbanks and adjacent Fort Wainwright from a 250,000-cfs flood in the Tanana River and an 85,000-cfs flood in the Chena River.

A major feature of the Chena River Lakes Project is the extensive cleared floodway upstream of the 7-mile-long dam. In the event of flooding in the Chena River drainage, this outlet will divert excess water through the floodway south into the Tanana River. Construction of the floodway necessitated relocating sections of the Alaska Railroad and the Richardson Highway onto overpasses under which the floodwaters will flow.

Flood-control and flood-management measures such as reservoirs, levees, and channel improvements may provide flood protection for many years, but flood protection is seldom complete. There is always a probability of an even greater flood than previously recorded.

NONSTRUCTURAL MEASURES

Many nonstructural prevention and reduction measures involve protection, removal, or conversion of existing development, discouragement of development, and regulation of flood-plain use. In areas where a small part of the city is located on the flood plain, flood reduction is possible by applying the latter three methods. There are several methods of removing people from flood-prone areas and for discouraging development, and often these are the only effective solutions. If a residential or commercial area is replaced by parks, the flood hazard is essentially solved. However, this technique is impractical in certain areas and illogical in Fairbanks, because the entire city would have to move.

Other nonstructural techniques that may be taken by individuals or city, state, and federal agencies to reduce flood loss include flood proofing, flood warning and evacuation, and flood insurance.

FLOOD PROOFING

Flood proofing prevents or reduces flood loss to structures that cannot be economically moved, or structures---such as certain public utilities---that must be maintained on the flood plain. In Fairbanks this includes most buildings. Flood proofing is most effective where floods are of short duration with low water levels and velocities.

The feasibility of modifying or installing protective equipment depends on the age, design, and economic value of the feature. Structural modifications include reinforcement of basement walls and floor underpinnings to withstand hydrostatic pressures of flood waters. In the Fairbanks area, reinforcement is especially important because hydrostatic pressures build rapidly in underlying permeable sands and gravel as the water table rises to and above the surface. Other potential modifications include the permanent sealing of exterior openings to the basement, use of masonry construction through-

Figure 93. Oblique aerial view to the southwest of the Moose Creek dam and dike on the Chena River. These structures were designed to divert Chena River flood waters along the floodway to the Tanana River in the distance. Photograph by J.W. Stuhler, U.S. Army Corps of Engineers, Alaska District, July 1981.

out, construction of low flood walls, and use of watertight bulkheads on windows and doors. In addition to modifications of individual buildings, it is necessary to ensure that water, sewage, and other public utilities are adequately protected to operate in times of flooding.

Special materials and provisions used in flood proofing include special cements for flooring, adequate electric-fuse protection, anchoring of buoyant tanks, sealing of outside basement walls, and installation of automatic sump pumps. In all cases, care must be exercised to avoid hydrostatic pressures that could collapse basement walls.

One of the most common methods of modification is elevation of the lowest floor and access roads to at least 2 feet above the 100-year-flood level. In the Fairbanks area this height is from 4 to 7 feet above the flood plain, depending on the depth of water during the 1967 flood. This method has been used in the older part of Sacramento, California, where roads have been elevated and basements and first floors in buildings abandoned. Most operations and traffic are now at the level of the second story.

FLOOD WARNING AND EVACUATION

An essential element in flood-plain-loss prevention is reliable and timely flood warnings that permit temporary evacuation of people and some personal belongings. Although Fairbanks has a long history of floods, very few people were adequately prepared in 1967. Knowledge of flood inundation was lacking, and immediate flood forecasting was very primitive. Fairbanks residents have expressed concern because they were not warned of the 1967 flood, but the real problem was that sufficient data simply did not exist to make this warning possible.

Immediately after the 1967 flood, U.S. Weather Bureau, U.S. Army Corps of Engineers, and U.S. Geological Survey personnel undertook construction and operation of a flood-warning system in the Fairbanks and Nenana areas. Six river-gauging stations were constructed prior to the 1968 flood season to provide instantaneous information to a flood-forecast center. Data from these river stations and from an expanding network of precipitation gauges are instantly telemetered to the Anchorage office of the National Weather Service Alaskan River Forecast Center, which closely monitors the situation and advises the public of any potential floods through its Fairbanks office.

FLOOD INSURANCE

In the not too distant past, it was completely illogical for private insurance companies to write flood insurance because their total assets would be quickly wiped out by a series of million- and billion-dollar-flood losses. Flood-insurance protection for property owners in flood-prone areas has since become available because of participation by the federal government.

Every president from Harry S. Truman on fought vigorously for some sort of flood-insurance program, but in spite of huge floods in various parts of the United States, progress was slow. A flood-insurance program initiated in 1956 did not become a reality because of lack of funding. Finally, on August 1, 1968, the National Flood Insurance Act was enacted to provide previously unavailable flood-insurance protection to property owners in flood-prone areas.

To participate and obtain insurance under this act, communities agreed to adopt and enforce land-use-control measures established by the Federal Insurance Administration (FIA) of the U.S. Department of Housing and Urban Development (HUD), which administers the program. Initially, premium rates were high and it was necessary for HUD to complete time-consuming mapping studies to determine special hazard areas below the level of the 100-year flood in participating communities. The program moved along slowly until 1972, when Hurricane Agnes gave the program a boost. At that time the Flood Disaster Protection Act was introduced to Congress and passed in December 1973. The number of insurance policies sold yearly since 1973 has risen dramatically.

Today an individual may buy flood insurance only after his community joins the FIA program. The simplest way for a community to join is to inform FIA of its intention, submit an application, which includes the adoption of a building-permit system, and express its willingness to comply with flood-plain-management requirements and standards set up by the federal government. The adoption of a building-permit system is vital because the National Flood Insurance Program was designed to protect those in danger of being flooded and to prevent an increase in damage by restricting construction in flood-prone areas.

Because the City of Fairbanks is in a flood-prone area, it is eligible for flood insurance provided by the FIA program. In addition, there are official FIA flood-hazard maps of the city. The area west of Fort Wainwright is covered by FIA Official Flood Hazard Map H02039077001, effective June 24, 1969, and by FIA Official Flood Insurance Map 102039077001, effective June 25, 1969. These maps were last revised December 9, 1977 (P.E. Berrian, written commun., July 10, 1978). Although typical FIA maps illustrate the approximate location of the 100-year flood level, they do not provide information on floodwater depths. Fortunately, the Fairbanks maps are derived from the 1967 USGS flood map, and thus are much more detailed than standard FIA flood-hazard maps.

Flood-insurance protection is offered by private insurance institutions. The program was established to promote public interest by providing appropriate protection against flood losses through the availability of flood-insurance coverage with the requirement of sound flood-plain management regulation to minimize flood risk to lives and property. The economic justification for the program, which initially required large public subsidies to produce affordable rates, is reduction of the dependence on flood-disaster-relief appropriations through safer construction practices in flood-hazard areas. To be eligible for federal financial assistance for acquisition or construction purposes within identified special flood-hazard areas, flood-insurance coverage must be available and subscribed.

SELECTED REFERENCES

Anderson, G.S., 1970, Hydrologic reconnaissance of the Tanana basin, central Alaska: U.S. Geological Survey Hydrologic Investigations Atlas HA-319.

Bue, C.D., 1967, Flood information for flood-plain planning: U.S. Geological Survey Circular 529, 10 p.

Childers, J.M., and Meckel, J.P., 1967, Flood of August 1967 at Fairbanks, Alaska: U.S. Geological Survey Hydrologic Investigations Atlas HA-294.

Childers, J.M., Meckel, J.P., and Anderson, G.S., 1972, Floods of August 1967 in east-central Alaska: U.S. Geological Survey Water-Supply Paper 1880-A, 76 p.

Federal Disaster Assistance Administration, 1975, Federal disaster assistance--final regulations: Federal Register, v. 40, no. 103, p. 23251-22269.

Federal Insurance Administration, 1975, National flood insurance program--proposed criterion: Federal Register, v. 40, no. 59, p. 13420-13433.

McPherson, H.J., and Saarinen, T.F., 1977, Flood-plain dwellers' perception of the flood hazard in Tucson, Arizona: Annals of Regional Science, July, p. 25-40.

National Flood Insurance Association, 1976, There is a high rock: Washington, National Flood Insurance Association, 9 p.

Nelson, G.L., 1978, Hydrologic information for land-use planning, Fairbanks vicinity, Alaska: U.S. Geological Survey Open-file Report 78-959, 47 p.

Péwé, T.L., 1958, Geology of the Fairbanks D-2 Quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-110, scale 1:63,360.

Robertson, G.R., 1978, 1978 plans for Corps of Engineers: Alaska Construction and Oil, p. 46-52.

U.S. Army Corps of Engineers, 1968, Flood of the Tanana River basin, Alaska, August 1967: Termination report, 60 p.

______________, 1978, Chena River Lakes project, Alaska; Tanana River Levee Phase IIB: Alaska District Design Memorandum 24, 63 p.

United States Congress, 1968, National Flood Insurance Act of 1968: Public Law 90-448, Title VIII *in* Housing and Urban Development Act of 1968, 82 Statute 572, 42 USC 4001-4127.

______________, 1973, Flood Disaster Protection Act of 1973: Public Law 93-234-87, Statute 975, 42 USC 4001-4128.

Waanaen, A.O., Limerinos, J.T., Kockelman, W.J., Spangle, W.E., and Blair, M.L., 1977, Flood-prone areas and land-use planning - selected example from the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 942, 75 p.

Wiitala, S.W., Jetter, K.R., and Sommerville, A.J., 1961, Hydraulic aspects of flood-plain planning: U.S. Geological Survey Water-Supply Paper 1526, 69 p.