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PERMAFROST ADVANCES: REPORT OF THE FOURTH INTERNATIONAL CONFERENCE ON PERMAFROST

INTRODUCTION

The Fourth International Conference on Permafrost was held in July, 1983 on the campus of the University of Alaska in Fairbanks, Alaska. The areas surrounding Fairbanks have excellent exposures of perennially frozen ground (permafrost) with abundant examples of the effect of permafrost on construction. The conference was the largest ever held in the field of frozen ground and it emphasized again the spectacular growth of the science and engineering application of permafrost. This conference was the fourth such international meeting on the subject in the last 20 years (others being 1963, U.S.A.; 1973, Siberia; 1978, Canada). The conference revealed the great increase in the intensity of the study of frozen ground by many nations, and the increase in the knowledge of distribution of frozen ground, especially of permafrost under the polar seas and in the high mountains of the temperate latitudes. One of the highlights was the widespread participation in all aspects of the conference of scientists and engineers from the People's Republic of China. The conference was held on July 17–22, 1983 under the auspices of the U.S. National Academy of Sciences and the State of Alaska. The U.S. Organizing Committee of the Academy of Sciences was responsible for the planning of the Conference, and the University of Alaska in Fairbanks was responsible for local organization and international announcements. The Governor of Alaska, Bill SHEFFIELD, was an honored guest at several sessions and he spoke of the importance of scientific and engineering research on frozen ground to the United States, especially to Alaska.

Although the existence of permafrost had been well known to the inhabitants of Siberia for centuries, not until 1836 did scientists of the Western world take seriously reports of thick, frozen ground existing under northern forests and grasslands. At that time, Alexander Theodor von MIDDENDORF measured temperatures to a depth of approximately 107 m of permafrost in the Shergin Shaft, an unsuccessful well dug for governor of the Russian-Alaskan Trading

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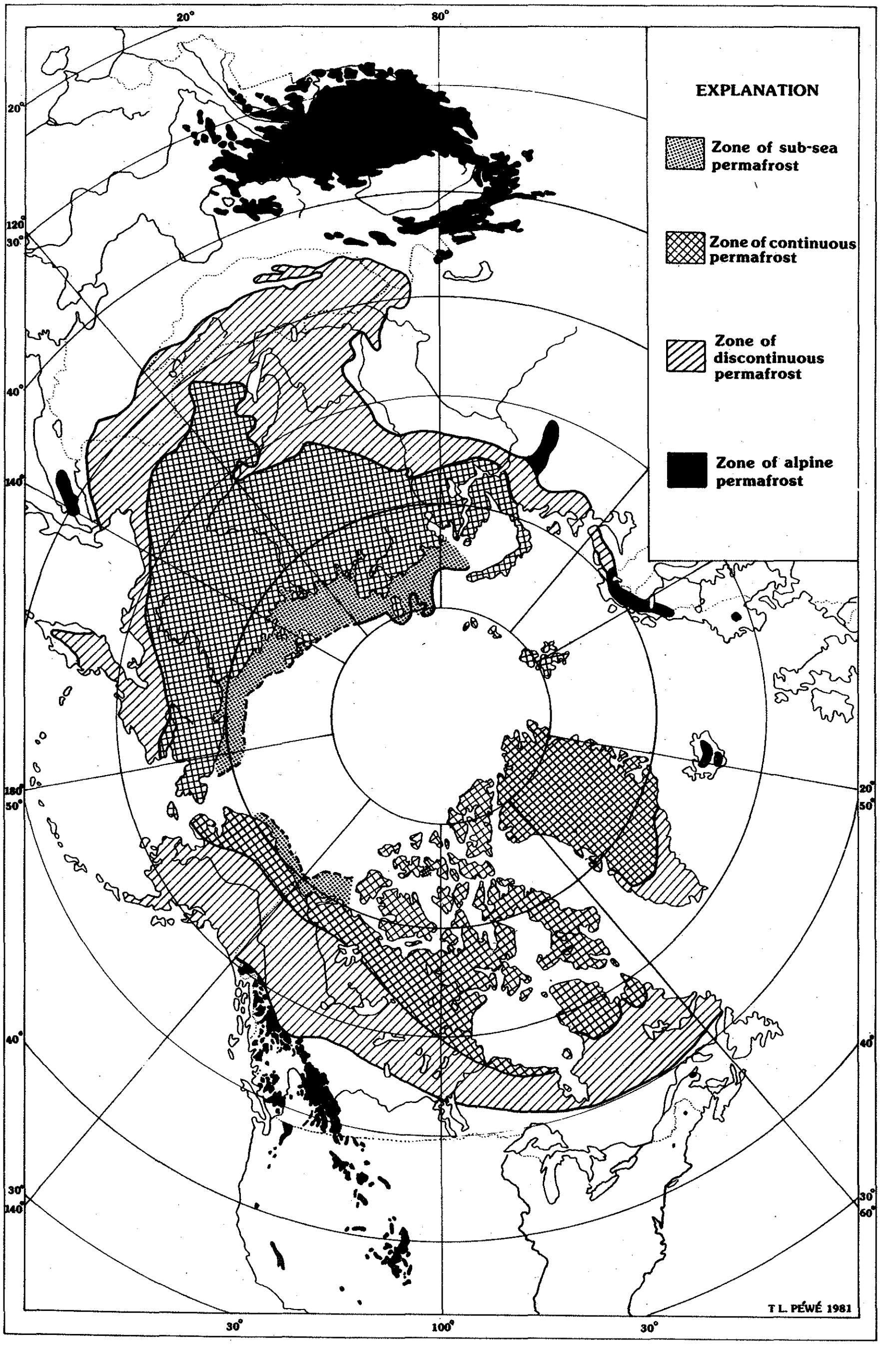


Fig. 1. Distribution of permafrost in the northern hemisphere. Isolated areas of alpine permafrost not shown on the map exist in high mountains and outside the map area in Mexico, Hawaii, Japan, and Europe

Company at Yakutsk. It was estimated that the permafrost there was 215 m thick. For the past century, scientists and engineers in Siberia have been actively studying permafrost and applying the results of their research to the development of the region. Similarly, prospectors and explorers were aware of permafrost in the northern part of North America for many years, but it was not until World War II were systematic studies of perennially frozen ground were undertaken by scientists and engineers in the United States and Canada. And not until 1949 was permafrost studied in the People's Republic of China.

Approximately 900 individuals from 25 countries participated in the conference. Major representation was from the United States and Canada, with other large groups from the People's Republic of China, West Germany and the United Kingdom. The technical program consisted of six panel sessions (pipeline construction, climatic change and geothermal regime, deep foundations and

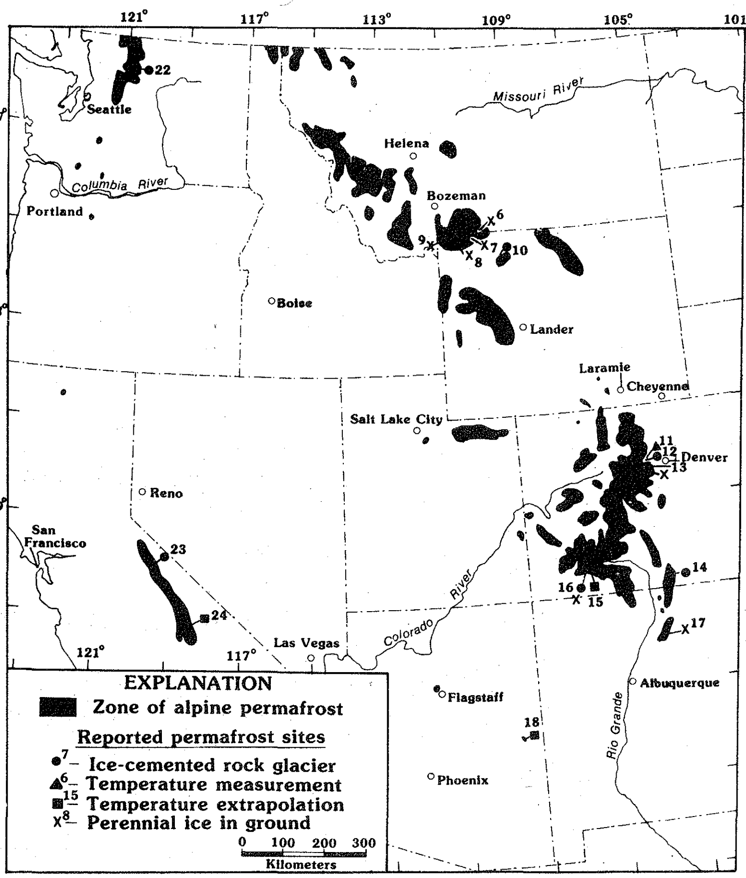


Fig. 2. Map of alpine permafrost in the western contiguous United States

Used with the permission of the Journal of Alpine and Arctic Research embankments, permafrost terrain and environmental protection, frost heave and ice segregation, and subsea permafrost) and invitational sessions from the People's Republic of China and the U.S.S.R. In addition, there were a total of 30 concurrent paper sessions, covering the seven major themes of the conference, and three full-day poster sessions. A total of 188 papers were listed for oral presentation, and 110 were scheduled for poster presentation. Most of the presentations at the conference involved research in the United States and Canada; about 80% of Alaska and 50% of Canada are underlain with permafrost. A major theme throughout the conference was the exploration, production, and transportation of petroleum and gas in Arctic and sub-Arctic regions, including the Continental Shelf of the Arctic Ocean.

Bonded permafrost (ground cemented with freshwater ice) 730 m thick occurs up to 10 – 20 km offshore in western North America. This has been referred to as subsea or offshore permafrost. Many studies that have been completed in the last 5 years or that are currently underway in the United States and Canada to determine the distribution, thickness and physical properties as well as the origin of subsea frozen ground were presented at the conference and discussed in the panel sessions. There were several new results and applications, including new methods and tools for subsea permafrost research. Considerable attention is now given to the role of salt and brine convection in the degradation of subsea permafrost.

New areas of permafrost research which were reported dealt with alpine permafrost and planetary permafrost. Alpine permafrost is the term now gaining popularity to designate perennially frozen ground in the high mountains and plateaus outside of the polar regions, which is now indicated as such on new maps. It is estimated that $2{,}3 \times 10^6$ km^2 of alpine permafrost exists in the Northern Hemisphere. Most of this lies in the high mountains and plateaus of western China – approximately 176×10^4 km^2 and represents 82% of the Chinese permafrost. About 100,000 km^2 of alpine permafrost exists in the western contiguous United States. It is evident that many problems of terminology, mapping techniques, and construction in such regions remain to be improved.

Many international planetary scientists reported widespread permafrost on Mars, and features analogous to Earth permafrost features. Features such as polygons and local ground collapse are known on Mars and the conference permitted scientists to examine comparable modern permafrost features on local and extended field trips.

As in the previous International Permafrost Conferences, a large number of the participants were interested in the various engineering and applied aspects of the problems concerned with seasonally and perennially frozen ground. Three of the discussion panel sessions and more than 30% of all the papers presented dealt with important research on topics in engineering.

A unique feature of the permafrost conference was the strong representation of scientists interested in periglacial research. Seven sessions were devoted to such subjects as ice wedges, ice wedge casts, freeze and thaw soil structures, patterned ground, rock glaciers, rock streams and similar phenomena. Much of the discussion involved the interpretation of inactive permafrost features in areas and countries where permafrost no longer exists. One of the great values of the study of periglacial features is that knowledge of active periglacial features permits an interpretation of the paleoenvironments in former permafrost areas in the temperate latitudes.

Perhaps the newest aspect of the conference was the major participation of scientists and engineers from the People's Republic of China. The 20 representatives from China made up the largest non-North American delegation. The group submitted 40 papers in English, all of which are published in the first volume of the proceedings. The special invitational session revealed for the first time the details and distribution character of permafrost in their country, and especially the problems encountered in construction of railroads in northeastern China and the highway problems on the Qinghai-Xizang (Tibet) Plateau. Approximately 22% of China is underlain by permafrost and upwards of 73% has only seasonally frozen ground. Most of the permafrost lies in the far west, or the Tibetan Plateau.

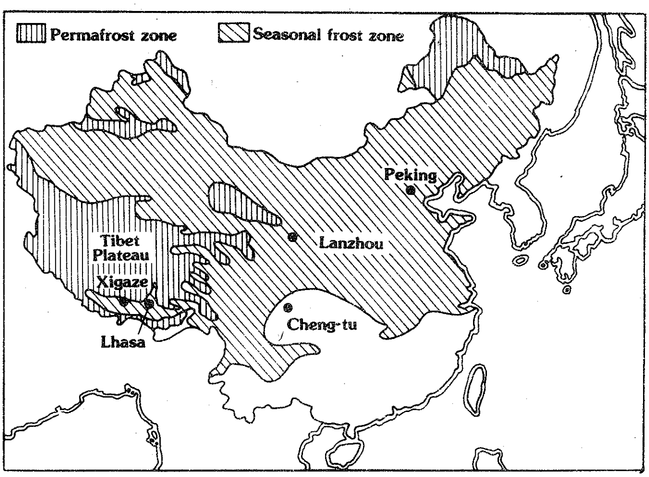


Fig. 3. Distribution of permafrost and seasonal frozen ground in the People's Republic of China (Academica Sinica)

Since the last conference, great strides have been made in frozen ground research in China. Scientists and engineers from more than 69 organizations are active in permafrost field and laboratory research. Most of the Chinese attendees were from the Institute of Glaciology and Cryopedology of Academica Sinica, the Chinese Academy of Railway Sciences, Provincial Low-temperature Institutes, Water Conservancy Surveys, and Universities.

PUBLICATIONS

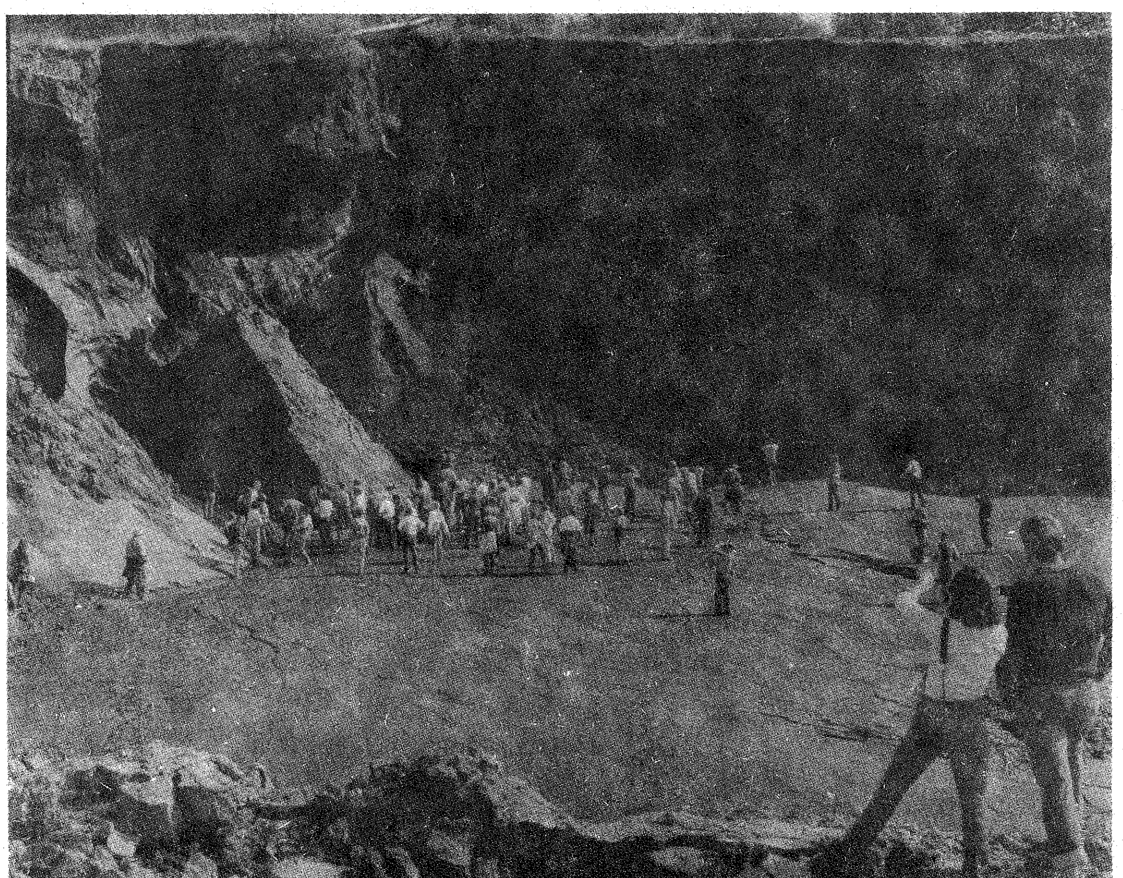
Registrants received a 278-page abstract volume 352 abstracts of papers, posters and panel sessions. This publication is available for $10 from the Geophysical Institute at the University of Alaska, Fairbanks, Alaska 99701, U.S.A. Registrants also received a 109-page well illustrated book of geologic hazards of the Fairbanks area, mainly permafrost characteristics, distribution and effect on man. Also distributed were four extensive quarto-size guidebooks for the extended pre- and post-conference field trips. The guidebooks were published by the Alaskan Division of Geological and Geophysical Surveys, and are available from their office at 794 University Avenue, Basement, Fairbanks, Alaska, 99701, U.S.A. Four more guidebooks for other extended and local field trips are now also available.

One volume of proceedings with 276 contributed papers and 3 invited papers involving more than 460 authors and totaling 1600 printed pages was published in December and is available as a quarto-size hardbound book for $65 from the National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418, U.S.A. A second volume, which includes panel discussions, invited papers opening and closing sessions, additional abstracts, and up to 50 contributed papers, were published in late 1984. In addition, a special bibliography of some 4500 permafrost citations of the last 5 years was published by World Data Center A for Glaciology in Boulder, Colorado, as Glaciological Data Report GD-14, and is available for $10. A total of more than 3100 pages of published documentation resulted from this conference.

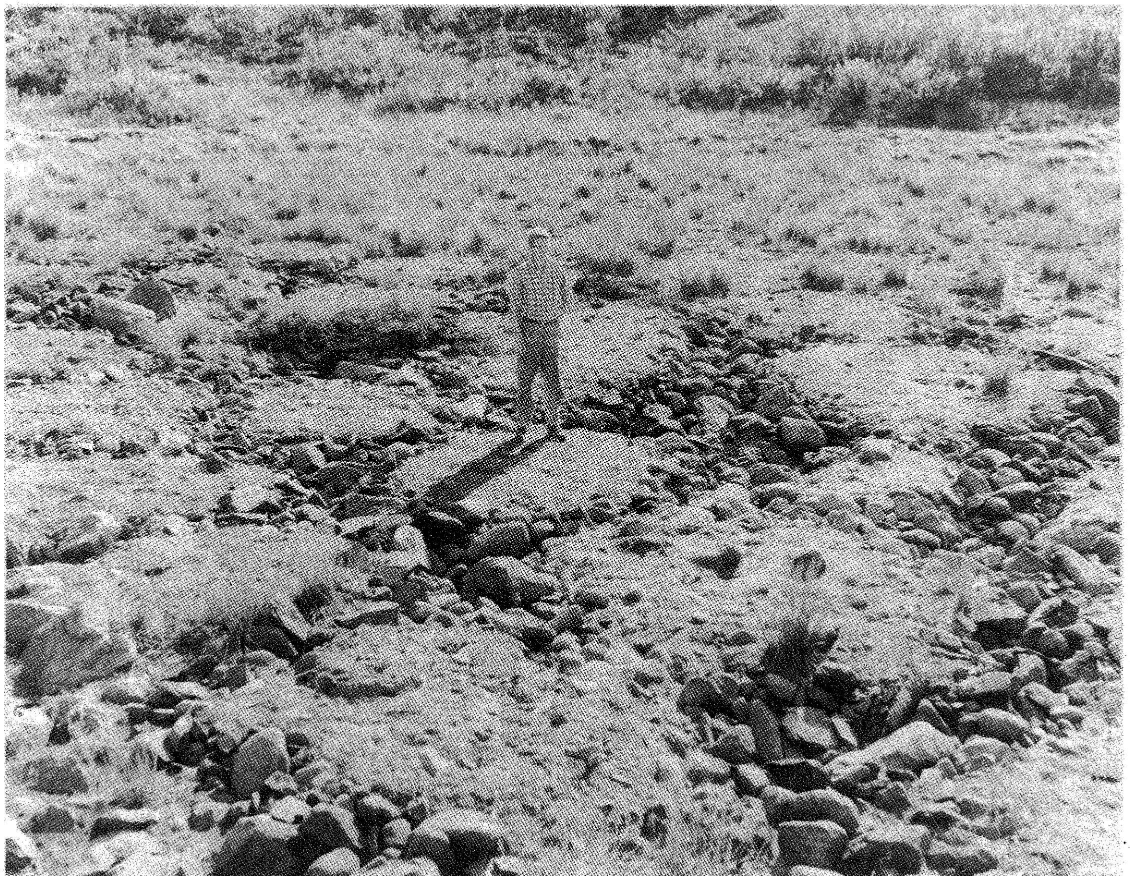
FIELD TRIPS

Field trips were the highlight of the conference. In addition to five extended field trips, three afternoons were taken from the conference schedule for trips to examine local permafrost phenomena. Pre-conference trips were made via the Alaskan Railroad from Anchorage to Fairbanks through the Alaska Range and another via bus from Fairbanks to Prudhoe Bay. By means of a chartered train, about 75 participants took 3 days to examine permafrost problems encountered along the 400 km route, including landslides on thawing perennially frozen clay in the Nenana River Canyon, frost heaving of bridge piles, strip coal mining in a permafrost environment. The field trip group stopped at many sites, including localities where test sections of the track were built over specially insulated subgrade to retard the thawing of permafrost. Among the participants was a 10-person railway delegation from the People's Republic of China, lead by Mr. LI YUSHENG, Vice Principal of the Chinese Academy of Railway Sciences.

The permafrost terrain from Fairbanks 800 km north to Prudhow Bay along a

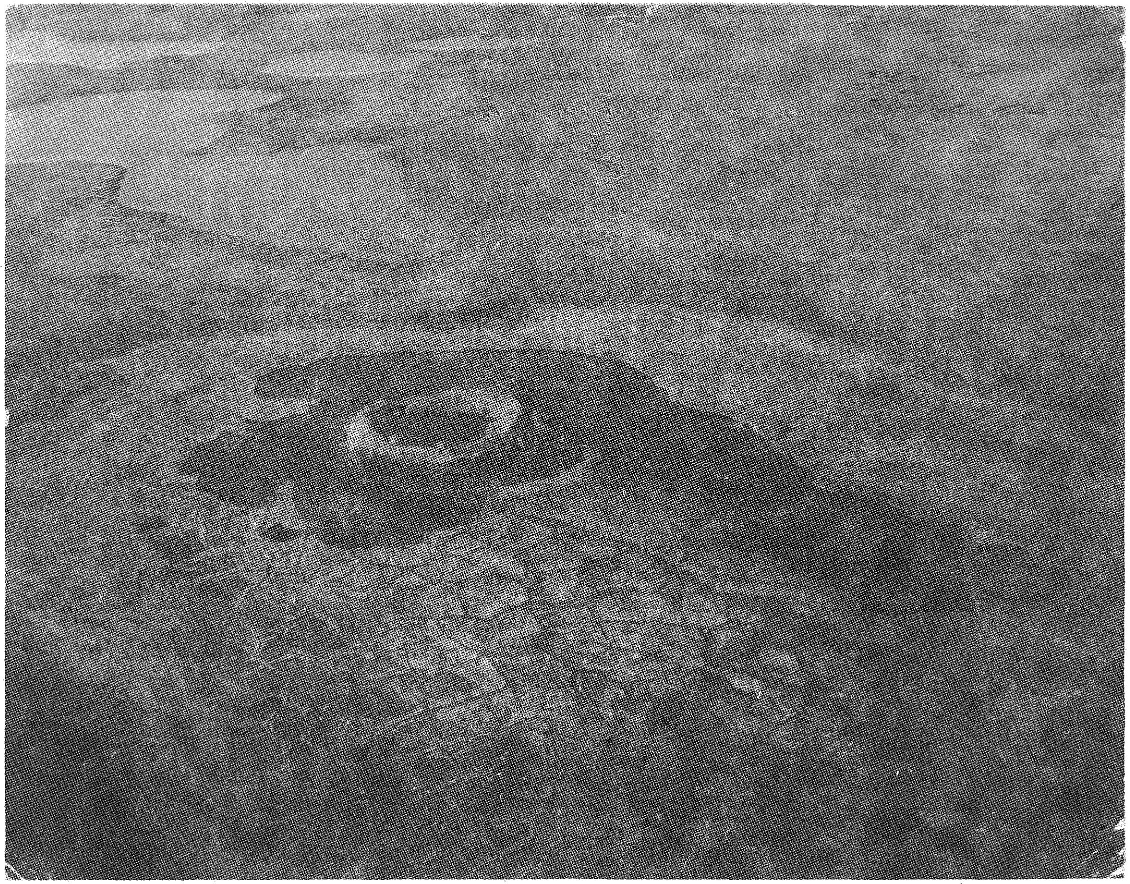


Pl. 1. Local field trip participants examining huge ice wedges in perennially frozen retransported loess of Wisconsin age near Fairbanks



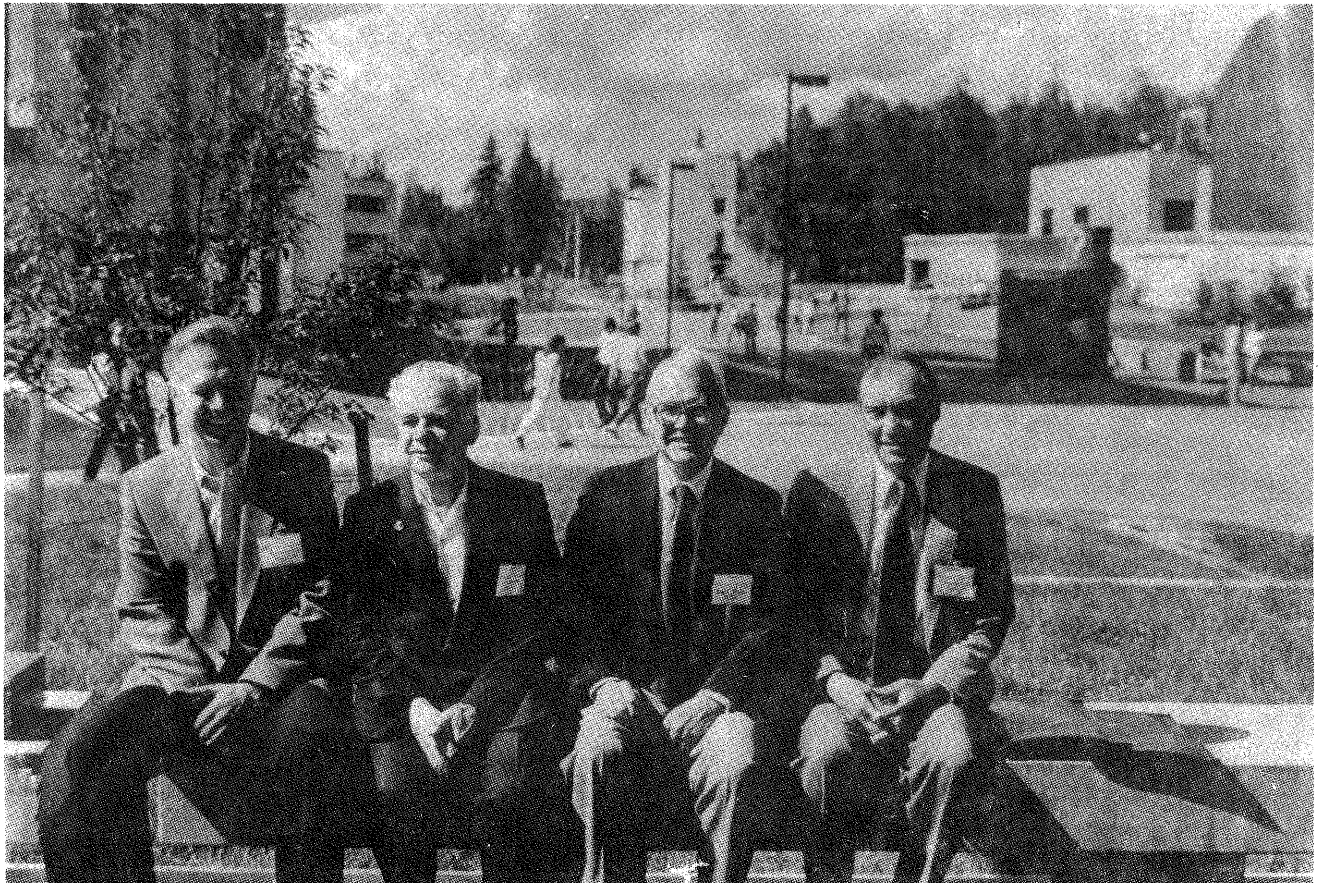
Photograph No. 1764 by T. L. Péwé, June 14, 1958

Pl. 2. Sorted stone circles in bottom of small drained pond along Denali Highway; south side of the Alaska Range at Alpine Creek



Photograph No. 1047, by T. L. Péwé, August 18, 1954

Pl. 3. Collapsed pingo on Mackenzie Delta near Tuktoyaktuk, 90 miles north of Aklavik, in northwestern Canada



Photograph No. PK 25499 by T. L. Péwé, July 21, 1983

Pl. 4. Founding Officérs of the newly formed International Permafrost Association. Dr. K. Flaate, Norway, 2nd Vice-president; Academician P. I. Melnikov, USSR, President; Dr. T. L. Péwé, USA, Vice-president; Prof. J. Ross Mackay, Canada, Secretary. University of Alaska, Fairbanks campus pioneer road was examined by 65 participants, representing 12 countries on a 5-day pre-conference trip. The route parallels the Trans-Alaska Pipeline System and, although the southern part of the route lies in the discontinuous part of the permafrost zone, the entire route is dominated by permafrost close to the ground surface.

Several permafrost features not common to the other extended field trips were examined along the highway. The road, for the most part, occupies valley bottoms and is in the area of widespread icings (aufeis). There icings or sheets of surface ice composed of a number of ice layers form during successive overflows in the winter on broad braided river flood plains, narrow channels of small streams, or downstream from seasonal or perennial springs. Icings are an important problem to consider the construction of highways and pipelines. Some icings grow to be more than 5 m thick and cover hundreds of hectares.

The 230-page guidebook notes that rock glaciers are very common in the central Brooks Range, and more than 500 lobate rock glaciers occur in the area around Atigun Pass, where the highway crosses the Continental Divide. On the south side of the range, about 50% of the lobate rock glaciers are active, on the north side 70% are active.

Flows of water-saturated snow, called slush flows, are common in stream courses in the alpine terrain in the central Brooks Range. They are a type of wet-snow avalanche, primarily occurring in Arctic and sub-Arctic mountainous regions, that is initiated by rapid spring melting of seasonal snow cover. They are powerful geomorphic agents, and their potential adverse effects on engineering structures are only now being fully appreciated in Alaska.

Past and present permafrost and Quaternary geology were reviewed in detail by the 48 participants of the 5 day trip from Fairbanks 750 km to Anchorage along the Richardson and Glenn Highways as one of the three extended post-conference trips. A 263-page illustrated guidebook reviewed the distribution, characteristics, and effect on man of the existing permafrost. Permafrost is up to 120 m thick near Fairbanks, thins to 30 to 60 m in the Copper River Basin, and exists only as small relic patches a few meters thick in the Anchorage area at the southern border of permafrost.

The discontinuous permafrost in south-central Alaska is relatively warm, $-0.5°C$ to about $-1°C$. Although much permafrost in the area is probably relic (from colder Wisconsin-age conditions) it also forms today. Pre-Wisconsin permafrost probably disappeared during the widespread thawing in Sangamon time.

In the Big Delta area, large-scale polygons occur on gravel outwash plains and are underlain by ice wedge casts of late-Wisconsin age. The ice wedge casts, plus the lower snowline calculated from the adjacent empty cirques, indicates that the mean annual air temperature was about 3°C colder than today, and permafrost was more widespread.

The field trip group examined the Alaska pipeline (Trans-Alaskan Pipeline System) from Fairbanks to Glennallen (approximately 300 km) and associated related permafrost problems. The Alaska pipeline is the largest completed private construction project in the world. Of a total cost estimated at $8 billion, about $1 billion was spent for permafrost study and special construction techniques to overcome problems created by frozen ground.

Since the crude oil transported in the pipeline is warmer than the surrounding permafrost, the ice-rich frozen ground would have thawed if the pipeline had been conventionally burried. Therefore, it was necessary to place about 600 km of the 1280 km pipeline above ground in these ice-rich areas. The above-ground pipeline is supported on 123,000 vertical support members which are 45-cm diameter steel pipes. A cross beam installed between these steel vertical members, and to guard against frost heaving, it is necessary to keep the piles frozen in permafrost. This can be done artificially and mechanically refrigerating the pile, which is very expensive. Recently, the thermal pile has been developed. Thermal piles are used on the Alaskan Pipeline and to date have been quite successful. This techniques consists of using anhydrous ammonia gas in the vertical steel pipe. In the winter, the gas rises to the top, cools, liquefies, and sinks to the bottom where it warms, boils, and again rises to the top hereby chilling the ground whenever the ground temperature is warmer than temperature in the air. The devices are non-mechanical and self-operating. It has been described as a single-phase, conduction-cell, heat-transfer system requiring no external power source. Aluminum radiator fins on top of the vertical support members permit rapid dispersion of heat.

One of the major periglacial phenomena examined on the trip was the well-developed inactive cryoplanation terraces on south side of the Alaskan Range along the Denali Highway. Cryoplanation terraces are giant bedrock steps that form on the crests and flanks of ridges and hills when frost action under and near snowbanks causes bedrock scarps to erode and retreat.

The cryoplanation terraces at this locality are on hilltops at about 1200 meters elevation; scarps are 3 to 10 meters high and the reads have broad convex slopes, generally 1 to 5°. The treads are bedrock surfaces mantled by slity, angular bedrock rubble. These particular well-developed terraces were formed in Wisconsin time and have been inactive for the last 10,000 years. It is believed that they form only under very rigorous periglacial environments.

From the Alaskan Range, the group crossed the Copper River Basin and proceeded along the Matanuska Valley, spending some time examining the Matanuska Glacier. West of the glacier, the late Wisconsin and Holocene glacial deposits were examined in the Upper Knik Valley region.

Thirty-seven persons participated in the 5-day post-conference field trip to Prudhoe Bay to view permafrost features and oil ield facilities. The Prudhoe Bay field was discovered in 1968 and the 9.6 billion barrels of proven reserves suggests that 33 percent of the oil reserves of the United States may be in northern Alaska. It is one of the largest oil fields known in a permafrost environment. The land in the Prudhoe Bay area is within the zone of continuous permafrost which is 660 m thick and has a temperature of about $-9°C$. Prior to the development of the Prudhoe Bay oil field, permafrost was undocumented beneath the ocean (Beaufort Sea) to the north, although it was commonly assumed to exist. Permafrost under the Beaufort Sea began to form in Wisconsin time when the Continental Shelf was exposed. A thickness of more than several hundred meters of sediments froze up to 20 – 30 km seaward from the present shore. These frozen sediments have since been inundated by the return of the sea, creating unique chemical and thermal systems. Two guide-books, one on the Colville Delta (34 pages) and one on the Prudhoe Bay area (200 pages) were available to the participants.

Forty persons from 13 countries participated in the Canadian field trip from Dawson City in the discontinuous permafrost zone to Tuktoyaktuk in the continuous permafrost zone of the Arctic. The 186-page guide-book describes the glacial geology and permafrost conditions of this northern interior Yukon and Mackenzie Delta regions of northern Canada. The excursion was conducted with the cooperation of the Commission of the Significance of Periglacial Phenomena of the International Geographical Union.

The Tuktoyaktuk Peninsula on the Arctic coast is one of world's most active areas of permafrost research and petroleum investigation. The peninsula is composed of frozen ice-rich till, and offers excellent opportunities for permafrost research and oil and gas exploration. Imperial Oil Company, Ltd., has been investigating the area since 1965. The first well was drilled in 1967, and there are now 118 gas wells, including 34 located offshore; of these 118, 67 are dry. Permafrost is 760 m thick on shore and extremely ice-rich. Considerable effort must be made to protect the permafrost during drilling.

Exploration for oil and gas offshore has been conducted by drilling from ships and from 20 artificial islands. Land created in 7 – 10 m of water by dredging and piling up sand and gravel. The islands rise 5 m above the water and cost $20 – 40 million each. Subsea permafrost can have considerable influence on the design of facilities like those to be used in northern waters. Pipelines are subject to damage by differential movement, and drilling and dredging operations may be influenced by the presence of the frozen ground. Gas hydrates have been widely encountered in wells drilled off shore in the nearby Beaufort Sea. It is apparent that permafrost conditions are of prime importance to all aspects of subsea northern resources development. The presence and properties of permafrost and gas hydrates must be fully considered in the design of structures and wells founded on the bottom or sub-bottom.

The Tuktoyaktuk Peninsula is the center of extensive research on pingos. A pingo is an isolated, steep-sided hill generally circular to oval in ground plan and from 3 to 50 m in height. It is composed of a massive core of ice overlain by several meters of silt, sand or peat. Pingos form when large masses of saturated sediment freezes near the permafrost surface. About 1350 pingos occur in the near-by coastal plain and 65 are within a 10 km radius of Tuktoyaktuk. The best known pingo in Canada is Ibyuk pingo, whose center rises 48 m above sea level. It is one of the many in the Pingo National Landmark area near Tuktoyaktuk.

LOCAL FIELD TRIPS

Local field trips during the conference permitted most of the participants to observe permafrost exposures and examples of its effect on construction. For example, a section of the paved highway over ice-rich permafrost at the entrance of the University of Alaska demonstrated how ground subsidence creates maintenance problems and inconveniences. Many of the participants took advantage of the special two-hour trips to a 120-m-long tunnel in permafrost used for engineering and scientific research. Trips emphasizing the geological aspects of permafrost were run concurrently with those emphasizing engineering aspects.

Permafrost is present nearly everywhere in the Fairbanks area except beneath hilltops on moderate to steep south-facing slopes. The Tanana River floodplain is underlain by perennially frozen ground, but large ice masses are absent. The gently sloping alluvial fans extend from the upland to the floodplain and creek--valley bottoms, and are underlain by continuous permafrost with abundant large ground ice masses.

The geological participants examined perennially frozen retransported loess of Wisconsin age with well-developed ice wedges 1 m wide in 15-m-high active placer gold mining exposures near Fairbanks, and noted the Quaternary stratigraphy and history of the frozen ground. Open system pingos, collapsed pingos, and thermokarst pits were also examined.

On the engineering trips, problems of highway construction were examined, as were water system and sewage treatment plants in a subarctic environment. Participants also examined a facility designed to study frost heaving in the construction of a potential multi-billion dollar chilled-gas pipeline in frozen ground.

INTERNATIONAL PERMAFROST ASSOCIATION

During the conference, the Canadians convened a meeting between the senior U.S.S.R., U.S.A., China, and Canada attendees to discuss the formation of the International Permafrost Association (IPA), a concept which was considered earlier at the 2nd and 3rd conferences. The main objectives of the association are to foster the dissemination of knowledge concerning permafrost and to promote cooperation among members of national or international organizations engaged in scientific investigations or engineering work on permafrost, mainly by convening the International Permafrost Conferences at intervals of approximately 5 years. The Canadians offered to support and host a secretariat for the first 5 years.

The founding slate of officers was nominated and approved: President: Academician P. I. MELNIKOV, Director of the Permafrost Institute of the Academy of Sciences, U.S.S.R.; Vice-President: Professor Troy L. PÉWÉ, U.S.A., Professor of Geology at Arizona State University and Chairman of the Organizing Committee of the Fourth International Conference on Permafrost; Secretary-General: Professor J. ROSS MACKAY, Professor of Geography, University of British Columbia, Vancouver, Canada.

Dr. Kaare FLAATE, Chairman of the Norwegian Committee on Permafrost announced that Norway would host the Fifth International Conference in 1988 in Trondheim. President MELNIKOV of the International Permafrost Association announced that Dr. FLAATE had been appointed Second Vice-president of the organization. The Canadians offered to support a secretariat for the first 5 years.

ACKNOWLEDGEMENTS

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