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PERMAFROST

FOURTH INTERNATIONAL CONFERENCE
Fairbanks, Alaska, U.S.A. July 18-22, 1983
University of Alaska

Abstracts and Program

organized by:
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National Academy of Sciences

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PREFACE

Perennially frozen ground, or permafrost, is estimated to underlie 20% of the land surface of the earth and affects many of man's activities and causes problems not experienced elsewhere. Agriculture, mining, water supply, sewage disposal, and construction of air fields, roads, railroads, urban areas, and recently," oil and gas pipelines, require extensive knowledge of the distribution, properties, and engineering performance of perennially frozen ground.

Although the existence of permafrost was 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 Shargin Shaft, an unsuccessful well dug for the governor of the Russian-Alaskan Trading Company at Yakutsk. It was estimated that the permafrost there was 215 m thick. For the last 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 the North America for many years, but it was not until World War 11 that systematic studies of perennially frozen ground were undertaken by scientists and engineers in the United States and Canada.

Because of the explosive increase in research concerning scientific and engineering aspects of frozen ground in several countries since the late 1940's, it became apparent that it was necessary for scientists and engineers working in the field to exchange information on an international level. Since that time, work in Canada, the USA, the USSR, and more recently in Japan and China, among other countries, has created a vast amount of basic and applied information on permafrost.

To exchange information on the subject of permafrost, the First International Conference on Permafrost was held in the USA at Purdue University in 1963. This relatively small conference was extremely successful and yielded a publication which is still used throughout the world. Ten years later, in 1973, the Second International Conference on Permafrost was held in Yakutsk, Siberia, USSR. Approximately 400 participants attended. In 1978, Canada hosted the Third International Conference on Permafrost in Edmonton, Alberta, with field trips to northern Canada. Approximately 500 participants from nine nations attended and Chinese scientists were present for the first time. In Edmonton, it was decided that the US would hold the Fourth International Conference on Permafrost, and a formal invitation was extended by the University of Alaska to hold the Conference on its campus in Fairbanks in *1983.*

The reasons for holding a conference every 5 years or so are: 1) to bring together scientific, engineering, and user communities **to** discuss the state-of-the-art in these respective fields; 2) to allow national and international participants to observe and discuss permafrost conditions and engineering problems; and 3) to relate permafrost conditions to other regions of the world, particularly to areas where only seasonally frozen soils currently exist.

The Fourth International Conference on Permafrost is being held at the University of Alaska at Fairbanks from July 17 to 22, 1983. It is organized by the National Academy of Sciences' Polar Research Board and the State of Alaska, with the University of Alaska in Fairbanks being the host and local organizer. Local and extended field trips to various parts of the State, to examine permafrost features, are an integral part of the Conference. Many engineering and scientific disciplines are represented, including civil and mechanical engineering, soil mechanics, glacial and periglacial geology, geophysics, marine science and technology, climatology, soils, hydrology, and ecology.

The sessions start with panel discussions and are followed by oral and poster presentations. The panel reviews consider the following themes: pipelines, climatic change and geothermal regime, deep foundations and embankments, permafrost terrain, environmental protection, frost heave and ice segregation, and subsea permafrost. Approximately 350 papers and posters from 25 countries are to be presented. The Conference proceedings will be published by the National Academy of Sciences' Academy Press. In addition a series of field trip guidebooks has been published by the Alaska Division of Geological and Geophysical Surveys and a special bibliography of some 4,500 permafrost citations was published by World Data Center A for Glaciology in Boulder, Colorado, as Glaciological Data Report GD-14. This last publication covers much of the world literature on permafrost over the last five years.

Troy L. Péwé, Chairman
Organizing Committee

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IMPORTANT INFORMATION

How to Locate Any Abstract

1. **If you know the author's name...**

Turn to page 263 which list all authors in alphabetical order. The page number in the last column indicates where the abstract will be found, the second column indicates the session in which the paper will be given. Time and location of sessions are given in the program of technical sessions on pages 20-39.

2. **If you want to read the abstracts of any particular session. . .**

Turn to pages 17-39 which give the authors, location and time of sessions. Then turn to page 263 which list all authors in alphabetical order. The page number in the last column indicates where the abstract will be found.

Authors' Briefing

There will be brief meetings for all authors presenting formal papers and all panel members with their session chairmen. These meetings will be held in the Green Room (down the stairs from the Regents Great Hall; see map on page 6). For morning sessions, authors and chairmen will meet from 8:00-8:30am; for afternoon sessions from 1:00-1:30pm on Monday and 1:30-2:00pm on Wednesday. 35mm slide trays will be available in the Green Room, as well as viewing equipment.

GENERAL INFORMATION

Registration

Registration is required for all attendees, including all field trip participants and guests. Name badges are required for admission to all events.

Full payment must accompany registration. Only U.S. funds are accepted on-site. Visa and Mastercard will be accepted.

Registration Fees: Full Registration - $225
Student Registration - $35
Daily Registration - $50
Accompanying Persons Registration - $50

Students, daily registrants and accompanying persons will not receive the pre- and post-conference proceedings or field trip guide books, but copies may be purchased.

Registration Schedule

Regents Great Hall, University of Alaska, Fairbanks

Sunday, 17 July	10:00am - 9:00pm
Monday, 18 July	8:00am - 5:00pm
Tuesday, 19 July	8:00am - 5:00pm
Wednesday, 20 July	8:00am - 5:00pm
Thursday, 21 July	8:00am - 5:00pm
Friday, 22 July	8:00am - 12:00noon

Ticket Sales

Tickets will be needed for the functions listed below. Tickets *will* be available at the registration desk on a first-come, first-serve basis.

Banquet, Thursday Evening: $10 (subsidized)
Maximum number of people: 500

(If you have paid for the banquet as part of your pre-registration, a ticket will be given to you automatically when you register).

Riverboat "Discovery" Dinner Cruise, Wednesday Evening: $25
Maximum number of people: 240

Local Field Trips: No charge, *but you must pick up tickets at the registration desk for any of the local field trips you want to take.*

Reception, Sunday Evening
& Barbecue Tuesday Evening

No tickets needed. Your registration badge is your admission ticket.

Campus Housing

The housing desk in Bartlett Hall is open 24 hours daily. Please register and pay your housing charges there.

Food Service

Meals are served in the University Commons at the following times:

Breakfast	7:00-8:30am	Monday to Saturday
Lunch	12:00-1:30pm	Monday
	12:30-2:00pm	Tuesday to Friday
Dinner	6:30-8:00pm	Monday to Friday (except Tuesday when a barbecue is scheduled)

Light meals and snacks are available in the Wood Center cafeteria, upper level. Soup, salad, sandwiches and beer and wine are available during the lunch hour in Sir Walter's, a pub on the lower level of the Wood Center.

There are several pizza and sandwich restaurants on College Road, within walking distance of the University. A complete restaurant guide for Fairbanks is available at the registration desk.

Transportation

Buses will pick up arriving conference attendees at the airport and take them to the dormitories or downtown hotels. Buses will take registrants to the airport on Friday afternoon and all day Saturday, leaving the dormitories and downtown hotels 1½ hours prior to *all* flight departures. *Please sign up at the registration desk if you want to take one of these buses.*

Buses will also pick up registrants at *downtown* hotels and return them daily. Schedules will be available at the downtown hotels and at the registration desk. Special buses will take everyone to and from the social functions.

Getting Around During the Day

The North Star Borough operates a bus service (MACS) between the University, downtown Fairbanks and other locations. Bus schedules are available at the registration desk.

Press Room

A press room will be in operation throughout the conference in the Kayak Room, next to the Regents Great Hall. The studios of KUAC-FM/TV are located on the level below the Regents Great Hall. Registration is complimentary to those with press credentials.

Telephones

Conference Secretary	(907) 474-7864
Registration Desk	474-7258
Travel Desk during Registration	474-7260

Pay telephones (25¢) are available for outgoing calls during the conference in the Wood Center and in Bartlett Hall.

Post Office

A post office is located in the basement of Constitution Hall.

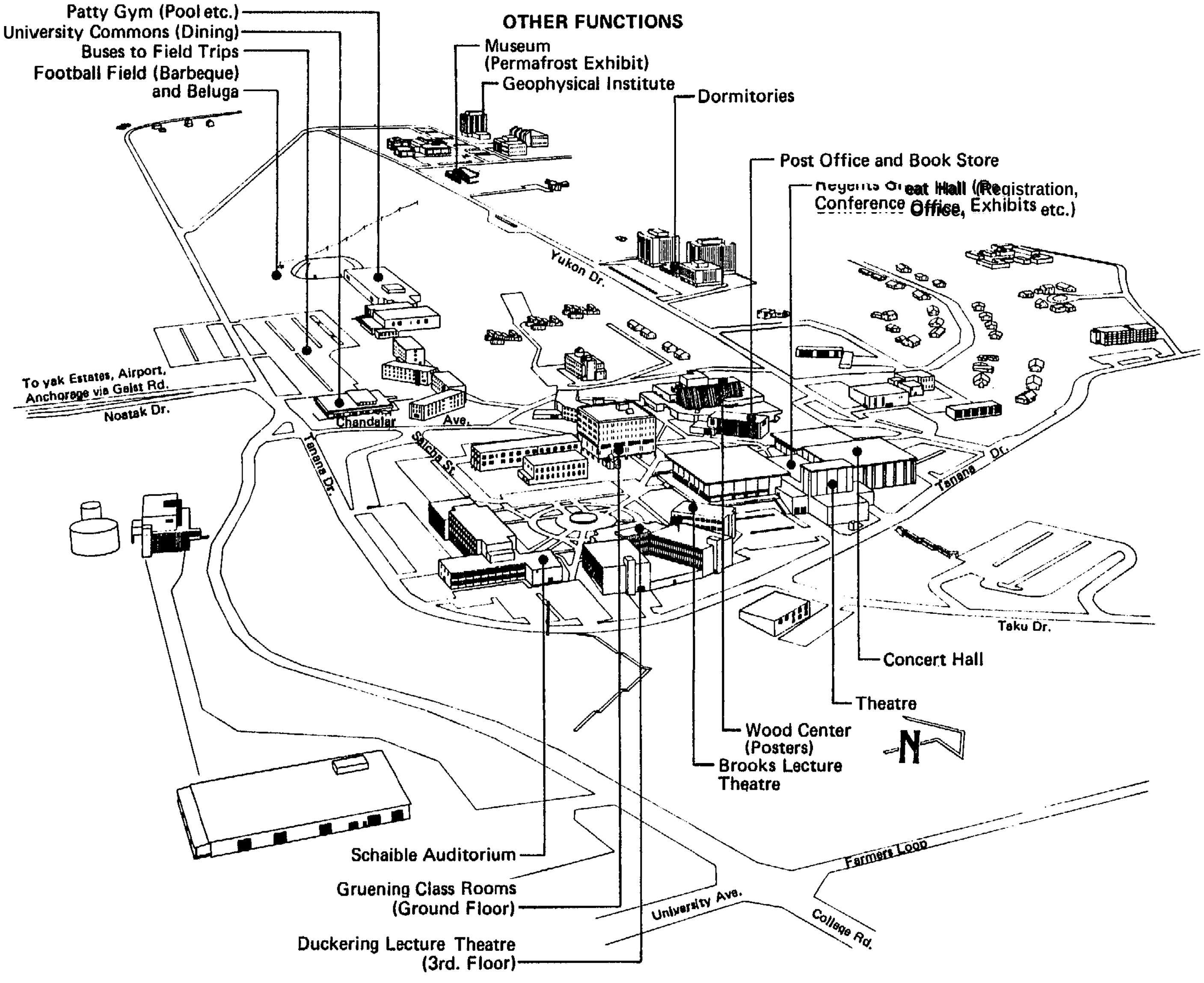
Book Store

A bookstore and souvenir shop is located on the second floor in Constitution Hall.

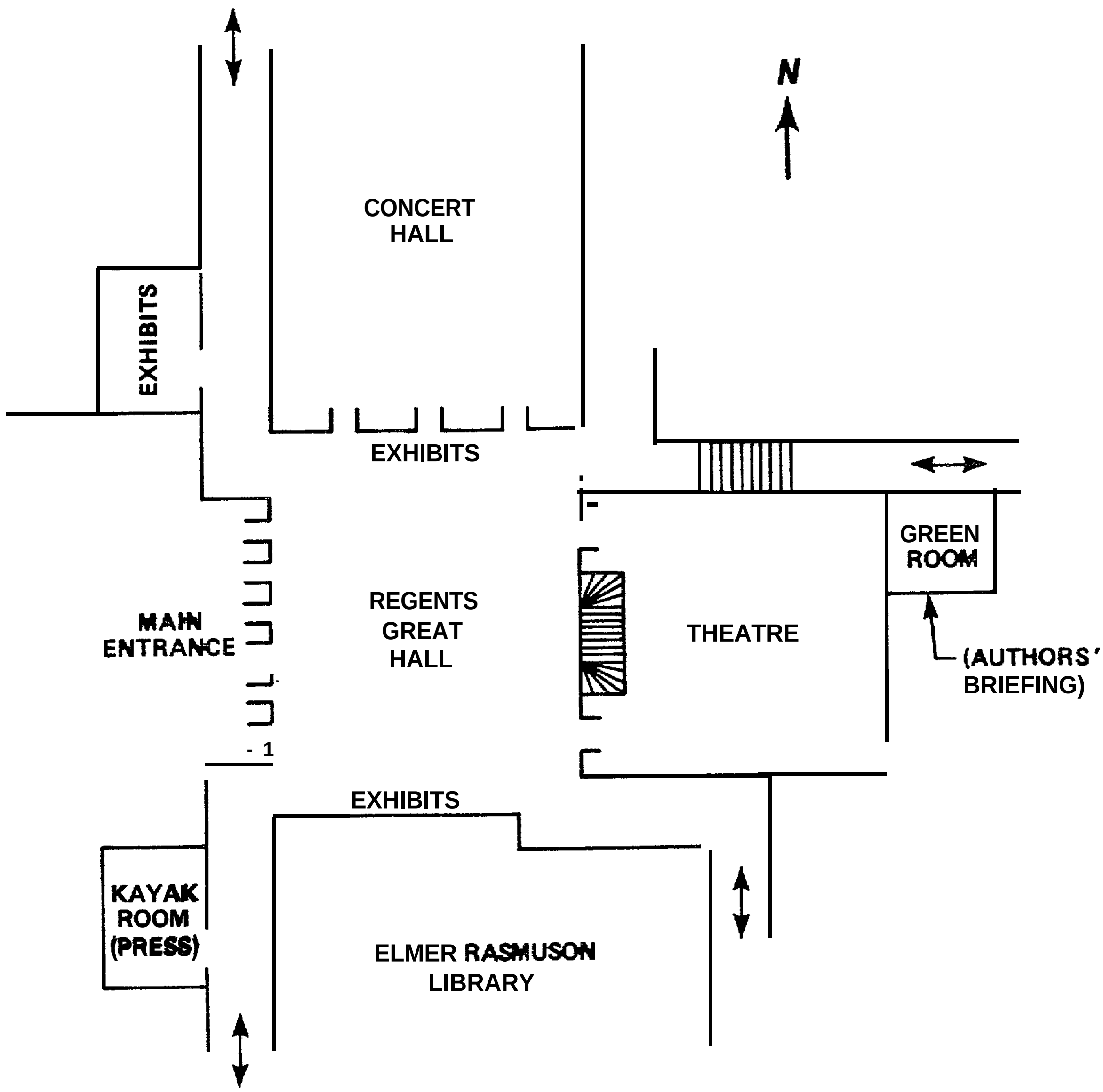
Banking

The closest bank is located at the corner of College Road and University Avenue, within walking distance of the University. Foreign currency cannot be exchanged there, however. If you need to exchange currency, please contact the registration desk.

Map of the campus of the University of Alaska, showing the locations of sessions and other functions.



MAP OF THE REGISTRATION AREA



SOCIAL PROGRAM

Reception

Sunday, 17 July, 5:00 -9:00pm Regents Great Hall, Campus

This is a welcoming party for all registrants. Drinks and hors d'oeuvres will be served. Admission is free of charge, but name badges must be worn (the registration desk is open in the Regents Great Hall during the reception).

Barbeque

Tuesday, 19 July, 6:30-10:00pm Football Field, Campus
(Beluga inflated dome next to football field in ease of rain)

Admission is free of charge, but name badges must be worn.

Dinner Cruise on the Sternwheeler Riverboat "Discovery"

Wednesday, 20 July, 6:30-10:00pm Cash bar available.

Tickets for this event should be purchased at the registration desk as soon as possible (first come, first served), since only 240 seats are available. Cost is $25, including a buffet dinner.

Banquet

Thursday, 21 July, 6:30-10:00pm Travelers Inn, Fairbanks

A nominal $10 will be charged. Tickets should be purchased as soon as possible at the registration desk since only 500 seats are available. Buses will transport attendees to and from the banquet. A schedule will be posted and announced.

Spouses and Accompanying Persons

A social program of sightseeing, shopping, and activities associated with "Golden Days" in Fairbanks, has been arranged. For details check at the special registration desk in the Regents Great Hall. The desk will be open on Sunday from 5:00-9:00pm and daily from Monday to Thursday at 8:00-10:00am prior to excursions.

EXHIBITS AND FILMS

Exhibits are located in the Regents Great Hall (and in a studio near the northeast corner of the Great Hall - see map on page 6). These exhibits will be in place throughout the conference. As of mid-June the following (commercial and non-commercial) exhibitors have requested space.

Alaska Department of Transportation & Public Facilities
Alaska Magnetics
American Association of Civil Engineers
Associated Pile and Fitting Corporation
Cold Regions Research and Engineering Laboratory
Engineering Sales Corporation
ERTEC, Inc.
Geological Survey of Canada
Geophysical Institute, University of Alaska
Institute of Arctic and Alpine Research, University of Colorado
R. A. Kreig & Associates, Inc.
Mobile Augers and Research Ltd.
National Aeronautics and Space Administration
National Research Council, Canada
3M Company
United States Geological Survey
World Data Center A for Glaciology

A permafrost exhibit is located in the University of Alaska Museum (see map on page 5}.

The Elmer Rasmussen Library (see map on page 6) is one of the major northern studies resource centers of the world. Books, maps, etc., are on display there.

Films

Films on permafrost-related subjects will be shown in the Eielson Building at the following times:

Tuesday, July 19	10:30 - 2: 00pm
Thursday, July 21	10:30 - 2:00pm
Friday, July 22	10:30 - 2: 00pm

LOCAL FIELD TRIPS

Important Information

Please register for the local field trips that you wish to take. In some instances there are only a limited number of trips or seats available and these will be available on a first-come basis. All these trips are free of charge, but tickets are required which can be obtained at the registration desk.

Field Trip Descriptions

Among the highlights of the conference are field trips in the immediate Fairbanks area to examine engineering and geological aspects of permafrost. During the conference, three afternoons (Tuesday, Thursday and Friday) and two evenings (Monday and Wednesday) have been set aside for these trips. No technical sessions will be held during these periods. (See conference calendar). The trips are provided at no extra cost to registrants. Guidebooks will be issued.

There are seven tours: two different tours on geological and vegetation aspects of permafrost and its relations to construction, and two different tours on engineering aspects of permafrost. A special tour is scheduled to a permafrost tunnel, and one to a frost heave facility. In addition to these bus trips there is a self-guided (with brochure) walking tour to examine permafrost features on the University campus.

Geological-Construction I (East, Tuesday)

The two tours on Geological-Construction aspects of permafrost are organized by R. D. Reger, Alaska Division of Geological and Geophysical Surveys, and T.L. Péwé, Arizona State University.

Trip I includes an examination of large ground ice masses in an active placer gold mine, the trans-Alaska pipeline, construction problems with roads and buildings, and thermokarst pits and mounds. (walking *boots preferable).*

Geological-Construction II (West, Thursday)

Trip 11 includes examination of thermokarst mounds and pits, open-system pingos, collapsed pingos, Quaternary stratigraphy, relationship of vegetation to permafrost and construction problems with roads and buildings *(walking bouts preferable).*

Engineering I (Southeast, Tuesday)

Organizers of the engineering permafrost field trips are A. J. *Alter,* Engineering Consultant, and F. L. Bennett, University of Alaska.

The Engineering I tour will visit the Fairbanks Waste Treatment Plant, where several energy conservation techniques are in use. The second stop will be the Borough Baler Facility, and the final stop will be a tour of the water treatment plant which uses waste heat from the MUS Power Plant to enhance water treatment and distribution.

Engineering II (East, Thursday)

The Engineering II tour will take the participants to a highway permafrost experiment, a close-up view of the Trans-Alaska Pipeline, and a walk through the University Utilidor System. Along the way, examples of frost jacking, permafrost subsidence, and an experimental solar culvert thawing device will be seen.

Permafrost Tunnel (Continuous 2-hour trips Monday and Wednesday evenings, and Tuesday, Thursday and Friday afternoons)

This visit is to a tunnel cut into perennially frozen organic-rich silt, and down into the underlying placer gold-bearing gravel. Excellent exposures of ice wedges and fossils are present.

Frost I-leave Test Facility [Tuesday, Thursday & Friday afternoons, 2-hour trip)

A frost heave test facility operated by Northwest Alaska Pipeline Company will be visited. This facility includes refrigerated buried sections of pipeline, insulated by a variety of different methods, and extensive instrumentation to measure temperatures and frost heave.

Campus Walking Trip (Friday afternoon)

The University of Alaska Museum has provided a self-guided trail tour brochure examining the thermokarst mounds and pits and vegetation sequences in a field at the northwest corner of the campus.

The trail starts at an octagonal wooden building, 100 m west of the Geophysical Institute (West Ridge). The tour is about 200 m walking distance into the area and back.

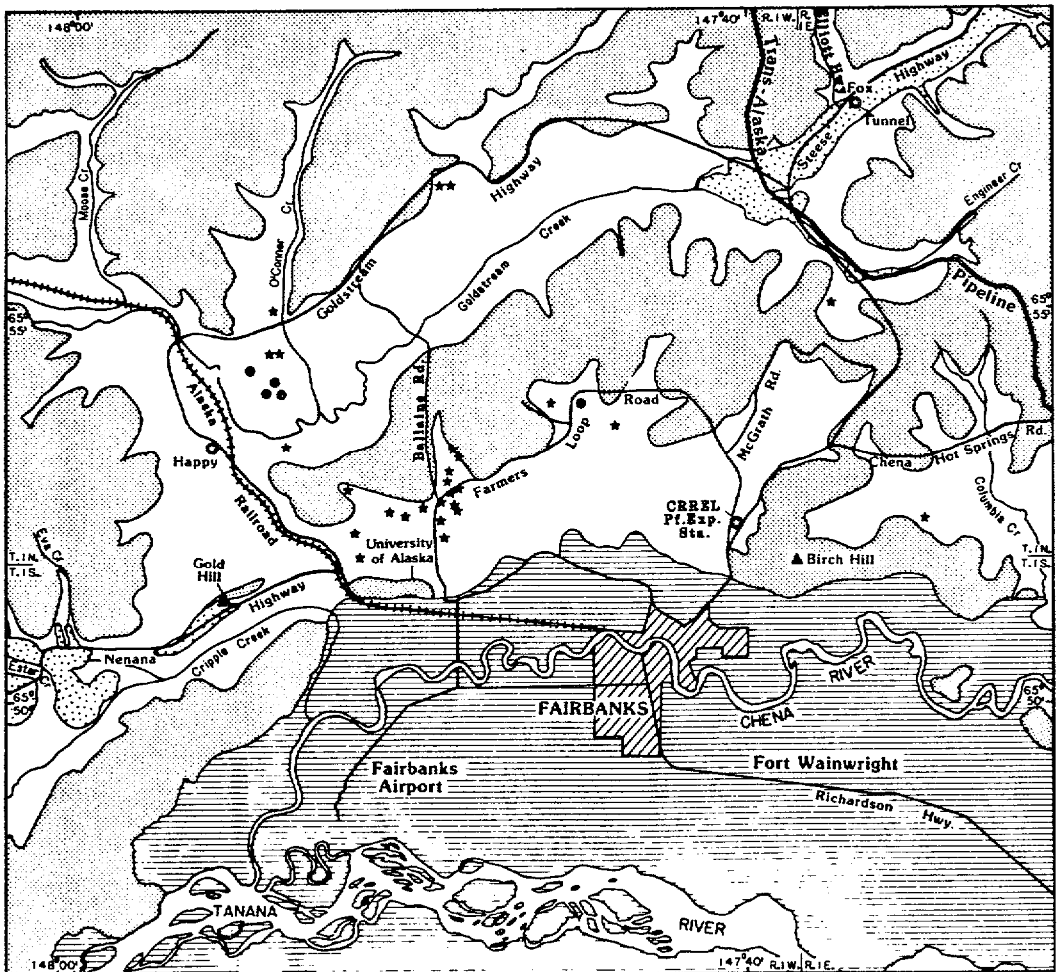
BUS SCHEDULE FOR LOCAL FIELD TRIPS

All buses will depart from and return to the parking lot west of the University Commons (see map on page 5).

Trip	No. of Buses		Mon 18July	Tues 19July	Wed 20July	Thurs 21July	Fri 22July
1. Geological - Construction I (East)	5	Depart		2pm			
		Return		6pm			
2. Geological - Construction II (West)	5	Depart				2pm	
		Return				6pm	
3. Engineering I (Southeast)	5	Depart		2pm			
		Return		6pm			
4. Engineering II (East) (East)	5	Depart				2pm	
		Return				6pm	
5. Permafrost Tunnel (Fox)	1	Depart		2pm		2pm	
		Return		4pm		4pm	
	1	Depart		3pm		3pm	3pm
		Return		5pm		5pm	5pm
	1	Depart		4pm		4pm	4pm
		Return		6pm		6pm	6pm
	1	Depart	7pm		7pm		
		Return	9pm		9pm		
	1	Depart	8pm		8pm		
		Return	10pm		10pm		
6. Frost Heave Test Facility (25 participants per trip)	1	Depart		1pm		1pm	1pm
		Return		3pm		3pm	3pm
	1	Depart		2pm		2pm	2pm
		Return		4pm		4pm	4pm

Some of the above trips may be cancelled if there is insufficient interest.

Walking Tour (Campus) - Self-guided tour on Friday afternoon or at your convenience. Brochures for this tour can be picked up at the registration desk.



GENERALIZED PERMAFROST MAP OF THE FAIRBANKS AREA, ALASKA

by Troy L. Péwé
1982

EXPLANATION

N

- **Bedrock hills** — Permafrost free and loess slopes
- **Dredge tailings** — Generally unfrozen
- **Flood-plain alluvium** — Permafrost with low ice content
- Lower **hillslope** silt and creek valley silt — Permafrost with high ice content

★ **Thermokarst** pit
● **Pingo**

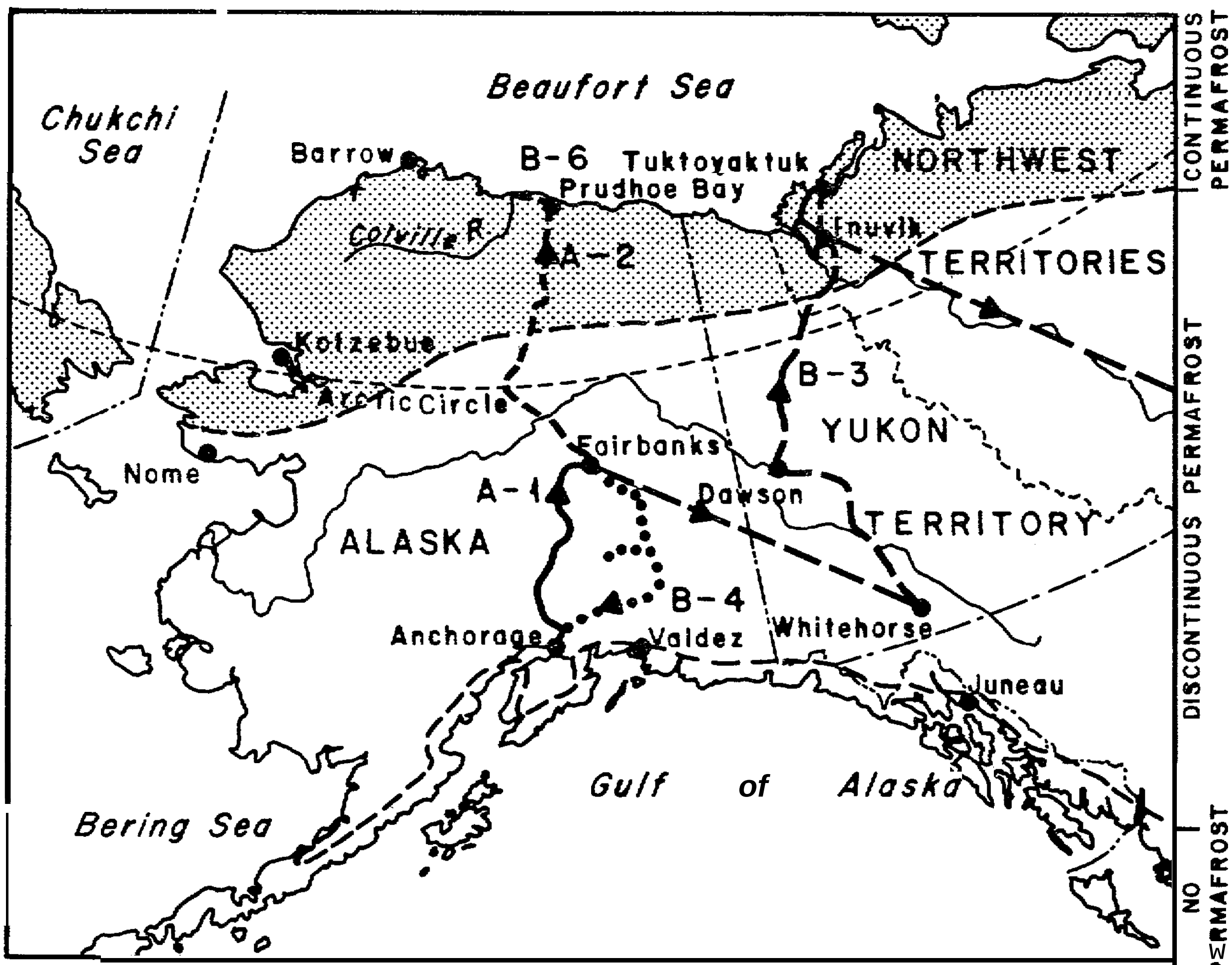
1 ½ 0 1 2 3 Miles
1 ½ 0 1 2 3 Kilometers

(Updated from Péwé, 1958)

Local field trips will follow the roads shown on this map.

PRE- AND POST-CONFERENCE FIELD TRIPS

Five extended field trips are scheduled before and after the conference. Guide books and other information on these trips are available at the registration desk. Most of the trips are completely filled, inquiries about possible openings due to late cancellations should be directed to the conference office. Field trip routes are shown on the map below.



ROUTES OF THE FIELD TRIPS

A-1 ALASKA RAILROAD AND MT. MCKINLEY PARK

14-16 July. Field Trip Leaders: F.W. Weeks, C. Fugelstad, O.J. Ferrians, Jr.

A chartered train, starting from Anchorage, will travel to McKinley Park Station. Participants will have a choice of either touring the park or visiting the Usibelli Coal Mine which is located in discontinuous permafrost terrain. After an overnight stop at the park, the field trip participants will continue on to Fairbanks. The technical part of the trip will emphasize special railroad maintenance and construction problems related to permafrost and mountainous terrain, and stops will be made along the route. These problems include differential thaw settlement, frost heave, erosion, flooding, slope stability, etc. In addition, extensive areas of glaciated and unglaciated terrain with a wide variety of glacial and periglacial landforms will be traversed.

A-2 FAIRBANKS TO PRUDHOE BAY

12-16 July. Field Trip Leaders: J. Brown and R. Kreig

Chartered buses will traverse an 800-km route between Fairbanks and Prudhoe Bay paralleling the trans Alaska oil pipeline routes. Climate, vegetation, soils, hydrology, permafrost, and glacial and periglacial geology will be discussed at approximately 30 sites along the route. Included is a four-hour hike to a glacier in the Brooks Range. At Prudhoe Bay the coastal plain tundra, oriented lakes, and oil field installations will be viewed.

B-3 NORTHERN YUKON TERRITORY AND MACKENZIE DELTA

23-29 July. Field Trip Leader: H.M. French

(In *association with the International Geographical Union Periglacial Commission*)

This excursion will examine periglacial and permafrost-related landforms and processes, and Quaternary geology, in a transect from Whitehorse (latitude 61°N), Yukon Territory, to Tuktoyaktuk (latitude 69°N), Northwest Territories. The route will follow the Klondike and Dempster Highways as far as Inuvik. Air transportation will be used in the Mackenzie Delta.

Both glaciated and unglaciated terrain will be traversed and special permafrost and Pleistocene phenomena will be examined. These phenomena include open- and closed-system pingos, seasonal frost mounds, ice wedges, ice-wedge casts, massive ground ice, and patterned ground. In addition, examples of geotechnical problems in townsites and modern placer mining activity will be observed.

B-4 FAIRBANKS TO ANCHORAGE VIA COPPER RIVER BASIN
23-27 July. Field Trip Leaders: T.L.Péwé and R.D. Reger

A chartered bus will travel 700 km from Fairbanks to Anchorage via Big Delta, Paxson, Copper River Basin and Palmer on the Richardson and Glenn Highways. Glacial and periglacial geology and permafrost will be discussed at several sites each day. The route will parallel the Alaska oil pipeline for about 400 km. Features will be examined in the Tanana River Valley, Alaska Range, Copper River Basin, and Matanuska River Valley. These features include solifluction and loess deposits, ice wedge casts, cryoplanation terraces, ventifacts, glacier topography, pipeline facilities and frozen glacial lake clays. A two-hour stop will be made at the terminus of the Matanuska Glacier.

B-6 ALASKA COASTAL PLAIN: PRUDHOE BAY TO COLVILLE DELTA
23-27 July. Field Trip Leaders: S.E.Rawlinson and H.J. Walker

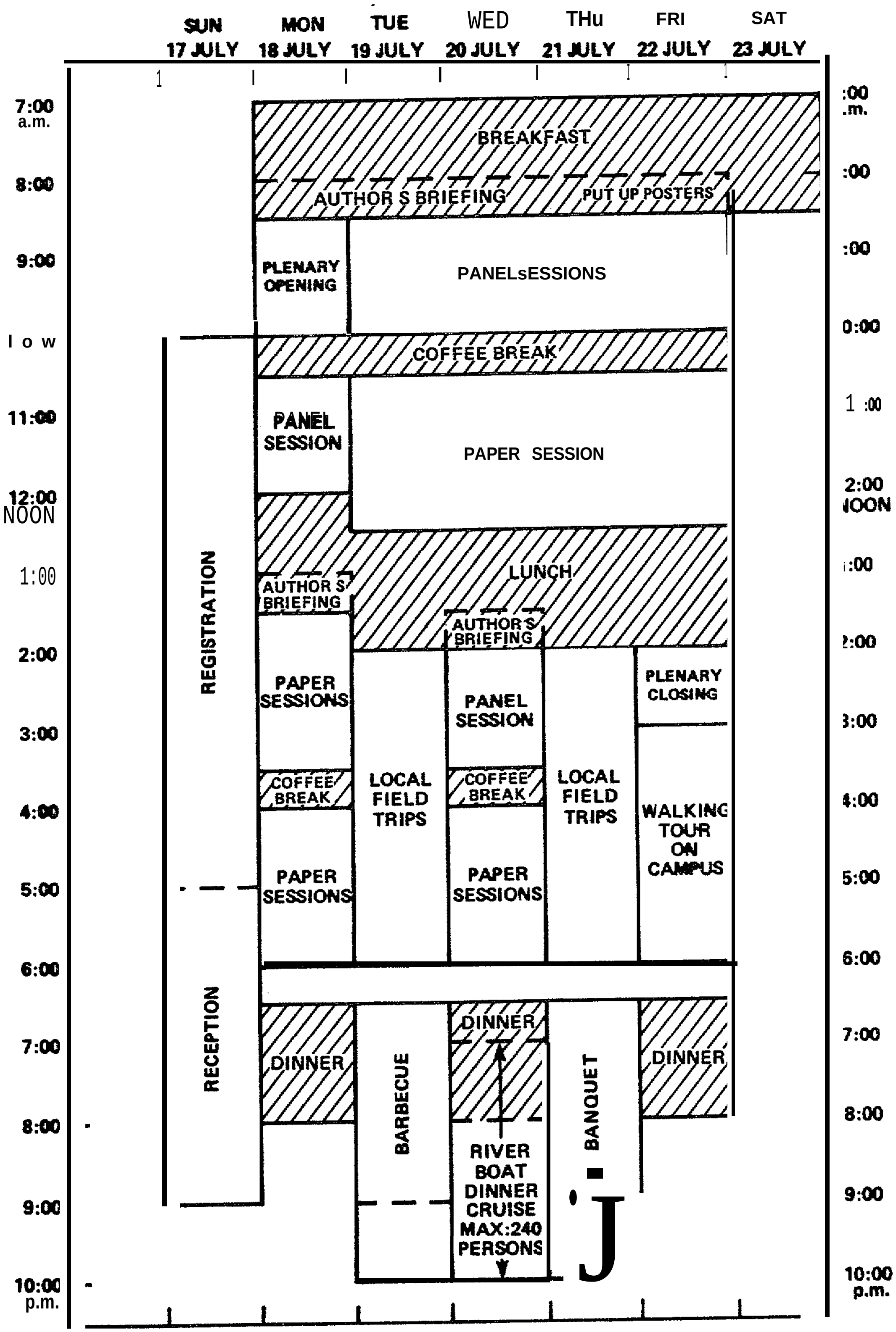
This trip will provide details on the coastal plain formation and current processes including the subsea permafrost and barrier islands. A visit to offshore islands and tours of the Prudhoe Bay oil field activities are included. A day trip to the Colville River Delta to view ice wedges, pingos, and coastal features and processes is planned. Included will be local helicopter flights, an overflight of the arctic coastal plain and possibly a visit to and departure from Barrow.

PUBLICATION OF PROCEEDINGS

The contributed papers are being published by the National Academy of Sciences Academy Press and will be available in Fall 1983. A final volume containing summary papers by the six panels, additional contributed and invited papers, conference resolutions and a list of all participants will be published within a year. Copies of these volumes will be sent to all full registrants free of charge.

PROGRAM OF EVENTS

The timetable below gives an overview of the main sessions and events. This is followed by a detailed technical program.



PROGRAM OF TECHNICAL SESSIONS

Panel Sessions

There are six panel sessions, each held without any other concurrent sessions, in which themes are reviewed that have been identified as being particularly timely. All these sessions are in the Concert Hall.

Paper Sessions

These contributed paper sessions follow the panel discussions with the same theme, and will each have about six formal presentations of not more than 20 minutes each.

	MON 1:30-3:30pm	MON 4:00-6:00pm	TUE 10:30-12:30pm	WED 10:30-12:30pm	WED 4:00-6:00pm	THURS 10:30-12:30pm	FRI 10:30-12:30pm
Civil Engineering	C-1	c-2(1)	c-2(2)	c-3(1)	C-3(2)	C-4	C-5
Mechanical/ Thermal	M-1	M-2	M-3	M-4		M-5	
Periglacial	P-1	P-2	P-3	P-4	P-5	P-6	P-7
Remote Sensing & Planetary Permafrost		R-1	R-2				
Climate, Geophysics & Subsea Permafrost					G-1	G-2	G-3
Hydrology					H-1(1)	H-l(2)	H-2
Environmental			E-1	E-2			E-3

Poster Sessions

Approximately 180 poster papers will be on display on the Wood Center upper level (60 each on three days). Posters will be put up by their authors before 8:30am and the authors will be available to discuss the posters between 10:30-12:30 daily, and at other times by arrangement. The posters will remain on display all day.

Locations of the various sessions and events are shown on the map on page 5, and in the program. Technical sessions are being held at the following locations:

Plenary and Panel Sessions.	Concert Hall
C - Civil Engineering	Concert Hall
P - Periglacial	Theatre
PRC and USSR Invited Sessions	Schaible Auditorium
M - Mechanical/Thermal.	Duckering Lecture Theatre
G-1 Climate.	Brooks Lecture Theatre
G-2 Geophysics.	Brooks Lecture Theatre
G-3 Subsea Permafrost	Duckering Lecture Theatre
E - Environmental	Brooks Lecture Theatre
H-1 Hydrology	Duckering and Schaible
H-2 Hydrology	Schaible Auditorium
R-1 Remote Sensing.	Brooks Lecture Theatre
R-2 Planetary Permafrost.	Schaible Auditorium
I - Poster Sessions	Wood Center (Upper Level)
Films.	Eielson Building (Rm 111)
Permafrost Exhibit.	Museum
Other Exhibits	Regents Great Hall and the Elmer Rasmussen Library

PROGRAM OF TECHNICAL SESSIONS

TIME	MONDAY 18 JULY	TUESDAY 19 JULY	WEDNESDAY 20 JULY	THURSDAY 21 JULY	FRIDAY 22 JULY
8:30 to 10:00 a.m.	Plenary Session	Panel Session: Environmental Protection of Permafrost Terrain	Panel Session: Deep Foundations ●nd Embankments	Panel Session: Frost Heave and Ice Segregation	Panel Session: Subsea Permafrost
10:00–10:30 a.m.	Coffee Break				
	Panel Session: pipelines in Northern Regions	Paper Sessions: ● Iharmodynamics (M-3) ● Mechanics of frozen soils-C-2(2) ● Mountiin and plateau permafrost (P-3) ● Effects of manmade disturbance (E-1) ● Piansrtary permafrost (R-2) ● Poster Session (1-l)*	Paper Sessions: ● Roads and railways—Thermal aspects (M-4) . Foundations-C-3(1) ● Frost mounds and 'other periglacial features (P-4) . Effect of man-made 'and natural disturbance (E-2) ● Invited Soviet Session-1 ● Poster Session (1.2)*	Paper Sessions: ● Frost heave (M-5) . Embankments, roads and railways (C-4) ● Patterned ground (P-6) ● Hydrology—H-1 (2) ● Geophysics (G-2) ● poster Session (1.3)*	Paper Sessions: ● Excavations, mining and municipal (C-5) ● old climate rock weathering (P-7) ● Groundwater in permafrost (H-2) ● &&ea permafrost (G–3) ● Ecology of natural systems (E-3)
12:00 noon 12:30 p.m. 1:30 p.m. 2:00 p.m.	LUNCH 12:00-1:30 p.m.	LUNCH 12:30–2:00 p.m.			
	● Thermal design (M-1) ● pipelines (Cl) . Ice and soil wedges (P-1) ● Invited Chinese Session-1	Local Field Trips	Panel 'Session: Climate Change and Geothermal Regime	Local Field Trips	Plenary closing
3:30–4:00 p.m.	Coffee Break		Coffee Break		Walking Tour of Local Permafrost Features
4:00 to 6:00 p.m.	● Thermal analysis (M-2) ● Mechanics of frozen soils C-2(1) ● Pleistocene permafrost conditions (P-2) ● Invited Chinese Session—2 ● Remote sensing (R-1)		● Foundations C-3(2) ● Ground ice and solifluction (P-5) ● Hydrology H-1 (1) . Invited Soviet Session-2 ● Climate (G-1)		

* Times during which authors will be present. Posters will be on display ● ll day long

Monday, 18 July

Panel Session 10:30 a.m. - 12:30 noon Concert Hall

PIPELINES IN NORTHERN REGIONS

O.J. l?errians, Jr. (Chairman), U.S. Geological Survey, USA
O.M. Ivantsov, USSR Ministry for Construction in Oil and Gas Industries, USSR
H.O. Jahns, Exxon Production Research Co., USA
E.R. Johnson, Alyeska Pipeline Service Co., USA
A.C. Mathews, Office of the Federal Inspector, ANGTS, USA
M.C. Metz, GeoTec Services, USA

Session M-1 1:30 - 3:30 p.m. Duckering Lecture Theatre

THERMAL ENGINEERING DESIGN

Chair: V. Lunardini, CRREL, USA
J. Harle, Alyeska, USA

Jahns, H.O. and C.E. Heuer. Frost heave mitigation and permafrost protection for a buried chilled-gas pipeline.

Walker, D.B.L., D.W. Hayley and A.C. Palmer. The influence of subsea permafrost on offshore pipeline design.

Cronin, J.E. Design and performance of a liquid natural convection subgrade cooling system for construction on ice-rich permafrost.

Zirjacks, W.L. and C.T. Hwang. Underground utilidors at Barrow, Alaska: a two-year history.

Reid, R.L. and A.L. Evans. Investigation of the air convection pile as a permafrost protection device.

Krivoshein, B.L. Thermal interaction between pipelines and the environment.

Monday, 18 July

Session C-1 | 1:30 - 3:30 p.m. | Concert Hall

PIPELINES

Chair: U. Luscher, Woodward-Clyde, USA
V.V. Spiridonov, Moscow, USSR

Thomas, H.P. and J.E. Ferrell. Thermokarst features associated with buried sections of the Trans-Alaska Pipeline.

Stanley, J.M. and J.E. Cronin. Investigations and implications of sub-surface conditions beneath t'ne Trans-Alaska Pipeline in Atigun Pass.

Hanna, A.J., R.J. Saunders, G.N. Lem and L. Carlson. Alaska Highway Gas Pipeline Project (Yukon section) - thaw settlement design approach.

Carlson, L. and D. Butterwick. Testing pipelining techniques in warm permafrost.

Spiridonov, V.V. Engineering designs for laying pipelines in permafrost areas and boggy terrain in the North.

Kondratyev, V.G. Geocryological monitoring of pipelines.

Session P-1 | 1:30 - 3:30 p.m. | Theatre

ICE AND SOIL WEDGES

Chair: M. Seppala, Uni. of Helsinki, Finland
J.R. Mackay, Uni. of British Columbia, Canada

Carter, L.D. Fossil sand wedges on the Alaskan Arctic coastal plain and their paleoenvironmental significance.

Black, R.F. Three superposed systems of ice wedges at McLeod Point, northern Alaska, may span most of the Wisconsinan stage and Holocene.

Lawson, D.E. Ground ice in perennially frozen sediments, northern Alaska.

Jahn, A. Soil wedges on Spitzbergen.

Thorson, R.M. Stratigraphic evidence for variable past permafrost conditions at Canyon Billage Bluff, Northeast Alaska.

Vasilchuk, Yu.K. and V.T. Trofimov. Cryohydrochemical peculiarities of ice-wedge complexes of the North of Western Siberia.

Tomirdiaro, S.V. Loess-like Yedom-complex deposits in North-Eastern stages, and interruptions in their accumulations and cryotextures.

Monday, 18 July

Session PRC — 1:30 - 3:30 p.m. — Continued 4:00 - 6:00 p.m. — Schaible Auditorium

INVITED CHINESE SESSION (PRC)

Chair: T. Péwé, Uni. of Arizona, USA
J. Brown, CRREL, USA

Shi Yafeng and Cheng Guodong. A brief introduction to permafrost research in China.

Li Yusheng, Wang Zhugui, Dai Jingbo, Cui Chenghan, He Changgen and Zhao Yunlong. Permafrost studies and railroad construction in permafrost areas in China.

Zhou Youwu and Guo Dongxin. Some features of permafrost in China.

Session M-2 — 4:00 - 6:00 p.m. — Duckering Lecture Theatre

THERMAL ANALYSIS

Chair: L. Goodrich, NRC, Canada
C. Heuer, Exxon, USA

Lin Sui and Shimao Ni. A collocation analysis for solving periodic thawing and freezing processes in active layer of permafrost.

Hildebrand, E.E. Thaw settlement and ground temperature model for highway design in permafrost areas.

Hromadka, II T.V., G.L. Guymon and R.L. Berg. Comparison of two-dimensional domain and boundary integral geothermal models with embankment freeze-thaw field data.

Zhao Yunlong and Wang Jianfu. Calculation of thawed depth beneath heated buildings in permafrost regions.

Lunardini, V.J. Thawing beneath insulated structures on permafrost.

Pakhomova, G.M. Investigations into the compaction of thawing earth materials.

Monday, 18 July

Session C-2(1) | 4:00 - 6:00 p.m. | Concert Hall

MECHANICS OF FROZEN SOIL

Chair: T.. Vinson, Oregon State Uni., USA

Baker, T.H.W. and G.H. Johnston. Unconfined compression tests on anisotropic frozen soils from Thompson, Manitoba.

Ohrai, T., T. Takashi, H. Yamamoto and J. Okamoto. Uniaxial compressive strength of ice segregated from soil.

Mahar, L.J., R. Wilson and T.S. Vinson. Physical and numerical modelling of uniaxial freezing of a saline gravel.

Ladanyi, B. and H. Eckardt. Dilatometer testing in thick cylinders of frozen sand.

Roman, L.T. Analog method for determining long-term deformability of permafrost materials.

Ukhov, S.B., E.F. Gulko, V.P. Merzljakov and P.B. Kotov. Stress-strain condition and the assessment of slope stability in areas of complex geological structure under various temperature regimes.

Session P-2 | 4:00 - 6:00 p.m. | Theatre

PLEISTOCENE PERMAFROST CONDITIONS

Chair: A. Jahn, Uni. of Warsaw, Poland
A.I. Popov, USSR

Haesaerts, P. Stratigraphic distribution of periglacial features indicative of permafrost in the Upper Pleistocene loesses of Belgium.

Langohr, R. The extension of permafrost in Western Europe in the period between 18,000 and 10,000 y. B.P.(Tardiglacial): Information from soil studies.

Svensson, H. Ventifacts as paleo-wind indicators in a former periglacial area of southern Sweden.

Kolstrup, E. Cover sands in southern Jutland (Denmark).

Vandenberghe, J. Ice wedge casts and involutions as permafrost indicators and their stratigraphic position in the Weichselian.

Lu Guowei, Guo Dongxin and Dai Jingbo. Basic characteristics of permafrost in Northeast China.

Nekrasov, I.A. Dynamics of the cryolithozone in the northern hemisphere during the Pleistocene.

Monday, 18 July

Session R-1 | 4:00 - 6:00 p.m. | Brooks Lecture Theatre

REMOTE SENSING AND PLANETARY PERMAFROST

Chair: A. Heginbottom, GSC, Canada
R. Kreig, Kreig and Assoc., USA

Clark, R.N. Ice-soil mixtures: Visual and near-infrared remote sensing techniques.

Boothroyd, J.C. and B.S. Timson. The Sagavanirktok and adjacent river systems, eastern North Slope, Alaska: An analog for ancient fluvial terrains on Mars.

Clifford, S.M. Ground ice in the equatorial region of Mars: a fossil remnant of an ancient climate or a replenished steady-state inventory?

Morrissey, L.A. The utility of remotely-sensed data for permafrost studies.

Gurney, J.R., J.P. Ormsby and D.K. Hall. A comparison of remotely sensed surface temperature and biomass estimates for aiding evapotranspiration determination in central Alaska.

Gavrilov, A.V., K.A. Kondratieva and Ye.I. Pizhankova. Methodology for using air photos and satellite imagery in permafrost surveys.

Tuesday, 19 July

Panel Session 8:30 - 10:30 a.m. Concert Hall

ENVIRONMENTAL PROTECTION OF PERMAFROST TERRAIN

James E. Hemming (Chairman), Dames & Moore, Anchorage, Alaska, USA
Max C. Brewer, U.S. Geological Survey, Anchorage, Alaska, USA
Hugh M. French, Ottawa Uni., Ottawa, Canada
Nikolai A. Grave, Permafrost Institute, Yakutsk, USSR
Curtis McVee, U.S. Bureau of Land Management, Anchorage, Alaska, USA
Patrick J. Webber, Uni. of Colorado, Boulder, Colorado, USA

Poster Session I-1 10:30 a.m. - 12:30 p.m. Wood Center
Details of the poster sessions are printed separately.

Session M-3 10:30 a.m. - 12:30 p.m. Duckering Lecture Theatre

THERMODYNAMICS AND TRANSPORT PHENOMENA

Chair: J. Oliphant, CRREL, USA
E. McRoberts, Hardy Assoc., Canada

Horiguchi, K. and R.D. Miller. Hydraulic conductivity functions of frozen materials.

Yoneyama, K., T. Ishizaki and N. Nishio. Water redistribution measurements in partially frozen soil by X-ray technique.

Kay, B.D. and P.H. Groenevelt. The redistribution of solutes in freezing soil.: exclusion of solutes.

Aguirre-Puente, J. and J. Gruson. Measurements of permeabilities of frozen soils.

McGaw, R.W., R.L. Berg and J.W. Ingersoll. An investigation of transient processes in an advancing zone of freezing.

Komarov, I.A. A theory of desiccation of unconsolidated rocks in areas with negative temperatures.

Tuesday, 19 July

Session C-2(2) 10:30 a.m. - 12:30 p.m. Concert Hall

MECHANICS OF FROZEN SOIL (CONTINUED)

Chair: S. Stearns, ASCE, Dartmouth College, USA
S.S. Vyalov, Moscow, USSR

Nelson, R.A., U. Luscher, J.W. Rooney and A.A. Stramler. Thaw strain data and thaw settlement predictions for Alaskan soils.

Zhu Yaunlin and D.L. Carbee. Creep behavior of frozen silt under constant uniaxial stress.

Vinson, T.S., C.R. Wilson and P. Bolander. Dynamic properties of naturally frozen silt.

Chamberlain, E.J. Frost heave of saline soils.

Corapcioglu, M.Y. A mathematical model for the permafrost thaw consolidation.

Maksimjak, R.V., S.S. Vyalov and A.A. Chapaev. Methods for determining the long-term strength of frozen soils.

Session P-3 10:30 a.m. - 12:30 p.m. Theatre

MOUNTAIN AND PLATEAU PERMAFROST

Chair: Shi Yafeng, Lanzhou Institute, PRC
S.A. Harris, Uni. of Calgary, Canada

Cheng Guodong and Wang Shaoling. The distribution of high-ice-content permafrost along the Qinghai-Xizang Highway.

King, L. High mountain permafrost in Scandinavia.

Qiu Guoqing, Huang Yizhi and Li Zuofu. Alpine permafrost in Tian Shari, China.

Haeberli, W. Permafrost-glacier relationships in the Swiss Alps, today and in the past.

Greenstein, L.A. An investigation of mid-Latitude alpine permafrost on Niwot Ridge, Colorado Rocky Mountains, USA

Zabolotnik, S.1. Conditions of permafrost formation in the zone of the Baikal-Amur Railway.

Tuesday, 19 July

Session E-1 | 10:30 a.m. - 12:30 p.m. | Brooks Lecture Theatre

EFFECTS OF MAN-MADE DISTURBANCES

Chair: L. Rev, Comité Arctique Inter., Switzerland
C. Slaughter, U.S. Forest Service, USA

Kershaw, G.I?. Some abiotic consequences of the CANOL Crude Oil Pipeline Project; 35 years after abandonment.

Klinger, L.F., D.A. Walker and P.J. Webber. The effects of gravel roads on Alaska Arctic coastal plain tundra.

Komarkova, V. Recovery of plant communities and summer thaw at the 1949 Fish Creek Test Well 1, Arctic Alaska.

Thorhallsdottir, T.E. The ecology of permafrost areas in Central Iceland and the potential effects of impoundment.

Linkins, A.E. and N. Fetcher. Effects of surface-applied Prudhoe Bay crude oil on vegetation and soil processes in tussock tundra.

Collins, C.M. Tong-term active layer effects of crude oil spilled in Interior Alaska.

Session R-2 | 10:30 a.m. - 12:30 p.m. | Schaible Auditorium

PLANETARY PERMAFROST

Chair: D. Andersen, State Uni. of New York, USA
M. Malin, Arizona State Uni., USA

Carr, M.H. The geology of Mars.

Lucchitta, B.K. Permafrost on Mars.

Fanale, F.P. and R.N. Clark. Solar system ices and Mars permafrost.

Nummedal, D. Permafrost on Mars: distribution, formation and geological ro Le.

Wednesday, 20 July

Panel Session 8:30 - 10:30 a.m. Concert Hall

DEEP FOUNDATIONS AND EMBANKMENTS

N.R. Morgenstern (Chairman), Uni. of Alberta, Canada
Ding Chingkang, Academy of Railway Science and Engineering, Lanzhou, PRC
D.C. Esch, Alaska Department of Transportation and Public Facilities, USA
B. Ladanyi, Ecole Polytechnique, Montreal, Canada
A.V. Sadovsky, NIIOSP, Moscow, USSR
F.H. Sayles, Office of the Federal Inspector, ANGTS, USA

Poster Session I-2 10:30 a.m. - 12:30 p.m. Wood Center
Details of the poster sessions are printed separately.

Session M-4 10:30 a.m. - 12:30 p.m. Duckering Lecture Theatre

ROADS AND RAILWAYS, THERMAL ASPECTS

Chair: G.H. Johnston, NRC, Canada
O. Gregorsen, Norwegian Geotech. Inst., Norway

Zarling, J.P., B. Connor and D.J. Goering. Air duct systems for roadway stabilization over permafrost areas.

Johnston, G.H. Performance of an insulated roadway on permafrost, Inuvik, N.W.T.

McHattie, R. and D.C. Esch. Benefits of a peat underlay used in road construction on permafrost.

Goodrich, L.E. Thermal performance of a section of the MacKenzie Highway.

Esch, D.C. Evaluation of experimental design features for roadway construction over permafrost.

Zhang Shixiang and Zhu Qiang. A study of the calculation of frost heaving.

Wednesday, 20 July

Session *C-3(1)* 10:30 a.m. - 12:30 p.m. Concert Hall

FOUNDATIONS

Chair: R. Fadum, North Carolina State Uni., USA
J.W. Rooney, R & M Consultants, USA

Andersland, O.B. and M.R. Alwahhab. Lug behavior for model steel piles in frozen sand.

Penner, E. and L.E. Goodrich. Adfreezing pressure on steel pipe piles, Thompson, Manitoba.

Dufour, S., D.C. Sego and N.R. Morgenstern. Vibratory pile driving in frozen sand.

DiPasquale, L., S. Gerlek and A. Phukan. Design and construction of pile foundations in the Yukon-Kuskokwim Delta, Alaska.

Nottingham, D. and A.B. Christopherson. Driven piles in permafrost: state of the art.

Manikian, V. Pile driving and load tests in permafrost for the Kuparuk pipeline system.

Session P-4 10:30 a.m. - 12:30 p.m. Theatre

FROST MOUNDS AND OTHER PERIGLACIAL PHENOMENA

Chair: H. Svensson, Uni. of Copenhagen, Denmark
R. Black, Uni. of Connecticut, USA

Mackay, J.R. Pingo growth and sub-pingo water lenses, 'western Arctic coast, Canada.

Seppala, M. Seasonal thawings of palsas in Finnish Lapland.

Pollard, W.H. and H.M. French. Seasonal frost mound occurence, North Fork Pass, Ogilvie Mountains, Northern Yukon, Canada.

Corte, A.E. Geocryogenic morphology at Seymour Island, Antarctica: A progress report.

Walton, D.W.H. and T.D. Heilbronn. Periglacial activity on the subantarctic island of South Georgia.

Pavlov, A.V. and F.E. Are. 'The thermal regime of thermokarst lakes in Central Yakutia.

Wednesday, 20 July

Session E-2 | 10:30 a.m. - 12:30 p.m. | Brooks Lecture Theatre

EFFECTS OF MAN-MADE AND NATURAL DISTURBANCES

Chair: T. Albert, North Slope Borough, USA
P. Duffy, Canada

Ebersole, J.J. and P.J. Webber. Biological decomposition and plant succession following disturbance on the Arctic Coastal Plain, Alaska.

Johnson, A.W. and B. Neiland. An analysis of plant succession on frost scars, 1961-1980.

Shaver, G.R., B.L. Gartner, F.S. Chapin III, and A.E. Linkins. Revegetation of arctic disturbed sites by native tundra plants.

Maltby, E. and C.J. Legg. Revegetation of fossil patterned ground exposed by severe fire on the North York moors.

Racine, C.H., W.A. Patternson III and J.G. Dennis. Permafrost thaw associated with tundra fires in northwest Alaska.

Johnson, L. and L. Viereck. Recovery and active layer changes following a tundra fire in northwestern Alaska.

Session USSR | 10:30 a.m. - 12:30 p.m. | Schaible Auditorium
Continued 4:00 - 6:00 p.m.

INVITED SOVIET SESSION (USSR)

Chair: J.R. Kiely, Bechtel, USA
O. Ferrians, USGS, USA

Melnikov, P.I. Principal direction and development of Soviet permafrost studies.

Grave, N.A. A geocryological aspect of the problem of environmental protection.

Vyalov, S.S. Principal problems of engineering permafrost studies.

Wednesday, 20 July

Panel Session 2:00 - 3:30 p.m. Concert Hall

CLIMATE CHANGE AND GEOTHERMAL REGIME

A.S. Judge (Chairman), Department of Energy, Mines and Resources, Canada
Cheng Guodong, Institute of Glaciology and Cryopedology, Lanzhou, PRC
J. Grey, L'University de Montreal, Canada
N.N. Romanovsky, Moscow State Uni., USSR
M. Smith, Carleton Uni., Canada

Session C-3(2) 4:00 - 6:00 p.m. Concert Hall

FOUNDATIONS (CONTINUED)

Chair: O.B. Andersland, Michigan State Uni., USA
R. Smith, ARCO, USA

Nixon, J.F. Geothermal design of insulated foundations for thaw prevention.

Keusen, H.R. and W. Haeberli. Site investigation and foundation design aspects of cable car construction in alpine permafrost at the "Chli Matterhorn," Wallis, Swiss Alps.

Luscher, U., W.T. Black and J.F. McPhail. Results of load tests on temperature-controlled piles in permafrost.

Gregersen, O., A. Phukan and T. Johansen. Engineering properties and foundation design alternatives in marine Svea clay, Svalbard.

Liu Hungxu. Calculation of frost heaving force in seasonally frozen soil.

Khrustalyov, L.N. Selection of principles for the use of permafrost materials as a foundation for buildings and structures.

Poleshuk, V.L. Prediction of construction characteristics of sluiced materials used in foundations under permafrost conditions and in severe climates.

Wednesday, 20 July

Session P-5 | 4:00 - 6:00 p.m. | Theatre

GROUND ICE AND SOLIFLUCTION

Chair: G. Gryc, USGS, USA
J. Akerman, Uni. of Lund, Sweden

Rampton, V.N., J.R. Ellwood and R.D. Thomas. Distribution and geology of ground ice along the Yukon Portion of the Alaska Highway Gas Pipeline north of Kluane Lake.

Ellwood, J. and J.F. Nixon. Observations of soil and ground ice in pipeline trench excavations in the South Yukon.

Harry, D.G. and H.M. French. The orientation and evolution of thaw lakes, Southwest Banks Island, Canadian Arctic.

Reanier, R.E. and F.C. Ugolini. Gelifluction deposits as sources of paleoenvironmental information.

Gamper, M. Controls and rates of movement of solifluction lobes in the eastern Swiss Alps.

Yershov, E.D., Yu. P. Lebedenko, O.M. Yazynin, E.M. Chuvilin, V.N. Sokolov, V.V. Rogov and V.V. Kondakov. The formation of cryogenic structure and texture in unconsolidated rocks.

Session H-1(l) | 4:00 - 6:00 p.m. | Duckering Lecture Theatre

WATERSHED STUDIES IN PEWROST REGIONS

Chair: R. Carlson, Uni. of Alaska, USA
B.E. Ryden, Unl. of Uppsala, Sweden

Slaughter, C.W., J.W. Hilgert and E.H. Culp. Summer streamflow and sediment yield from discontinuous permafrost headwaters catchments.

Drage, B., J.R. Gilman, D. Hoch and L. Griffiths. Hydrology of North Slope coastal plain streams.

Woo, M., P. Marsh and P. Steer. Basin water balance in a continuous permafrost environment.

Wright, R.K. Relationships between runoff generation and active layer development near Scheferville, Quebec.

Flügel, W.A. Summer water balance of a high arctic catchment area with underlying permafrost in Oobloyah Valley, N. Ellesmere Island, N.W.T., Canada

Chaco, E.F. and S.R. Bredthauer. Runoff from a small subarctic watershed, Alaska.

Wednesday, 20 July

Session G-1 | 4:00 - 6:00 p.m. | Brooks Lecture Theatre

CLIMATE CHANGE AND GEOTHERMAL REGIME

Chair: S.A. Bowling, Uni. of Alaska, USA
Xu Xiaozu, Lanzhou Institute, PRC

Rouse, W.R. Active layer energy exchange in wet and dry tundra of the Hudson Bay lowlands.

Smith, M.W. and D.W. Riseborough. Permafrost sensitivity to climatic change.

Harris, S.A. Comparison of the climatic and geomorphic methods of predicting permafrost distribution in western Yukon Territory.

Nelson, F. and S.1. Outcalt. A frost index number for spatial predictions of ground-frost zones.

Xu Xiaozu and Wang Jiacheng. A preliminary study on the distribution of frozen ground in China.

Gavrilova, M.K. The thermal regime of permafrost soils in the USSR.

Thursday, 21 July

Panel Session 8:30 - 10:00 a.m. Concert Hall

FROST HEAVE AND ICE SEGREGATION

E. Penner (Chairman), National Research Council, Canada
R.L. Berg, Cold Regions Research and Engineering Laboratory, USA
Chen Xiaobai, Academia Sinica, Lanzhou, PRC
S.E. Grechishchev, All Union Research Institute of Hydrogeology and Engineering Geology, Moscow, USSR
R.D. Miller, Cornell Uni., USA
P.J. Williams, Carleton Uni., Canada

Poster Session I-3 10:30 a.m. - 12:30 p.m. Wood Center
Details of the poster sessions are printed separately.

Session M-5 10:30 a.m. - 12:30 p.m. Duckering Lecture Theatre

FROST HEAVE

Chair: E. Chamberlain, CRREL, USA
A.R. Jumikis, Rutgers Uni., USA

Holden, J.T. Approximate solutions for Miller's theory of secondary heave.

Lovell, C.W. Frost susceptibility of soils.

Akagawa, S. Relation between frost heave and specimen length.

Konrad, J.M. and N.R. Morgenstern. Frost susceptibility of soils in terms of their segregation potential.

Rieke, R.D., T.S. Vinson and D.W. Mageau. The role of specific surface area and related index properties in the forst heave susceptibility of soils.

Chen Xiaobai, Wang Yaqing and Jiang Ping. Influence of penetration rate, surcharge stress and ground water table on frost heave.

Thursday, 21 July

Session C-4 | 10:30 a.m. - 12:30 p.m. | Concert Hall

EMBANKMENTS, ROADS AND RAILWAYS

Chair: C.W. Lovell, Purdue Uni., USA
K. Flaate, Norway

Bell, J.R., T. Allen and T.S. Vinson. Properties of geotextiles in cold regions applications.

Hayley, D.W., W.D. Roggensack, W.E. Jubien and P.V. Johnson. Stabilization of sinkholes on the Hudson Bay railway.

LaVielle, C.C., S.C. Gladden and A.R. Zeman. Nuiqsut Airport dredge project.

Tart, R.G., Jr. Winter constructed gravel islands.

Wang Liang, Xu Bomeng and Wu Zhijin. Properties of frozen and thawed soil and earth dam construction in winter.

Melnikov, P.I. and B.A. Olovin. Permafrost dynamics in the area of the Viluy River hydroelectric scheme.

Session P-6 | 10:30 a.m. - 12:30 p.m. | Theatre

PATTERNED GROUND AND ROCK STREAMS

Chair: A. Corte, IANIGLA, Argentina
V.N. Konishchev, Moscow State Uni., USSR

Walters, J.C. Sorted patterned ground in ponds and lakes of the High Valley-Tangle Lakes region, central Alaska.

Muir, M.P. The role of pre-existing, corrugated topography in the development of stone stripes.

Hagedorn, H. Periglacial phenomena in arid regions of Iran.

Cui Zhijui. An investigation of rock glaciers in the Kunlun Shari, China.

Sadovsky, B. and G.I. Bondarenko. Creep of frozen soils on rock slopes.

Tyurin, A.I. Classification of rock streams.

Thursday, 21 July

Session H-l(2) 10:30 a.m. - 12:30 p.m. Schaible Auditoriu

WATERSHED STUDIES IN PERMAFROST REGIONS (CONTINUED)

Chair: M.K. Woo, McMaster Uni., Canada
R.O. van Everdingen, Env: ronment Canada

Ashton, W.S. and R.F. Carlson. Predicting fish pas: age design discharges for Alaska.

Lewkowicz, A.G. Erosion by overland flow, Central Banks Island, Western Canadian Arctic.

Onesti, L.J. and S.A. Walti. Hydrologic characteristics of small arctic-alpine watersheds, Central Brooks Range, Alaska.

Price, J.S. The effect of hydrology on ground freezing in a watershed with organic terrain.

Makarov, V.M. Migration of elements in water in taiga-permafrost landscapes.

Session G-2 10:30 a.m. - 12:30 p.m. Brooks Lecture Theatre

PERMAFROST GEOPHYSICS

Chair: K. Kawasaki, Uni. of Alaska, USA
G.D. Hobson, PCSP, Canada

Collett, T.S. Detection and evaluation of natural gas hydrates from well logs, Prudhoe Bay, Alaska.

Kay, A.E., A.M. Allison, W.J. Botha and W.J. Scott. Continuous geophysical investigation for mapping permafrost distribution, Mackenzie Valley, N.W.T., Canada.

Sinha, A.K. and L.E. Stephens. Deep electromagnetic sounding over the permafrost terrain in the Mackenzie Delta, N.W.T., Canada.

Ehrenbard, R.L., P. Hoekstra, and G. Rozenberg. Transient electromagnetic soundings for permafrost mapping.

Arcone, S.A. and Delaney, A.J. VHF propagation experiments in the permafrost tunnel, Fox, Alaska.

Boikov, S.A., V.E. Afanasenko and V.M. Timofeyev. Investigation of areas of icing (naled) formation and subsurface water discharge under permafrost conditions using surface geophysical techniques.

Friday, 22 July

Panel Session | 8:30 - 10:30 a.m. | Concert Hall

SUBSEA PERMAFROST

D.M. Hopkins (Chairman), U.S. Geological Survey, USA
F.E. Are, Permafrost Institute, Yakutsk, USSR
P.V. Sellman, Cold Regions Research and Engineering Laboratory, USA
L.J. Toimil, Harding-Lawson Associates, USA
J. Weaver, Dome Petroleum, Canada

Session C-5 | 10:30 a.m. - 12:30 p.m. | Concert Hall

EXCAVATIONS, MINING AND MUNICIPAL FACILITIES

Chair: J. Usibelli, Usibelli Coal Mines, TJSA
R. Abbott, Shannon & Wilson, USA

Rooney, J.W. and J.H. Wellman. Fairbanks wastewater treatment facility - geotechnical considerations.

Simpson, J.K. and P.M. Jarrett. Explosive excavation of frozen soils.

Weerdenburg, P.C. and N.R. Morgenstern. Underground cavities in ice-rich frozen ground.

Williams, D. The stabilization of the Nanisivik concentrator foundation.

Sun Yuliang. Deformability of canals due to freezing and thawing.

Ryan, W.L. Design considerations for large storage tanks in permafrost areas.

Friday, 22 July

Session P-7 | 10:30 a.m. - 12:30 p.m. | Theatre

COLD CLIMATE ROCK WEATHERING

Chair: H. Hagedorn, FRG
S. Kinosita, Hokkaido Uni., Japan

Akerman, J. Notes on chemical weathering, Kapp Linné, Spitsbergen.

Hallet, B. The breakdown of rock due to freezing: A theoretical model.

Hyers, A. Some spatial aspects of climate-dependent mechanical weathering in a high altitude environment.

Ray, R.J., W.B. Krantz, T.N. Caine and R.D. Gunn. A mathematical model for patterned ground: Sorted polygons and stripes, and underwater polygons.

Vitek, J.D. Stone polygons: Observations of surficial activity.

Konishchev, V.N. and V.V. Rogov. The cryogenic evolution of mineral matter (an experimental model).

Afanasenko, V.E., V.N. Zaitsev, V.E. Romanovsky and N.N Romanovsky. On the relationship between the structure and characteristics of bedrock masses and their permafrost history.

Session H-2 | 10:30 a.m. - 12:30 p.m. | Schaible Auditorium

GROUND WATER IN PERMAFROST

Chair: V.M. Makarov, Permafrost Institute, USSR
P. Emery, USGS, USA

Kane, D.L. and J. Stein. Field evidence of groundwater recharge in Interior Alaska.

Brook, G.A. Hydrology of the Nahanni, a highly karsted carbonate terrane with discontinuous permafrost.

Michel, F.A. Isotope variations in permafrost waters along the Dempster Highway pipeline corridor.

van Everdingen, R.O. and H.D. Allen. Ground movements and dendrogeomorphology in a small icing area on the Alaska Highway, Yukon, Canada.

Chizhov, A.B., N.I. Chizhov, I.K. Morkovkina and V.V. Romanov. Tritium in permafrost and ice.

Klimovskiy, I.V. The process of icing (naled) formation in the troughs of the Pacific mountain belt.

Shepelev, V.V. A classification of ground water in the cryolithozone.

Friday, 22 July

Session G-3 10:30 a.m. - 12:30 p.m. Duckering Lecture Theatre

SUBSEA PERMAFROST

Chair: G. Shearer, Minerals Management Service, USA
F.E. Are, Permafrost Institute, USSR

Morack, J.L., H.A. MacAuley and J.A. Hunter. Geophysical measurements of the sub-bottom permafrost in the Canadian Beaufort Sea.

Neave, K.G. and P.V. Sellmann. Seismic velocities and subsea permafrost in the Beaufort Sea, Alaska.

Walker, H.J. Erosion in a permafrost-dominated delta.

Swift, D.W., W.D. Harrison and T.E. Osterkamp. Heat and salt transport processes in thawing subsea permafrost at Prudhoe Bay, Alaska.

Are, F.E. Thermal abrasion of coasts.

Zhigarev, L.A. Permafrost beneath the Arctic seas.

Session E-3 10:30 a.m. - 12:30 p.m. Brooks Lecture Theatre

ECOLOGY OF NATURAL SYSTEMS

Chair: H.W. Gabriel, BLM, USA
K. MacInnes, Dept. of Indian Affairs, Canada

Viereck, L.A. and D.J. Lev. Long-term use of frost tubes to monitor the annual freeze-thaw cycle in the active layer.

Walker, D.A. A hierarchical tundra vegetation classification especially designed for mapping in northern Alaska.

Schell, D.M. and P.J. Zieman. Accumulation of peat carbon in the Alaska arctic coastal plain and its role in biological productivity.

Koizumi, T. Alpine plant community complex on permafrost areas of the Daisetsu Mountains, Central Hokkaido, Japan.

Murray, D.F., B.M. Murray, B.A. Yurtsev and R. Howenstein. Biogeographic significance of steppe vegetation in subarctic Alaska.

Van Cleve, K. and L.A. Viereck. A comparison of successional sequences following fire on permafrost-dominated and permafrost-free sites in Interior Alaska.

PANEL ABSTRACTS

PIPELINES IN NORTHERN REGIONS

Ferrians, O.J.,(Chairman), U.S. Geological Survey, Menlo Park, California, 94025, U.S.A.
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General statement -- Because of the critical need for developing new sources of oil and gas, several major pipelines and related facilities have been constructed in the arctic and subarctic regions of the world during the last two decades, and undoubtedly, more will be constructed in the future. These regions pose special engineering problems and are environmentally "sensitive". Consequently, they require careful consideration to insure the integrity of the pipelines and related facilities, and to minimize adverse environmental impacts. One of the most important factors to be considered is permafrost.

Permafrost is a widespread natural phenomenon. It underLies approximately 20 percent of the land area of the world. The permafrost region of Alaska includes 85 percent of the state, and the permafrost regions of Canada and the U.S.S.R. cover about 50 percent of each country.

The most serious permafrost-related engineering problems generally are caused by the thawing of ice-rich permafrost, which results in a loss of strength and a change in volume of ice-rich soil. Under severe conditions, the ice-rich soil can liquefy and lose essentially all of its strength. A more common occurrence is differential settlement of the ground surface.

Proposals to chill the natural gas in buried pipelines as a means of mitigating the problems caused by the thawing of permafrost pose different problems--namely frost heaving due to the freezing of pore water in soils surrounding the pipe, and to the freezing of additional water attracted to the freezing front.

Pipelines in northern U.S.S.R. -- The first major pipeline constructed in the Far North was the 529 mm-in-diameter, 600 km-long natural gas pipeline serving Yakutsk. This pipeline, which includes 250 km of aboveground line, has been operating successfully for more than 15 years. A system of gas pipelines serving the city of Norilsk was constructed entirely aboveground except for river crossings. One line is over 600 km long and 720 mm in diameter, another is 300 km long but has a smaller diameter. These early gas pipelines in permafrost areas were built largely aboveground to eliminate the possibility of adverse impacts on permafrost. As more experience is gained in pipeline construction in northern areas, underground placement has gained favor.

Large transcontinental gas pipeline systems were constructed in the 1970's. These pipelines have a diameter of 1,420 mm and pressures of 75 kg/cm^2. The first giant pipeline, with a length of 3,000 km, originated in the northern part of the Tyumen region near the Medvezhye gas field. During 1981-1985, a multiline system of five parallel pipelines will be constructed, each with a diameter of 1,420 mm. Three of these lines, the Urengoy-Gryazovec-Moscow, Urengoy-Petrovsk, and Urengoy-Novopskov, have already been constructed. In addition, during this period the Urengoy-Pomary-Uzhgorod gas pipeline for exporting gas will be put into operation. The length of this pipeline is 4,500 km. Oil pipelines from the northern regions also are under construction. One of the largest oil pipeline systems is the main pipeline Ust-Balyk-Kurgan-Ufa-Almetyevsk, having a diameter of 1,220 mm and a length of over 1,800 km.

The construction of pipeLines is most advantageously done in winter, when damage to the ground surface can be held to a minimum and the frozen ground insures that heavy equipment can move about easily on the tundra and in swampy areas. Underwater crossings are built in the winter using the ice cover as a platform. In order to reduce the impact of gas pipelines on permafrost, a method of cooling the gas to a temperature of -2°C to -3°C has been developed, and cooling facilities are currently being constructed at the Urengoy gas fields.

Hot oil and chilled gas pipeline interaction with permafrost -- The complications arising from the interaction of pipelines and permafrost generally can be categorized as: 1) surface deterioration, 2) erosion, 3) drainage interruption, 4) thaw settlement, 5) frost heave, and 6) effects associated directly with the construction effort. In dealing with these complications, there is no clear cut distinction between cause and effect--drainage interruption can cause aufeis, which can cause surface deterioration, which causes drainage interruption etc. It is this circular, exacerbating chain of events that can cause such chaos if permafrost problems are not anticipated and designed for, or if mitigative measures are not taken immediately when a problem is identified.

For reasons of both security and economy, pipelines generally are best kept belowground. Therefore, the trans-Alaska oil pipeline was buried wherever possible, in unfrozen soil and in thaw-stable permafrost. Refrigerated piles were used to elevate the line and to preclude settlement of the piles due to permafrost thawing. Designers of the proposed Alaska Highway natural gas pipeline plan to bury the line everywhere, with the exception of a few stream crossings. Because the gas is chilled, this should work well in permafrost areas, provided that thawing problems do not arise during the dormant period prior to startup. But in non-frozen frost-susceptible soils the designers face a frost heave problem whose magnitude is just now beginning to be fully understood. They plan to solve this problem by identifying the areas that contain these frost-susceptible soils and then employing suitable mitigative measures in construction.

Thermal aspects of pipeline design -- Thermal considerations are of paramount importance in designing "warm" oil pipelines and "cold'" gas pipelines. 'The impact of the construction disturbance on the thermal regime and, in offshore areas, the potential effects of salt migraion on permafrost degradation below the pipeline are important concerns. Calculation methods have been developed to estimate these effects and to identify situations that require special pipeline designs. Design options include pipeline insulation, heat extraction by passive refrigeration (heat pipes), and "over-excavation." Heat pipes may be used to freeze the soil below the pipeline and to change the geometry of the freeze bulb in such a way that heaving will be minimized. As a last resort, pipelines can be elevated. Short causeways may be used in shallow water where offshore pipelines approach the shoreline. Since special designs tend to be costly, and therefore should be limited, pipeline designers must carefully identify the conditions under which special design is to be used.

Pipeline workpads -- The construction of oil and gas pipelines in remote northern regions generally requires the preparation of a working surface or workpad that will support construction traffic and provide access during the operation of the pipeline. Commonly, gravel fill is used for this purpose. Locally, polystyrene insulation has been used in conjunction with fill material to decrease the amount of gravel needed and to improve the performance of the workpad. When construction is limited to the winter season, snow and ice can be used for workpads and to widen existing narrow gravel workpads. A gravel workpad can cause significant terrain disruption and permafrost degradation, and consequently, requires primary consideration in the design of both elevated and buried pipelines.

Performance of the trans-Alaska oil pipeline -- The exemplary performance of the trans-Alaska oil pipeline can be attributed to the major effort made to design the pipeline to withstand the adverse effects of permafrost, and to a comprehensive monitoring program. To date, the most significant geotechnical maintenance problems have been caused by the thawing of ice-rich permafrost both above and below the pipe. The most serious of these incidents occurred at Atigun Pass and Little Tonsina River where ice-rich permafrost under the pipe thawed causing severe differential settlement. In both areas the ice-rich permafrost was not detected during pre-construction soil surveys and during construction. Remedial measures have been developed to repair pipeline sections deformed because of differential settlement, and the experience gained from these and other geotechnical problems has been used to improve a rigorous monitoring program that will minimize future problems.

ENVIRONMENTAL PROTECTION OF PERMAFROST TERRAIN

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Environmental planning: Rapid development of arctic Alaska in the past two decades, coupled with increased environmental regulatory control, has required the development of special techniques to reduce impacts while maintaining construction efficiency. An approach to reduction of environmental impacts by interdisciplinary planning is discussed including field delineation of natural resource and engineering constraints that is subsequently used for determining the final location of facilities such as transportation corridors, camps, pipelines, ports, etc.

U.S. Regulatory Process: Three major laws were passed by the Congress of the United States during the past 20 years resulting in the distribution of land in Alaska. The Statehood Act entitled the State of Alaska to 103 million acres (416,800 square kilometers) of federally managed lands. The Alaska Native Claims Settlement Act authorized the native villages and regional corporations 44 million acres (178,000 square kilometers). Additional lands were designated for National Parks and Fish and Wildlife Refuges. These changes in land ownership and management have changed the regulatory basis for managing lands in Alaska. Not all lands ace susceptible to mineral exploration or oil and gas exploration and development. Because of this, there are a variety of laws and regulations. The governmental regulatory processes applied by land managers are similar to a degree; (1) the basis for land use decisions are land use plans, and (2) projects are regulated through each phase -- exploration, development, operations, and maintenance under standards commensurate with the intensity of the activity and public interests at risk. In the sparsely inhabited regions of the Arctic and Subarctic, natural resource extraction is usually accompanied by a series of permits, e.g., separate land use permits are required for exploration, production facilities, or transportation systems. Regulations are expressed in stipulations or terms and conditions accompanying various licenses and permits authorizing the projects.

Mitigation techniques: Methods to reduce permafrost degradation during oil and gas exploration in arctic Alaska are discussed. These include methods of construction of snow and ice roads, insulated runways to reduce the amount of sand and gravel fill, and restoration techniques. Included is a discussion of government stipulations that are imposed to reduce impacts in permafrost regions.

Terrain sensitivity and recovery: The arctic regions have a large within-system variability. This variability contributes to the difficulty of making generalizations on the nature of damage to and the recovery and restoration of vegetation. The physical environment controls vegetation via climate and substrate. The interrelationships of surface energy, surficial materials, and biotic ecosystem components, control the likelihood and extent of damage imposed by a specific impact. The term "fragile" is widely applicable to the tundra of the Alaska arctic slope which is a wet maritime tundra underlain by large amounts of ground ice and interstitial ice. However, it is frequently forgotten that large areas of the arctic, especially where underlain by coarse-grained materials or bedrock, are the very reverse of this concept of "fragile." The definition of fragility used here emphasizes the abiotic aspects and gives insufficient attention to the plant cover itself. From other standpoints, the notion of fragility of tundra plant communities has been created from consideration of their slowness to recover from disruption, rather than from their actual susceptibility of disruption per se. Some tundra plant communities often show a remarkable resiliency to disturbance or environmental change. Many man-induced disturbances have natural analogs; man, however, increases the frequency and extent of disturbance which leads to questions about thresholds, stress indicators, and cumulative impacts about which little is known. Considerable attention must be paid to the question of standards concerning the acceptability of vegetation disturbance which leads to change.

Protection in the USSR: The processes associated with thermokarst activity, thermal erosion, and thermal abrasion, and the relative sensitivity of various geographic areas of the U.S.S.R. to permafrost degradation is discussed. The responses to disturbance are explained according to climate, hydrological, geobotanical, lithological, and general geocryological conditions. Special emphasis is given to the selection of areas where systematic, long-term monitoring can be accomplished on both natural and disturbed sites. Additional comments are made about geocryological mapping for purposes of reducing impacts during project planning and monitoring with the use of satellite imagery and standard aerial photography.

The Canadian High Arctic Experience: Permafrost-related environmental problems in northern Canada, especially the High Arctic islands, are a phenomena of the last 15 years. Because of its later development, Northern Canada has been spared many of the esthetic and terrain problems associated with the early development of Northern Alaska. Environmental concerns in Northern Canada are largely related to the search for hydrocarbons in the Mackenzie Valley, the High Arctic islands, and offshore in the Beaufort Sea. With the exception of the Norman Wells oilfield in the Mackenzie Valley, and the Pointed Mountain and Kootaneelee gas fields in the Southern Yukon, the developmental stage has yet to be reached. The extraction of other non-renewable resources in the High Arctic, such as iron ore, lead and zinc, is only just beginning on Baffin Island and Little Cornwallis Island.

Parallel to these activities has been a public awareness of the sensitive ecological nature of much of Northern Canada. In the High Arctic, polar desert and semi-desert conditions" are widespread, in addition to tundra and shrub-tundra. Unfortunately, some of the recently discovered hydrocarbon resources occur in the more fragile tundra and marine environments where plant and animal life is relatively abundant and where ice-rich permafrost is widespread. A cornerstone of federal government policy has been that northern development can only be sanctioned if all possible effort is made to minimize the environmental impact of such activities upon both the physical environment and the indigenous peoples.

One OE the more important steps taken to promote this general objective was the passing of the Territorial Land Use Act and Regulations in 1971. Under this act, land use permits are required and operating conditions are attached. Other initiatives taken include (a) terrain sensitivity and surficial geology mapping programs in areas of potential economic activity by the Geological Survey of Canada and other agencies, (b) preparation of Environmental Impact Statements by industry and their assessment by federal government agencies prior to the granting of land use permits, (c) establishment of government sponsored commissions of enquiry into the social and environmental affects of major development proposals, and (d) support of research into Arctic land use problems by the Arctic Land Use Research (ALUR) Program of the Department of Indian Affairs and Northern Development.

With respect to oil and gas exploration, environmental concerns in the early 1970's were related to seismic and other transportational activities, particularly in the Mackenzie Delta and Valley. Terrain (thermokarst) and ecological concerns were dominant. By contrast recent experience suggests that the physical impact of modern transportational activities has been reduced to a minimum; improvements in industry operating conditions (e.g., the use of vehicles equipped with low pressure tires) and the strict application of the Arctic Land Use Regulations (e.g., the restriction of cross tundra vehicle movement to the winter months) are important factors. Modern terrain disturbance problems appear restricted to localities such as borrow pits, sites of deliberate and unauthorised removal of surface material, and to emergency situations where the movement of equipment in summer is permitted. Viewed in this light, potential for the most serious terrain and environmental damage is now associated with the drilling operation itself and the disposal of waste drilling fluids.

In the High Arctic several factors accentuate terrain disturbance problems adjacent to wellsites. First, there is an absence of easily accessible gravel aggregate suitable for pad construction on many islands. This problem is particularly acute on the Sabine Peninsula of Eastern Melville Island where the Drake and Hecla gas fields are located and where there is a near-continuous vegetation cover overlying soft ice-rich shales of the Christopher Formation. Moreover, the latter are highly prone to rapid and unpredictable "skin-flows". 'Wherever possible urethane matting is placed around the rig and beneath buildings to compensate for any gravel deficiency. Road construction is also a problem due to the lack of aggregate in many localities. Furthermore, although compacted snow is often used for winter roads elsewhere in northern Canada, the very low snowfall of the High Arctic limits this possibility and strong winds leave many flat areas virtually snow free during the entire winter.

A second factor indirectly promoting terrain disturbance is that an increasing number of wells are being drilled to deeper depths as deeper geological structures are tested. Since the time taken to drill a hole increases with depth, activity at many Arctic wellsites often continues into the critical summer months. The movement of equipment and supplies around the site at this time of year can lead to considerable terrain disturbance, especially if there is a gravel shortage at the site.

Environmental problems of land-based wells often relate to the disposal of waste drilling fluids. These may be toxic in nature. As a consequence, the Arctic Land Use Regulations require that they be buried in below-ground sumps, such that these fluids freeze in situ and become permanently contained within the permafrost. In itself, the construction of a sump is a major terrain disturbance. In addition, the influx of relatively warm drilling fluids can lead to significant changes in the thermal regime of the permafrost adjacent to, and beneath, the sump. Moreover, if a well is drilled deeper than anticipated, for various technical or geologic reasons, the sump may be too small to contain the fluids used and additional sumps are required. In other instances, fluids have not been totally contained and toxic materials have been either spilt on the tundra or allowed to enter water bodies. In recent years, the deeper drilling associated with many onshore wells and the larger volumes of drilling muds required are highlighting waste fluid disposal problems.

There appears to be no easy solution to the terrain and environmental problems of land-based drilling in the High Arctic islands. However, the positive attitudes adopted by the companies concerned and the continued application of the Arctic Land Use Regulations are leading to fewer problems which cannot either be resolved or minimized.

DEEP FOUNDATIONS AND EMBANKMENTS

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This panel presentation combines two of the most important aspects of Permafrost Engineering. The underlying theme of the presentation is to review current practice, identify deficiencies and draw attention to the major problems that need further attention. The validation of current practice from performance records is to be emphasized wherever possible.

A distinction is made between road/railway embankments on permafrost and water-retaining embankments. The review of current practice for the design of road and railway embankments distinguishes between the preliminary investigation phase, the design stage, the construction stage, and the maintenance and operation stage. A variety of research needs for each of these stages is identified. Examples include the need for remote detection of subsurface conditions which affect embankment performance and the need to quantify the thermal effects of alternative embankment side-slope surfaces, surface vegetation covers and the role of snow-cover in embankment performance. Several case histories of embankment performance are discussed.

Both the USSR and North American experience with water-retaining embankments in permafrost are summarized. This indicates that the design, construction and maintenance of safe , economical earth dams and preservation of natural earth slopes in the arctic and subarctic is strongly dependent upon such considerations as structural stability, seepage control, the handling of materials, erosion control, and the environmental effect of the impoundment. Extensive development of both analytical and construction techniques is required to address the attendant problems.

The presentations concerned with deep foundations consist of three regional reports. The report on North Americcan practice discusses developments related to pile installation methods, the behaviour of piles under Load, the improvement of bearing capacity using special types of piles and the design of piles. It is concluded that we now have a relatively good idea on 'now a pile, installed by a given method, will behave under an axial load. Much less is known, however, on the effect of seasonal changes of permafrost temperature on pile behaviour. The need for more studies of thermopiles is also emphasized.

In China, deep foundations in permafrost have been tested and used since the early sixties. The types employed are described. To provide a basis for rational design, studies have focussed on the bearing characteristics of single reinforced piles, the freezeback rate of soil around a pile, concrete for use under negative temperatures, the resistance of foundations to frost heave , and methods for protecting pile foundations from frost-heaving. As a result of experience various problems have been identified and they are discussed.

It is anticipated that a summary of current Soviet practice in the design and construcitn OF deep foundations in permafrost will also be available and that this will emphasize what is being done, what validation exists for current practice, and what outstanding problems merit attention.

CLIMATE CHANGE AND GEOTHERMAL REGIME

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Introduction

Changes in climate have long challenged man and his activities, indeed his survival, on this planet. Many periods of a general cooling of the northern hemisphere have occurred accompanied by the advance of glaciers, greater severity of winters and ice-choked sea lanes. A Norwegian priest wrote in the mid-fourteenth century "Now the ice has come.. . no one can sail by the old route without risking death" of the tragic interruption of Scandinavian settlement of Greenland. Several recent climatological reports have demonstrated that a generally increasing CO_2 content of the atmosphere would be accompanied by a general increase of the mean annual air temperature at the earth's surface. The magnitude of the increase would be most pronounced at high latitudes; possibly as much as 3 to 6 K for a doubling of the CO_2 content.

The energy crisis in 1973 emphasized the need to find and develop arctic hydrocarbon reserves. A similar need for the other mineral resources will develop in the next few decades. Exploitation of these resources and the associated infrastructures of buildings and transportation facilities will be on and in permafrost which underlies 24% of the land area of the globe. Much of this permafrost contains massive ice to considerable depths and reaches total thicknesses of up to 700 m. Numerous reports and papers have documented the immediate impact of development through clearing vegetation, interrupting drainage and operating hot oil and chilled gas pipelines. A 2 m diameter pipeline buried in permafrost, for example, will thaw to 9 m in five years. Mean air temperature changes of several degrees can be expected to occur over the lifetime of such projects, with possible long-term regional effects on the terrain traversed by a pipeline or highway as important as the short-term localized impact of the development itself. Knowledge or prediction of such climate trends become a critical aspect of design for long term performance. In general direct observational measurement of climate change in the Arctic is limited in Canada, for example, to the past 35 years, so proxy methods such as palynology, oxygen isotope distribution and geothermal analysis become important ways of extending the record of the past. Geothermal analysis does offer a direct, if resolution limited method, of examining past changes in mean ground temperature.

Permafrost and Climate Change

The regional distribution of permafrost is a function of climate although wide variations in ground thermal conditions do occur in small areas of uniform climate due to site specific conditions. Where mean annual ground temperatures are close to 0°C, in the sporadic and discontinuous zones of permafrost, specific local factors can determine whether or not permafrost is present.

Changes in the ground thermal regime, and hence in the distribution and thickness of permafrost, can result from both changes in climate and local conditions. The specific effects on permafrost of a macro-scale climate change are not necessarily simple, depending on the complex interaction of climate, microclimate, surface and ground thermal conditions. If, for example, a global warming, concentrated in the Arctic, results from higher CO_2 levels, the effect will certainly be profound, but increased precipitation and deeper snow cover may slow the warming of the ground surface. Such a lowering of the effect of atmospheric warming on the ground thermal regime will partially protect the existing permafrost.

Supposing that a rise in mean annual air temperature is translated directly into a similar increase in mean annual ground temperature, permafrost at the southern limit may retreat northwards by as much as 100 km K^{-1}. This has been observed in Manitoba where over the past 200 years the areal extent of permafrost has diminished from 60 to 15%. Within the discontinuous permafrost a thicker active layer will develop, widespread thaw settlement in areas of massive ice will occur, south-facing slopes will become permafrost-free and surface and groundwater patterns will change. Extensive thermokarst features will form from the thaw of massive ice leading to the formation of lakes, new drainage patterns, alass areas, etc. Slopes in general will become less stable leading to extensive failures and erosion. Rivers less confined by frozen banks will change course and carry increased sediment loads. Coastal areas could well be innundated by the sea as the thaw settlement lowers elevations to below sea level, especially if a general rise in sea level occurs. The impact of differential thaw settlement as much as a meter on constructions such as roads, pipelines and buildings is not difficult to visualize. In the continuous permafrost zone, the southern boundary of which will also move northwards, ground temperatures will also rise leading to similar phenomenon but on a lesser scale. Most of the immediate impact will be close to the surface where human activities are most dramatically affected.

A decrease in air and ground temperature will lead to a reversal of the above features including a southerly advance of the discontinuous and continuous boundaries of permafrost, and corresponding vegetation zones. More importantly it will lead to the growth of massive ice bodies, a reactivation of the growth of ice wedges in more southerly areas, and a generally thickening of permafrost and consequent changes in surface morphology and drainage patterns.

Many of these processes can happen quickly, even on the scale of the lifetime of human endeavors. For example, only 150-200 years would be required to completely melt 25 meters of permafrost in the discontinuous zone in response to a moderate increase of surface temperature. Extensive modification to the active layer and resulting thaw settlement will occur after 3-4 years. This is less dramatic than the 9 meters of thaw predicted within a period of five years around a hot oil pipeline but it is more widespread, at present less predictable and hence more difficult to design for. In general discontinuous permafrost occurs at mean ground temperatures between O and -6°C, and for the temperature rise of 3 K predicted for a doubling of CO_2 content, as much as 25% of permafrost in Canada might" be expected to disappear, which would leave the southern boundary about half way between Great Slave and Great Bear Lakes.

Evidence for Climate Change

Much of Canada has become free of the Wisconsin ice-sheet only in the past 8000 to 16000 years. If that were not significant enough, many analyses of past trends have shown how dramatically climate has varied in the past few thousand years that man has kept records. Manley, for example, pieced together a remarkable historic record for central Britain from a wide range of sources. The mean air temperature was found to be the lowest in the period 1680-90, gradually rising until 1880 when a pronounced rise continued until 1950. One of the longest lived societies in the world is that of China with documents dating from 1100 BC. Chu has examined a broad range of agricultural records from the dates of blooming of cherry trees to annual harvests. At the start of the records 3000 years ago, mean annual air temperatures were 2 K higher than today, superceeded by a series of swings of 1 to 2 K amplitude with minima at 100 EC., 400 AD, 1200 AD, and 1700 AD. The latter lends a global perspective to Manley's observations, and the so-called "Little Ice Age" starting in the late 14th century and persisting into the 17th.

Long term documented evidence for climate variability in the northern permafrost regions is more fragmentary. Short records do exist, as for example Greely's observations at Fort Conger and Ellesmere Island during the First Polar Year, but the first permanent weather stations in the Canadian Arctic started only in 1947. Archeological evidence suggests that the most northerly Inuit sites in northern Ellesmere and the Viking settlement of Greenland coincide with the "little climate optimum" and the subsequent disappearance of the settlements with the "Little Ice Age". Recent evidence since meteorological records began suggest as time dependent a climate as observed elsewhere in the world. Alaska and northwestern Canada, for example, in general warmed by 1 K between 1875 and 1940, and cooled by about 0.5 K until 1960. Such trends are hidden beneath much wilder short term swings of 1 K. These variations are not uniform, however, for a while a cooling trend has continued at Barrow, at Fairbanks the mean air temperature has been warmer than the long-term mean for the past six years.

Many of these trends seem in fact to be reflected in permafrost behavior, for example, the retreat of the southern permafrost boundary, the initiation of extensive thermokarsting in the southern Mackenzie Valley in the past hundred years, and within the last decade, the reactivation of ice wedges on the Arctic coast.

Brown and Andrews have recently summarized the trends from many arctic series of proxy information as follows;

1. A long-term cooling trend of the order of 0.7 K per thousand years.

2. Superimposed on the long-term trend, a series of major oscillations with wavelengths of 500 to 600 years.

3. Evidence from the Eastern Canadian Arctic that summer temperatures fell below the mean for the past 6000 years between 2500 and 1500 years ago and did not rise above the mean until the last 100 years.

4. Temperatures in the 20th century that are, on average, as warm as they have been for several hundred years, if not thousands of years.

The latter point may be something of an exaggeration although certainly no warmer periods have occurred since the llth century. Whether or not the general trends will continue or whether the impact of CO_2 in the atmosphere will dramatically reverse such trends remains a point of considerable debate.

The Geothermal Regime and Climate Change

Lane first proposed in 1923 that the underground thermal field contained a "memory" of past changes in surface temperatures. He attributed a reduction of temperature gradient above 1000 m to the effect of Tee-cover during the ‘'Glacial Age". Basically the earth can be treated as a semi-infinite medium in which the surface temperature is the upper boundary condition of a medium subjected to a constant heat flux from below. Due to the low thermal diffusivity of rocks, any temperature change at the boundary is propagated slowly downwards remaining recorded but attenuated and dispersed at depth. Following the classical treatment of Birch, the geothermics community recognizes that all continental heat flow measurements in the upper kilometer need a correction for different surface temperatures during Pleistocene glaciation. Theoretically the reduction below the true heat flow in low temperature gradient regions could be up to 40%. A lack of deep holes in areas of uniform geological conditions, a poor knowledge of the role of slow water movements at shallow depths and of the energy conditions controlling surface temperature has, however, led to considerable dispute and uncertainty as to the magnitude of the corrections.

Aside from the problems of interpreting the strongly attenuated events in the distant past, geothermal analysis of more recent climatic events has had notable success. The evidence in temperature logs throughout eastern North America, the Mackenzie Valley and the Arctic coastal plain for a general warming trend starting a century ago followed by a recent downturn agrees well with meteorological data. In general the evidence indicates that ground temperatures increased more than air temperatures. A detailed study in the uniform shield rocks of Northern Ontario revealed perturbations caused by surface ground temperatures increasing by 1.5 K in the Little Climatic Optimum from 1000 to 1200 AD and decreasing by 1 K during the Little Ice Age from 1500 to 1700 AD. As Lachenbruch has pointed out, the resolution of recent climate events within the permafrost should be aided by the lack of water movement, although response of the active layer will to some extent mask surface events in the more southerly permafrost areas.

One of the serious problems with using geothermal analysis as a proxy technique arises from the non-uniqueness of the solutions. Given a series of dates at which climate change occurred from other sources, the techniques will successfully resolve amplitudes of the change for up to about four events. Improved continuous or semicontinuous logging methods may eventually improve upon this. In summary, the present strengths and uses of this type of analysis of borehole temperatures are probably as follows:

1. Given good meteorological information on climate change over the past 100 years, to determine how that change has been translated into ground temperature. The analysis will enable some prediction of how future trends will effect permafrost.

2. In areas where meteorological data is non-existent or of short duration, to determine the long-term fluctuations of ground temperature over the past several centuries. Some answers will be derived as to whether areas such as the high Arctic follow global trends.

3. Given proxy information on the dates and duration of climatic events, some ideas of amplitude can be derived from geothermal analysis.

4. Promising areas of application to more remote climate events including the derivation of ice-base conditions during Wisconsin glaciation require further refinement.

FROST HEAVE AND ICE SEGREGATION

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A survey of the literature shows that the controversy about the nature of the ice segregation process in soils has not subsided; this component of frost heaving has been more controversial than any other subject concerning ground freezing. The important possibility now exists however the the highly complex mechanism of frost heaving can be successfully modelled. With some simplifications such a model would have many important applications' in engineering.

Numerical simulations of the ice segregation process so far have been disappointing although many advances have been made. Berg has questioned the validity of using macroscopic relationships, e.g., Darcion-type moisture flux, for microscopic processes, e.g., ice formation in porous systems. Until recently computer modelling research was mostly concerned with the frost heave component of frost action, i.e., heave rate, soil properties that affect heave, the effect of pressure and water supply, the influence of freezing rate, etc. but now another dimension has been added which is the modelling of thaw-weakening following soil freezing.

Miller contends that numerical solution of the "rigid ice model'" has been achieved for the special case of air-free solute-free soil systems but that "reasonable input data'" is difficult to attain hence the evaluation of computed results against experimental results has yet to be done in an objective way. It is believed however, that a significant advance has been made in defining ice lens initiation.

Berg reinforces Miller's contention about the need for improvements in the reservoir of knowledge of the thermal, hydraulic, chemical and mechanical processes if advances are to be made in numerical modelling. Berg concludes that while many numerical models have been proposed, no one frost heave model has been widely accepted. Modelling has been mostly confined to uniform soils and thus applying present models to layered soils with success seems remote.

In addressing the complicated process of moisture migration in frozen soils Williams cites examples from the literature of moisture redistribution presumably transported by mobile unfrozen films. The driving force he contends is related to the increase in suction with decreasing temperatures, hence temperature gradients induce suction gradients. Layers of ice, e.g., ice lenses, should not be barriers to the passage of water through frozen soils.

In the area of current engineering problems Isaacs points out that until recently no rational system has been available for the design of buried gas pipelines it-i discontinuous permafrost. Use of a chilled pipeline (below 0°C) causes the generation of a frost bulb and the associated heaving in unfrozen zones that induce stresses on the buried pipeline. Isaacs suggests that design solutions that envisage a bare pipe in permafrost and an insulated pipe in unfrozen soils are not feasible because of the difficulty and cost of delineating with sufficient accuracy where such transitions occur. An improved solution suggested is to predict frost heave of the soil and its effect on the pipeline. Major design difficulties with respect to pipeline integrity are the predictions of heaving forces, the resisting forces and their effect and the span over which the differential heave occurs.

Grechishchev maintains that regardless of the high level of research - in soil freezing - carried out, the fundamental problems relating to the conditions of the growth of *ice* crystals and the migration of moisture remain unresolved. A theory is proposed with the aid of thermodynamic analyses which makes it possible to unite physico-chemical, mechanical and thermophysical aspects of cryogenic processes and presents a number of consequences of the proposed theory.

In reviewing the current developments about frost heave processes in the PR of C, Chen Xiaobai states that the important research problems are concened with the mechanism of frost heave and how to prevent engineering structures from frost damage. Frost susceptibility laboratory studies have been on frost penetration, surcharge and depth of the groundwater table. Grain size distribution, frost penetration rates, the influence of surcharge on heave and the level of the groundwater table have been important parameters for field application. Secondly, studies are devoted both in the laboratory and the field to the division of total frost heave forces into tangential normal and horizontal forces on foundations. Finally, attention is also being given to the mechanism of water migration during soil freezing. In unsaturated systems, moisture conductivity is based on water characteristic curves at different temperatures and the superimposed characteristics of moisture flow and moisture potential during freezing. Moisture measurement techniques have involved neutron moisture meters, tensiometers and other instrumentation. A model for calculating water migration during freezing in closed and open systems has been set up.

SUBSEA PERMAFROST

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Permafrost, in the sense of earth materials at temperatures below zero degrees Celsius, is widespread beneath the sea bed in Arctic continental shelf areas. The presence in some areas of interstitial brines and in others of sediments composed of the finest grain sizes, however, allows many sea bed materials to remain unfrozen despite negative geothermal temperatures. Consequently, the extent of arctic continental shelf areas underlain by ice-bonded sediments is much more restricted than is the extent of non-ice-bonded subsea permafrost.

Little was known about the distribution and character of subsea permafrost prior to about 1970; many North American researchers doubted its existence, although the presence of subsea permafrost had been established on parts of the Siberian arctic shelves by F.E. 4re and his colleagues *as* early as *1950.* Modeling studies by A.H. Lachenbruch, based on geothermal observations in deep boreholes onshore but near the beach at Cape Thompson and Barrow, Alaska, indicated that permafrost is absent beneath the adjoining Chukchi Sea shelf. The first evidence of ice-bonded permafrost beneath the Beaufort Sea probably came from the Canadian offshore drilling program conducted by the Arctic Petroleum Operatorfs Association (APOA) in the late 1960's. The existence of subsea permafrost beneath westernmost Beaufort Sea near Point Barrow was first established in boreholes drilled by R.E. Lewellen in the early 1970's.

Petroleum exploration in the Arctic precipitated a need for a better understanding of subsea permafrost. The new studies showed that subsea permafrost differs from permafrost beneath adjoining land areas in being mostly relict, generally warmer, and generally poorer in ice.

Though it may be hundreds of meters thick, subsea permafrost is generally at temperatures only a few degrees below zero. Segregated ice masses are mostly small and sparsely distributed. Considerable quantities of non-crystalline water may be present in brine lenses or adsorbed to clay particles. One effect of the presence of the non-crystalline water is to reduce seismic velocities below those typical of more completely frozen materials. The geometry of bonded and unbended material is likely to be complex, in some cases reflecting penetration of brine into extensive gravel bodies and in others the intercalation of unbended clay strata and ice-bonded sand.

Much of the ice-bonded permafrost found beneath the sea bed is out of equilibrium with its present environment, in the process of degradation, and thus relict. Most of the relict premafrost originated on the exposed continental shelf at times of lowered sea level. Migrating spits and emergent barrier islands, however, fern cold windows that can cause freezing or refreezing of underlying marine sediments; thus, some bodies of relict subsea permafrost represent trails that mark the passage of these mobile features across the sea floor. Boreholes near Prudhoe Bay have penetrated alternations of bonded and unbended material that evidently consist of degrading shallow permafrost left behind by a migrating barrier island, separated by unbended material from deeper, thicker ice-bonded material relict from a time when the sea level was low and the shelf emergent.

Relict ice-bonded sediment warms and thaws within a few decades beneath shelf water at temperatures at or above zero degree Celsius. Many Arctic shelves, however, have bottom water well below zero, and there, destruction of ice-bonded permafrost results mainly from salt penetration. Ice-bonded gravel and coarse sand at the sea bottom is readily penetrated by sea water. Convective movements of interstitial brine then result in rapid thawing of interstitial ice along a broadening front with little change in geothermal temperatures. 'l'he ultimate driving mechanism may be gravity, because thawing generates relatively fresh, thus buoyant, water. Salt enters the ice-bonded silt and clay by diffusion processes and thus orders of magnitude more slowly; consequently, relict ice-bonded permafrost may persist for centuries or even millenia at depths of only a few meters below the sea bottom in Pleistocene silt and clay.

Under special conditions, new ice-bonded permafrost can form in the marine environment. This can be expected wherever a link exists with cold air temperatures, e.g., in shoals where sea ice freezes to the bottom during much of the winter and, as noted above, beneath migrating spits and barrier bars. However ice-bonded surficial sediments have also been found in water deeper than 2 meters, suggesting that other processes are also active. These deeper examples of modern subsea frozen sediments evidently result from the exclusion, during winter, of cold, heavy, hypersaline brine from the thickening ice canopy. Subsequent movement of the very cold brine along the sea bed may bring it into contact with materials that have ideal properties for freezing. Examples of frost-susceptible sea bed materials may be those with low permeability and low-salinity pore waters.

The regional distribution of permafrost has been most thoroughly studied on the shelf of the Beaufort Sea. Permafrost distribution is especially well studied in the coastal water inshore from the 15-meter isobath on the *central* part of the Alaskan segment of the Beaufort Sea shelf between Flaxman Island and Harrison Bay. Analysis of seismic data and borehole and penetrometer-probe observations indicate that ice-bonded material is widespread. Extensive zones of shallow ice-bonded sediment, often 10 to 20 meters below the sea bed, occur in this region. Shallow, high-velocity materail that can be traced to ice-bonded permafrost encountered in boreholes and, in some seismic lines, to cold permafrost onshore continues seaward as much as 40 km and may lie *as* deep as 600 meters. In many parts of the coastal zone, high velocity material inferred to represent firmly ice-bonded permafrost is overlain by a seaward-thickening layer of intermediate-velocity material. The shallower layer of intermediate velocities seems to consist of warm permafrost that contains brine lenses or a considerable quantity of liquid water adsorbed to clay particles.

Little is known about the distribution and state of permafrost on the outer part of the Alaskan Beaufort Sea shelf. However, seismic lines that extend out to the shelf edge in the Prudhoe Bay area display deep horizontal reflectors discordant to bedding and lying at depths of 200 and 450 meters. Possibly these represent the top and bottom of ice-bonded material.

The shallower part of the Mackenzie Bight in the Canadian segment of the Beaufort Sea has also been extensively studied, with special attention to confirmation of acoustic results by means of shallow boreholes. A submarine valley, the Mackenzie Trough, seems to lack permafrost, but shallower waters to the east are underlain by a complex of frozen and unfrozen sediments. Shallow fine-grained sediments, probably of Holocene age, contain stratigraphically controlled ice-bonded sandy layers interspersed with unbended clay. The factors that permitted these Holocene materials to become frozen while submerged is still unclear. An underlying thick sand unit, probably of Pleistocene *age,* contains thick and extensive permafrost, but unfrozen zones underlie channels, possibly former stream courses, that incise the sand and that are now partly filled with finer Holocene sediments.

Every new detailed study of offshore permafrost brings to light new distribution patterns, which clearly indicates that our knowledge of the factors governing distribution patterns of bonded and unbended permafrost in the sea bed is still far from complete.

ABSTRACTS

Note: Some abstracts of papers which were submitted but *not* presented at the conference will be published in the proceedings volume but are not included here.

Abstracts of papers which were submitted late are either not included, or earlier versions, rather than the final ones, are included here.

EFFECTS OF OFF-ROAD VEHICLE TESTS ON TUNDRA TERRAIN IN NORTHERN ALASKA	I

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Traffic tests were conducted at two sites in northern Alaska with an air cushion vehicle, two light tracked vehicles, and three types of wheeled Rollingon vehicles. The traffic impact (surface depression, effect on thaw depth, damage to vegetation, traffic signature visibility) was monitored for periods of up to 10 years. Data show the immediate and long-term impact from the various types of vehicles for up to 50 traffic passes and the rates of recovery of the active layer. The air cushion vehicle produced the least impact. Multiple passes with the Rollingons caused longer-lasting damage than did passes with the light tracked vehicles because of their higher ground contact pressure and wider area of disturbance. Recovery occurs even if the initial depression of the tundra surface by a track or a wheel is quite deep (15 cm), as long as the organic mat is not sheared or destroyed.

ON THE RELATIONSHIP BETWEEN THE STRUCTURE AND CHARACTERISTICS OF BEDROCK MASSES AND THEIR PERMAFROST HISTORY	P-7

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Comprehensive investigations in the areas of permafrost hydrogeology and engineering geology within the Stanovoy and Mongo-Okhotsk folded systems revealed the presence of horizons and zones of severe jointing in the bedrock. They occurred both where there was no permafrost and at the top and bottom of the permafrost. The thickness of the zones involved reaches 100 m and more, and the ice content where the rock is frozen reaches 6-10% by volume. The formation of these horizons of severely-jointed rock is related to the dynamics of permafrost development during climatic changes in the Late Pleistocene and Holocene, specifically to intense frost shattering caused by repeated freeze-thaw. These horizons and zones of severe jointing exert a

major influence on the formation of the existing subsurface drainage and to talik zones which operate both as recharge and discharge zones in terms of groundwater and also as lateral transfer zones beneath the permafrost.

MEASUREMENT OF' PERMEABILITIES OF FROZEN SOILS — M-3

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A method for the measurement of the permeability of frozen soils is proposed. It consists of applying a temperature below O"C only to the central portion of a cylindrical specimen of a porous medium and a positive temperature to the other two portions. To fix and know the position of the 0°C isotherm it is necessary to impose the same absolute value to the two temperatures. It is possible to use this method without limitation of the explored domain of temperatures. The first apparatus that was constructed is described, and the results of permeability measurements on a silt at -0.3°C are given and discussed. The experience acquired has led to the construction of a second, improved permeameter and to foresee new supplementary protections against small variations of temperature in the experimental room, which were found to have an important influence on the stabilization of the thermal and flowing regimes and reproducibility of experiments.

RELATION BETWEEN FROST HEAVE AND SPECIMEN LENGTH — M-5

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A distinct relation was entailed through boundary temperature fixed open-type heave tests that the heave rate of last ice lens growth decreases proportionally to elapsed time. In relation to the above empirical fact, the following two facts were revealed: (1) the last ice lens grows logarithmically as time elapsed and (2) the logarithmic curve can be defined by two parameters; one is determined by heave test and another one is obtained from heat conduction analysis. The relation between last ice lens growth characteristics and frozen soil specimen length were also studied. As the result it was found that a longer specimen has higher heave susceptibility and the longer duration of heave. In this paper, the experimental approaches for the above

conclusions are described showing the heave test data which was carried out on specimens of various length under constant temperature gradient and over-burden pressure.

NOTES ON CHEMICAL WEATHERING, KAPP LINNE, SPITSBERGEN	P-7

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Surface karst features upon outcrops of dolomitic limestone are described from an area in the western part of Spitsbergen (78°04'N, 13°38'E). The morphometric characteristics of karrenforms are compared with the height above sea level, position in the terrain and upon the outcrops, exposure to prevailing winds, the snow *cover.* The best developed forms are found between 50 and 150 m a.s.l. upon gently sloping rock surfaces where there is a thick snow cover which can provide water during the melt season. Signs of differential chemical weathering are common in the area in the form of elevated quartz-filled joints forming complex patterns on the surfaces of the outcrops. A good correlation is found between the height of these quartz veins and the height above sea level. As the isostatic uplift history of the area is well known, it is possible to estimate the denudation rate of the dolomitic limestone to be 2.48 mm/1000 yr.

THE PHYSICOCHEMICAL NATURE OF THE FORMATION OF UNFROZEN WATER IN FROZEN SOILS	I

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The paper examines how the liquid phase of H20 is influenced by the basic physiochemical factors in permafrost: average size of particles and pore-spaces, polydispersity and heteroporosity, specific surface, surface energy, structural bonds, composition of the solutions in pore-spaces, temperature, etc. The trend of the curve showing the relationship between the unfrozen water content and temperature is described theoretically; physics-based constants are *an* integral part of the formula used in calculating this relationship. The surface energy of the mineral skeleton of the soil is found to be dominant in dictating the presence of H_2O in the liquid phase; the contribution made by the quasi-liquid film on the ice surface was proved to be

non-critical. As one proceeds from macro- to microporous soils and from coarse to fine ones, the percentage of capillary water increases and that of film water decreases. It was shown that the relaxation time of unfrozen water does not exceed one hour. The correlation between typical soil moisture contents and the amount of unfrozen water was explained on a physiochemical basis; the thermodynamic characteristics of the unfrozen water are also discussed. The relationships between the physiochemical and petrographic parameters of frozen soils were demonstrated and on this basis the rules governing the formation of liquid H20 in soils of differing genesis, age and granulometric, chemical and mineralogical compositions are demonstrated and explained.

LUG BEHAVIOR FOR MODEL STEEL PILES IN FROZEN SAND	C-3(1)

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The adfreeze bond strength for piles embedded in frozen sand includes ice adhesion to the pile, friction between the pile surface and sand particles, and mechanical interaction between frozen sand and the pile surface roughness. Experimental work has shown that the presence of lugs, small protrusions, increased the volume of ice matrix and soil particles involved in the initial rupture, thereby increasing bond due to ice adhesion. Additional pile movement and soil interaction with lugs mobilized sand dilatancy and particle reorientation effects along with soil bearing forces on the lugs. The model pile load was significantly increased. The net result was that creep displacement behavior will differ considerably depending on pile movement. Very small displacements characterize the start of tertiary creep (failure) for applied shaft stresses below those required for initial rupture of ice adhesion. Larger displacements and higher shaft stresses are associated with mobilization of mechanical interaction forces. Experimental relations presented include load displacement curves for constant displacement rate tests; constant load creep curves for a model pile with multiple lugs; and the dependence of creep displacement rates and/or adfreeze bond on Lug size, temperature, and sand volume fractions (ice content).

EFFECTS OF VARIATIONS IN THE LATENT HEAT OF ICE FUSION IN SOILS ON INTKRACTION OF BOREHOLES WITH PERMAFROST	I

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Experimentally derived values of varying latent heats for fusion of ice (ΔH_m) in samples simulating permafrost over a temperature range of −30°C to 0°C are cited. The value ΔH_m was shown to be heavily temperature-dependent and at -5°C it is more than six times less than the 'neat of fusion of homogeneous ice. Calculations of the thermal interaction of boreholes with permafrost have demonstrated that for clayey materials adjustments in the calculated radii of warming due to changes in ΔH_m may reach 150-300%.

INCREASE WITH DEPTH OF FREEZE-BACK PRESSURES ON THE SIDES OF DRILLHOLESASSOCIATED WITH FREEZING OF A FLUID IN A CAV ITY	I

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Recently, there has been a considerable growth of interest in the problem of secondary freezing of thawed materials around a drillhole. This is associated with the fact that the process of secondary freezing leads to the development of considerable freeze-back pressures on the walls of drillholes, which may lead to their collapse. Analysis of studies of secondary freezing has shown that no satisfactory theory has been advanced thus far which would permit reliable forecasting of a stressed condition in the freezing materials around a drillhole. The present paper suggests an approximate theory for calculating maximum freeze-back pressure G_{max} on the walls of a drillhole as the materials freeze around it and as drilling mud filtrates freeze in a cavity. Identification of the dependence of G_{max} on depth is based on the solution of the problem of the axially-symmetrical plane on the development of the freeze-back pressure $G_{(t)}$.

VHF PROPAGATION EXPERIMENTS IN THE PERMAFROST TUNNEL, FOX, ALASKA

C-2

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Radiowave propagation experiments utilizing short pulses in the VHF band were conducted in the permafrost tunnel in Fox, Alaska. The purpose was to measure dielectric properties of this deep (approximately 10-12 in) frozen organic silt for which ice content had been previously documented to vary between 54 and 79% by volume, Transmissions across the tunnel septum dividing two rifts gave dielectric constant values between 3.9 and 7.3. The low values resulted when transmission was predominantly through an ice wedge. Propagation along the septum gave values of 3.3 and 5.0 for two different polarizations, respectively, and the propagation modes here were influenced by the dry, surface silts, as was propagation along a ceiling section, which gave an approximate value of 3.3. The data from attempted transmissions from the ground surface directly to the tunnel are ambiguous, as signals that propagated indirectly along the transmitter cable through a ventilation shaft may or may not have masked direct transmission through the permafrost. The results agree with previous laboratory investigations conducted at temperatures well below that of the tunnel, suggesting that winter refrigeration by circulated outside air greatly affected the natural conditions at this site.

MASS TRANSFER IN THE SNOW COVER OF CENTRAL YAKUTIYA

I

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On the basis of ten years of experimental research it has been established that the intensity of mass transfer in the snow pack is temperature-dependent and reaches its maximum at snow temperature above -20°C. The mean rate of vapor diffusion in snow layers near the base of the pack varies between $(2.0-2.5)\times10^{-3}$ and $(3.0-4.0)\times10^{-3}$ g/cm^2 per day. The "norms" were obtained for snow sublimation for all types of landscape in Central Yakutia, e.g. 12 mm on meadows; 5.5 mm in pine forest; 6.2 mm in larch forest; and 8.5 mm on lake ice. The value for mean daily sublimation of snow is determined on the basis of the air humidity deficit and the wind velocity. Ten-day sublimation totals were determined on the basis of the absorbed radiation.

THERMAL ABRASION OF COASTS	G-3

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Thermal abrasion of the shores of any water body or stream is controlled by the same basic laws and is distinguished by peculiarities dictated by differing hydrological regimes. The main influence of the frozen state of the materials on the development of thermal abrasion is determined by their ice content and reveals itself when the materials slump on thawing. The greater the potential for settlement, the greater is the rate of thermal abrasion and the limiting value of shore retreat. The frozen condition of the materials does not prevent destruction of t'ne shores. In the case of large water bodies the thermal abrasion rate is dictated by the removal of the thawed materials from the shore zone, while in small water bodies and in shores developed in massive ice bodies the limiting factors are the thermal processes. During recent decades climatic cooling has slowed the rate of thermal abrasion by the sea. One of the possible controls on the orientation of thaw lakes is the irregular development of thermal abrasion due to spatial variations in the distribution of sediments prone to thermal abrasion collapse in these shores. Rates of erosion in river banks developed in similar materials are identical whether or not permafrost is present.

PREDICTING FISH PASSAGE DESIGN DISCHARGES FOR ALASKA	H-1(2)

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Improper placement of highway culverts may selectively or totally block fish migration, thereby decreasing available spawning and rearing habitat. Blockage will occur with a combination of excessive culvert water velocities, lack of fish resting areas upstream and downstream of the culvert, and scour at the culvert outlet, creating perched conditions. Previous studies of fish passage culverts have determined fish swimming abilities and profiles of culvert water velocity. There are limited studies of the hydrologic relationship among frequency, duration, season, and magnitude of discharge for the design of fish passage through culverts in northern regions. We analyzed streamflow records from 14 gaging stations in south central, interior, and arctic Alaska (drainage area < 260 km^2) to determine the peak mean discharge with 1, 3, 7, and 15 day durations. Streamflows during three periods were analyzed: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to November 30. The Lognormal distribution, using the Blom plotting position, predicted flood frequency values. Regionalization, with the index-flood method, of single station values provides a method for predicing discharges from ungaged drainage basins. Regressions developed to predict the 2-year return period discharge found that the significant basin characteristics were basin area and forest cover in the spring period, and basin area, forest cover, and mean annual precipitation in the summer and fall periods.

COLD WEATHER EFFECTS ON BURIED PIPE FACILITIES	I

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Buried pipes break more frequently during winter. A study of the influence of cold climate upon buried-pipe failures was undertaken utilizing an analysis of the past water main break records and meteorological data for Madison, Wisconsin, U.S.A. The analysis is supplemented with the field data obtained from an instrumented section of a water main in the same locality and the available data from a related laboratory model study of the problem. The analysis indicated that a greater frequency of buried pipe breaks is encountered during the winter months due to an increased number of breaks following a sudden decrease in the air temperature (a cold snap). The field study indicated, as did the laboratory study, that a cold snap is accompanied by increased pipe bending stresses in buried pipes. Most failures are circumferential and observed in small pipes (< 150 mm in diameter) supporting the notion that the increased bending stresses are responsible for the greater frequency of winter breaks. Depth and rate of ground freezing and availability of ground water are significant factors influencing the increased bending stresses in pipes even if they are buried at some distance below the frost depth.

PERIGLACIAL GEOMORPHOLOGY IN THE KOKRINE-HODZANA HIGHLANDS OF ALASKA	I

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The portion of the Kokrine-Hodzana Highlands near the Arctic Circle and adjacent to the Dalton Highway is an easily accessible area containing a diverse assortment of periglacial features. The region is within the discontinuous permafrost zone and probably has never been glaciated. Bedrock is principally metamorphic with major intrusions of porphyritic granites arid some mafic and ultramafic rock. The nature of the bedrock profoundly affects the type and character of the local landforms. Finely jointed and foliated bedrock tends to promote development of cryoplanation terraces. Terraces are most fully and distinctly developed on metamorphic bedrock, especially schist and phyllite, at elevations above 600 m. Terraces are usually obscure or absent on igneous bedrock. Widely jointed massive bedrock tends to form the best tors. Of the 128 tors physically inspected in the field, 88 are composed of highly weathered porphyritic granite distributed over a wide range of elevations. Both the diameter and the particle size of sorted polygons are likewise determined in part by bedrock type. Other periglacial landforms include felsenmeer, sorted circles, ice-wedge polygons, thermokarst depressions, open-system pingos, extensive gelifluction slopes, and anthropogenic palsas.

UNCONFINED COMPRESSION TESTS ON ANISOTROPIC FROZEN SOILS FROM THOMPSON, MANITOBA, CANADA	c-2(1)

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Laminated frozen soils, consisting of alternate horizontal layers of dark brown clay and light brown silt, with ice lenses between the layers, are found in the northern area of ancient glacial Lake Agassiz. Laboratory tests confirmed the results of in situ ground anchor, penetrometer, and pressuremeter tests performed at Thompson, Manitoba, which showed these soils to be stronger in the horizontal direction, parallel to the layers, than in the vertical direction. Undisturbed block samples of these laminated (varved) frozen soils were obtained and test specimens were prepared at various orientations to the direction of layering. Unconfined compression tests, using both naturally frozen and remoulded frozen specimens, have shown the extent of strength anisotropy due to the natural anisotropic soil structure.

POSSIBLE APPLICATIONS OF FOAM CEMENTS IN PROTECTING THE ENVIRONMENT IN CONNECTION WITH WELL DRILLING

I

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The article presents the results of investigations into the application of crystallochemical intensification of the oil-well foam cements of the "Aerotam" type (aerated plugging material) with densities of 800 to 1600 kg/m^3 and thermal conductivities of 0.35 to 0.55 $Watt/m^2K$ at temperatures from -10"C to +160°C. It demonstrates that cement slurries of the "Aerotam" type may find wide industrial application for protecting the environment in well construction and as "passive'* thermal insulation for cementing the casings of oil and gas wells in permafrost areas, and also as a super-light plugging material for cementing casings under conditions of abnormally low well pressure and intense grout absorption. Thawing of the permafrost during drilling and operation of wells in oil and gas condensate fields leads to irreversible ecological damage. Various methods of "active" and

"'passive" thermal protection are used; to prevent such thawing, in either case practice has shown that the best results have been achieved by the application of special plugging materials with high thermal insulating properties, namely foam cements, for well cementing.

MECHANISMS AND TRENDS WITH REGARD TO CHANGES IN THERMAL CONDUCTIVITY OF SOILS DURING FREEZING AND THAWING

I

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The paper examines the results of comprehensive experimental studies of the mechanisms and laws governing the heat conducting properties of a variety of soils of differing geneses and ages. These soils differ in their granulometric and chemical-mineralogical compositions, their degree of salinization and peat-formation, and in their cryogenic texture. The studies were carried out by the stationary regime method applied during the process of freezing and subsequent thawing over a temperature range of +25° to -25°C, which encompasses the temperature range of intense phase changes in water in soils.

PROPERTIES OF GEOTEXTILES IN COLD REGIONS APPLICATIONS | C-4

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To investigate properties of geotextiles in cold regions applications, a laboratory program was conducted with five geotextiles. Freeze-thaw durability in fresh and saline water *was* considered. Geotextile strength before and after 300 freeze-thaw cycles showed no serious degradation. Geotextile load-deformation-time relationships were determined at +22°C and -12°C by wide-strip tensile and static creep tests. Temperature had little effect on strength, but creep was significantly affected. Lower temperatures resulted in reduced creep. Both geotextile structure and polymer type were significant to creep. Polypropylene geotextiles were affected to a greater degree by temperature than polyester geotextiles. A preliminary investigation was performed to determine the potential of geotextiles as capillary breaks in a highly frost susceptible silt. Soil columns were frozen from the top at a constant rate. Free water was available at the bottom for two columns--one contained a geotextile layer and one did not. A third control column was frozen without free water or a geotextile. Heave and water content increases during freezing were determined for each soil column. The results indicate some geotextiles have the potential to significantly reduce frost heave. The effectiveness is different for different geotextiles.

MAPPING OF PERMAFROST IN THE FAIRBANKS AREA, ALASKA, FOR URBAN-PLANNING PURPOSES | I

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A series of large-scale (1:24,000) maps showing distribution and characteristics of permafrost and other frozen ground phenomena has been developed for an 825 km^2 area in the Fairbanks area, Alaska. Each map delineates the occurrence of various types of near-surface permafrost and classifies deposits into generalized units exhibiting similar frozen ground properties and land-use hazards. Eight primary permafrost units are mapped. Loess-covered hillslopes are generally permafrost free and provide excellent sites for unrestricted urban development. Upland bedrock, flood-plain sand and gravel, and mine dredge

tailings have low perennial ice contents and little to no seasonal frost activity, providing good sites for generally unrestricted land use. Silty alluvial fans with moderate perennial ice contents exhibit moderate to intense seasonal frost activity, resulting in fair land utilization characteristics. Flood-plain slough deposits have moderate to high perennial ice contents and intense seasonal frost activity, making them poor areas for general urban construction. Valley-bottom muck and valley-bottom peat muck are distinguished by high perennial ice contents in the form of seams, lenses, and large masses, all of which produce great differential subsidence upon thawing, thus creating very poor sites for urban use.

EFFECT OF COLOR AND TEXTURE ON THE SURFACE TEMPERATURE OF ASPHALT CONCRETE PAVEMENTS

I

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During the fall of 1981 and the spring of 1982, eight test items were established on an asphalt pavement in Fairbanks, Alaska. The test items were: two sections of untreated pavement, yellow-painted pavement, white-painted pavement, *'standard" chip seal, fine-grained "'standard" chip seal , chip seal with drak brown aggregate, and chip seal with white marble aggregate. The test items were located on a main road. Surface temperatures were monitored hourly by thermocouples attached to an automatic data collection system. The ambient air temperature, wind speed and direction, amount of precipitation, and radiation balance were continuously recorded at an untrafficked pavement approximately 100 m from the test items. Incident and reflected shortwave radiation measurements were made nearly every weekday over each test item using a hand-held radiometer. N-factors, ratios of surface thawing indexes to air thawing indexes, varied from about 1.2-1.3 for the white- and yellow-painted surfaces, respectively, to about 1.4-1.5 for the other surfaces. Daily and monthly n-factors for a particular surface. varied depending on precipitation, wind speed, the durability of the surface treatment, and the amount of incident solar radiation. Approximately 2200 vehicles per day crossed the test sections; turbulence induced by the traffic caused n-factors to be lower than reported by other authors. Abrasion by traffic reduced the effect of the surface treatments.

THREE SUPERPOSED SYSTEMS OF ICE WEDGES AT MCLEOD POINT, NORTHERN ALASKA, MAY SPAN MOST OF THE WISCONSINAN STAGE AND HOLOCENE

P-1

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Actively growing, surface ice wedges up to 9 m wide in primary, secondary, and tertiary polygons began growing by about 12,000 Years B.P. at McLeod point, 120 km southeast of Barrow, northern Alaska. Below the surface wedges two superposed, buried systems of inactive ice wedges in primary, secondary, and tertiary polygons were both truncated by separate episodes of deep thaw. The younger episode clearly resulted from a thaw-lake cycle. The older is attributed to a thaw-lake cycle, but available evidence is less definitive. The two buried systems of truncated ice wedges are in deposits that are separated by an organic horizon that is >40,000 radiocarbon years B.P. By analogy and correlation with the major events in the Quarternary history of northern Alaska, it is inferred that the three systems of ice wedges and associated sediments may span most of the Wisconsinan Stage and Holocene.

InVeStigatiOn OF AREAS OF ICING (NALED) FORMATION AND SUBSURFACE WATERDISCHARGE UNDER PERMAFROST CONDITIONS USING SURFACE GEOPHYSICAL TECHNIQUES

G-2

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The article identifies the major tasks faced by the permafrost hydrologist in areas of icing (naled) formation and of subsurface water discharge, using surface geophysical techniques. A comparative evaluation of the possibilities and potential usefulness of various geophysical methods, both traditional and modern, is attempted. The peculiarities of geophysical procedures under varying conditions, both winter and summer are discussed and methods of integrating various geophysical methods are considered.

THE SAGAVANIRKTOK AND ADJACENT RIVER SYSTEMS, EASTERN NORTH SLOPE, ALASKA: AN ANALOG FOR ANCIENT FLUVIAL TERRAIN ON MARS

R-1

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The large-scale geomorphic features of the Eastern North Slope, Alaska were formed by the Sagavanirktok and adjacent rivers during Quaternary time. The largest landforms are low hills, here called erosional remnants, situated between active and abandoned river courses. The erosional remnants are flanked by Pleistocene age terraces and abandoned floodplains lower than the remnant surfaces. Formation of remnants and terraces proceeded more rapidly during times of deglaciation when discharge was greatest, augmented by catastrophic drainage of moraine-dammed lakes. There has been extensive modification of valley floors and of remnant and terrace slopes by eolian, cryogenic, and debris-flow activity. Geomorphic processes on the Eastern North Slope have produced a suite of morphologic features characteristic of those seen, or inferred, on Viking Orbiter images of Mars in areas containing smaller outflow channels and depositional basins. The formation of these channels and basins--Ladon Vanes (24°S, 29.5°W) is a good example--predates the development of most major outflow channels and may have occurred at a time when the Martian climate was "'wetter" and thus more akin to present conditions on the North Slope. The similarity of the two suites of morphologic features suggest that similar processes, in type and magnitude to Quaternary processes that have shaped the Eastern North Slope, may have operated on Mars.

PALEOCLIMATE INFERENCES FROM PERMAFROST FEATURES: A METEOROLOGICAL POINT OF VIEW

I

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Quite a number of relict permafrost-related features have been used, correctly or not, to infer elements of past climates. In order to extract more information from these features, improvements are needed both in dating and in understanding the climatic and other conditions controlling the distribution of permafrost-related features today. Ice wedges provide good illustrations of both problems. Dates on organic material in ice wedges or in surrounding sediments in the

Fairbanks area tend to fall into periods when the pollen record suggests trees were growing in the area. Such dates are more likely to record periods when organic material was preserved in abundance than the actual time of ice wedge formation. Likewise, the physical requirements for wedge growth make it apparent that mean annual temperatures alone cannot define regions of active ice wedge growth. We have modeled the penetration of cooling rates into frozen ground with and without snow cover. The results suggest that snow cover may play a critical role in determining the distribution of ice wedges.

PALEOTEMPERATURE ESTIMATES OF THE ALASKAN ARCTIC COASTAL PLAIN DURING THE LAST 125,000 YEARS

I

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Beach, nearshore, and shallow-marine deposits of the Gubik Formation in the western portion of the Alaskan Arctic Coastal Plain have been subdivided by stratigraphy, sedimentology, and amino acid geochronology into transgressive/regressive sequences representing six high stands of sea level of Pliocene and Pleistocene age. Combined with paleoclimatic proxy data and assumptions concerning permafrost conditions, amino acid results on mollusks from the last interglacial high sea stand, the Walakpa member (≈ 125 ka B.P.), provide a means of quantifying paleotemperatures in permafrost throughout Wisconsin time and places limits on the possible magnitude of temperature change throughout this period. The results indicate that glacial-age mean permafrost temperatures on the coastal plain averaged -18°C or lower and were more than 8° cooler than today. This implies that mean annual air temperatures probably averaged between -19°C and -24°C and arctic summers were probably cooler than at present. Areas such as Ellsmere Island, N.W.T., or the Dry Valleys of Antarctica may serve as partial modern analogs for the glacial climates of the North Slope.

SHALLOW DRILLING IN PERMAFROST, NORTHERN ALASKA | I

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The modification of an inexpensive drill has provided arctic researchers with the ability to acquire continuous core samples (7.7 cm diameter) of chemical and petrographic quality in a variety of frozen grounds. The coring depth is determined by the composition of the frozen material. Since the drill operation is based on low power and the sharp cutting tools on a SIPRE coring auger, the ice content and grain size of the frozen material regulate the maximum sampling depth (Table 1). Drilling and sampling is most efficiently conducted by a three-person crew during late winter or early spring when the active layer is frozen. The self-contained lightweight drill and all components are readily transportable off-road by helicopter or snow vehicle, or by towing over roads. It is self-mobile incrementally over distances of < 100 m. Total cost of the drill and all modifications is estimated to be ≃ $10,000.

TABLE 1

Material	Ice Content (≃ %)	Coring Depth (m)
ice	100	> 30
gravel	< 50	> 3 (auger only)
sand	5-70	> 10
silt	< 50	> 6
silt	> 50	> 20
silty clay	< 50	≃ 5
organics	30-90	5

HYDROLOGY OF THE NAHANNI, A HIGHLY KARSTED CARBONATE TERRAIN WITH DISCONTINUOUS PERMAFROST

H-2

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Groundwater recharge rates are usually low where permafrost is present. However, in carbonate regions where a karst drainage system predates permafrost development, groundwater recharge and circulation may be vigorous. This is the case in the Nahanni north karst of northwestern Canada. Not only is the volume of groundwater flow in this permafrost region considerable--$102x10^6$ m^3 of water flows annually to each of two springs which drain the area--but hydrologic activity is spectacular. Between July 19 and 31, 1972, an extreme summer storm deposited 224 mm of rain on the area. First, Second, and Third poljes flooded; maximum water depths were 8.5, 25, and 8 m respectively; and Third Polje overflowed. The level of Raven Lake (0.25-0.50 km long) rose 49 m at an average of 2.9 m/day. Field observations and evidence from LANDSAT images have provided a hydrologic record for the karst for the years 1972-1978. These data indicate that immediately prior to spring snowmelt depressions are dry, and that when snow and ice melts in May, several depressions may flood temporarily because their drainage routes are blocked by ice. The major surface and groundwater activity in Nahanni is not induced by snowmelt but results from unusually high rainfall *in* the ❑onths of June-August.

OBSERVATIONS OF ICE-CORED MOUNDS AT SUKAKPAK MOUNTAIN, SOUTH CENTRAL BROOKS RANGE, ALASKA

I

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A field of several hundred ice-cored and frost-heaved mounds occurs on the lower slope of Sukakpak Mountain. This site is located along the Dalton Highway some 300 km north of Fairbanks. The area is within the northern-most discontinuous permafrost zone. Mean annual

air temperature is estimated at -7°C. Mean mound height is approximately 1 m and most are elliptical or circular in plan. Clear, massive ice can be found within, below, and adjacent to some mounds. Other mounds are underlain by ice-rich to dry sand and silt. Within and adjacent to some mounds, free water under low pressure is observed in late winter and spring. Trees with smooth trunk curvature atop many mounds suggest a long period of stability for them. Recent tilting of trees is also observed on and adjacent to mounds. Most mounds are found in active drainage channels that develop thick surface icings each winter. The causes, frequency of occurrence, and annual magnitude of the upheaving are under investigation.

SOIL FREEZING AROUND A BURIED PIPELINE: DESIGN OF AN EXPERIMENT IN A CONTROLLED ENVIRONMENT FACILITY

I

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This paper discusses the design, installation and instrumentation of a joint France-Canada project to study in detail freezing around a refrigerated pipeline buried in the controlled environment facility at the Centre de Geomorphologie of the Centre National de la Recherche Scientifique, Caen, France. A 273 mm diameter pipe is buried at a depth of 30 cm in a 18 m long x 8 m wide x 2 m deep pit. Half of the excavation (lengthwise) is filled with a non frost-susceptible sand and half with a frost-susceptible silt. The water table is positioned at the top of the pipe and is maintained by supplying additional water to the base. A refrigeration system maintains the ambient temperature of the chamber at slightly below O"C, and the temperature of the pipe at -2°C. A network of sensors is installed in each soil to monitor the thermal regime (thermistors, thermocouples, frost tubes), the moisture regime (TDR probes, tensiometres, piezometres), ground heave (telescoping heave tubes, "doubles sondes") and pipe deformation and displacement (strain gauges, rods welded to pipe). A data acquisition system is dedicated to temperature measurements although all other instruments require manual observations.

THERMOKARST DEVELOPMENT: SOME STUDIES FROM THE YUKON TERRITORY, CANADA | I

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Investigations of ground ice conditions and the relationship between thermokarst development and climate in the Stewart River Valley, Yukon Territory are reported. Core dining to 5 m at 17 locations in an area of glacio-lacustrine clays and silts revealed extensive ice-rich permafrost. The development of two retrogressive thaw flow slides is reconstructed with air photographs and ground surveys. Studies of retreat over a summer session are reported. Although the initiation of the thaw slides was not climatically controlled, a weak positive correlation between rate of retreat and air temperature is detectable. Thaw lake development *is* **also** reconstructed with air photographs, surveys and by cross-dating of ring series from submerged trees. Three lakes studied in detail were probably initiated around 1880 and are presently growing at a constant rate of 93 $m^2 yr^{-1}$. Numerical simulations of the effects of climate change and fire on the ground thermal regime, indicate that fire produces a greater change in surface temperature than a climatic warming of 2"C. However, no fire scars *were* detected in the rings of 200 year old black spruce trees at the site; the development of the thaw lakes does coincide with the post-1850's climatic warming.

TANANA RIVER MONITORING AND RESEARCH PROGRAM | I

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The Tanana River Monitoring and Research Program is being conducted for the Alaska District, Corps of Engineers in order to monitor the effects of the Corps* construction of the levee and protective groin system, of the Chena River Lakes Project, on the Tanana River near Fairbanks, Alaska. The program provides for a systematic data collection and analysis effort to evaluate the effects of in-river construction on the natural processes of a northern braided river. A literature review and a brief study to assess the effects of permafrost streambank erosion were inconclusive. Additional studies currently underway will influence future construction on the Tanana River, add to our knowledge on northern braided rivers and provide a data base for further research.

TESTING PIPELINE TECHNIQUES IN WARM PERMAFROST | C-1

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A thaw settlement research facility was built by Foothills Pipe Lines (Yukon) Ltd. as part of the permafrost engineering design for the Alaska Highway Gas Pipeline Project. The main purposes of the test facility were (1) to study construction methods for the installation of large diameter pipelines in permafrost, (2) to observe the effectiveness of mitigative designs in minimizing thaw settlement of the pipe and right-of-way surface, (3) to study the behavior of cuts in ice rich hills, and (4) to provide data on the thermal behavior of design models for comparison with thermal model predictions. This paper discusses the observations of the pipeline design performance and the comparison of that performance with initial predictions.

THE GEOLOGY OF MARS | R-2

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Mars has had a long and varied geologic history. Large sparsely cratered volcanoes and vast lava plains attest to sustained volcanism. An extensive system of fractures appears caused by a bulge of continental dimensions in the Tharsis region. Well-integrated valley networks imply slow erosion by running water, while large channels appear formed by catastrophic floods. Collapsed ground, moraine-like ridges, and pitted terrains suggest the effects of ice, landslides and rock glaciers" indicate large-scale mass wasting, and dunes and yardangs are evidence of wind action. Despite the similarity in the range of processes that have affected Mars and Earth, differences between the two planets remain large. Under present climatic conditions liquid water is unstable everywhere on the surface and ice is unstable at latitudes below 40°. A permafrost zone is 1 km thick at the equator and 4 to 5 km thick at the poles. Climate changes caused by perturbations in the orbital and rotational motions are small although they may cause alternating cycles of erosion and deposition at high latitudes. Climatic variations during the current epoch appear representative of climates throughout most of Mars' history. Branching valley networks in old terrain suggest different conditions over 3.5 billion years ago. Persistence of climatic conditions that hinder flow of water has prevented cycling of surface materials by erosion, sedimentation, burial, and metamorphism.

FOSSIL SAND WEDGES ON THE ALASRAN ARCTIC COASTAL PLAIN AND THEIR PALEOENVIRONMENTAL SIGNIFICANCE	P-1

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Fossil sand wedges occur over a broad area of the Arctic Coastal Plain of Alaska upwind of a large field of stabilized linear dunes. The sand wedges are as much as 3 m wide and 7 m deep and form polygonal systems. They developed when wind-driven sand moving across the coastal plain toward the dunes dropped into open thermal-contraction cracks. Radiocarbon dating of organic remains from deposits overlying the sand wedges and from eolian sand in the dune field, together with the age of the deposits in which the sand wedges developed, show that the sand wedges and dunes are Wisconsinan. Growth of the sand wedges could have occurred continuously or episodically throughout the time the dunes were active, but probably *was most* rapid during the coldest periods, and particularly during late Wisconsinan time. The sand wedges and associated dunes record desert conditions over a significant part of the Arctic Coastal Plain during middle and late Wisconsinan time and perhaps throughout the Wisconsinan Stage.

RUNOFF FROM A SMALL SUBARCTIC WATERSHED, ALASKA	H-l(1)

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Precipitation-runoff ratios were measured on Glenn Creek, a small, second-order, subarctic stream located near Fiarbanks, Alaska, in the Yukon Tanana Uplandd physiographic province. Glenn creek drains a watershed of 2.25 km^2, of which 70% is underlain by permafrost. A Parshall flume was used to measure streamflow, and a pair of **1.22 m** by **2.44** m lysimeters were used to measure precipitation and runoff from the moss-covered permafrost slope. The data from one summer season (1979) and one snowmelt season (1980) indicate the sloping surfaces of the watershed have a very fast response time, long recession, and subsurface runoff prior to complete saturation of the overlying organic material. Glenn Creek streamflow is comparable to the lysimeter runoff with regard to response time and runoff recession, however the watershed precipitation-runoff ratio is much lower. This is attributed to longer travel distances in the watershed, which result in greater evapotranspiration losses, little contribution from the non-permafrost areas, and only partial areas of the watershed contributing to the streamflow.

FROST HEAVE OF SALINE SOILS	C-2(2)

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Theories of ice segregation and frost heave processes in saline soils are briefly examined and modified to explain observations made on clay and sand soils frozen under laboratory conditions. Seawater was observed to reduce the rate of frost heave by more than 50% for both soil types and to reduce dramatically the size of ice lenses. The effect of seawater is to cause the formation of a thick active freezing zone with many ice lens growth sites, each with its own brine concentration. Unbended brine-rich soil zones between ice lenses are identified as potential zones of low shear strength.

HOLOCENE TEMPERATURES IN THE UPPER MACKENZIE VALLEY DETERMINED BY OXYGEN ISOTOPE ANALYSIS OF PEAT CELLULOSE	I

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Oxygen isotope ratios in nonexchangeable plant cellulose extracted from samples of Sphagnum are positively correlated with the mean annual temperature at their respective growth sites. Furthermore, the isotope ratio of aquatic plant cellulose is independent of the plant species. These results were used to extract a paleotemperature record, spanning the last 10,300 years from an Upper MacKenzie Valley peat core. Temperature does not appear to have been an impediment to permafrost aggradation in this area for the period of record. A comparatively cool climate between 10,000 and 7,000 years B.P. was followed by a warming trend between 6,000 and 5,000 years B.P. Cooling followed, reaching minimum Holocene temperatures approximately 3,500 years B.P. Preliminary results suggest this temperature was 3° to 4°C cooler than present day mean annual temperatures. Steady warming since that date has resulted in widespread permafrost degradation. Present day temperatures are the warmest that have occurred during the Holocene for the area.

INFLUENCE OF PENETRATION RATE, SURCHARGE STRESS, AND GROUND WATER TABLE ON FROST HEAVE	M-5

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To protect structures in permafrost and seasonal frost regions from damage, the authors studied the factors that influence the frost-heave process by conducting experiments on various types of soils, such as loess, clayey loam, loam, sandy loam, and sand, both in the laboratory and in situ. The results showed that the frost penetration rate, surcharge stress, and ground water table are important factors, in addition to soil particle size. Two critical penetration rates divide the extent of the frost-heave ratio into intensive, slow, and no changing stages, and indicate whether ice will be segregated in the soil. Under surcharge stress, because the freezing point of the soil water is lowered and the specific suction water ratio in the soil at the freezing front decreases, the heave ratio descends, as shown by Equation 7. The influence of the ground water table on frost heave of soils is obvious and must be considered in practice.

THE DISTRIBUTION OF HIGH-ICE-CONTENT PERMAFROST ALONG THE QINGHAI-XIZANG HIGHWAY	P-3

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Investigations along the Qinghai-Xizang Highway show that in similar geomorphological units, the lower the mean annual ground temperature, the higher the ice-content of permafrost will be. In the same permafrost temperature zone, the most favorable conditions for the development of high-ice-content permafrost occur in low mountains and hills, especially on gentle, north-facing slopes and foothills; than in the middle and high mountains. Valley and plains regions are usually poor in ground ice; only in those places with lacustrine fine-grained deposits and sufficient water supply can high-ice-content permafrost develop. In the depressions between alluvial fans, high-ice-content permafrost is common.

VERTICAL AND HORIZONTAL ZONATION OF HIGH-ALTITUDE PERMAFROST	I

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Alpine permafrost cannot be classified into continuous, discontinuous, and island types, since no alpine permafrost is actually continuous. According to its stability, indicated by its thickness and the mean annual ground temperature, the permafrost on the Oinghai-Xizang Plateau should be divided into three zones: upper zone (extremely stable), middle zone (stable, substable, and transitional), and the lower zone (unstable and extremely unstable). The distribution of alpine permafrost shows latitudinal variation. The lower limit rises northwards to its extreme value at latitude 25°22'N, then descends as the latitude continues to increase. Data show that the elevation of the permafrost lower limit is related to the aridity of the area. A region with higher precipitation usually has more cloud cover, which reflects both outgoing and incoming radiation. North of about 40°N, the incoming radiation is less than the outgoing so that the main effect of the cloud cover is to heat the air, raising the alpine permafrost's lower limit; south of 40°N, however, the incoming radiation is greater than the outgoing, so the main effect of the cloud cover is to cool the air, lowering the permafrost's lower limit.

ULTIMATE LONG-TERM STRENGTH OF FROZEN SOIL AS THE PHASE BOUNDARY OF A VISCOELASTIC SOLID-FLUID TRANSITION	I

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Herein we explore the possibility of using wave propagation methods to determine the ultimate long-term strengths of frozen soils. Our discussion is based on the assumptions that the creep behavior of frozen soils (under conditions of nonfailure) could be modeled as nonlinear viscoelastic, that the ultimate long-term strengths of a frozen soil in fact constitute the phase boundary of a viscoelastic solid-fluid transition, as well as the lack of smoothness of such a transition. The general discussion is illustrated by a detailed analysis of one particularly simple example, namely, why we could likely locate by experiments of wave propagation the phase boundary of a saturated sandice material under low-stress conditions. Finally we discuss the possibility that for frozen soils the transition from solid to fluid behaviour be strain-controlled rather than stress-controlled, and explain briefly how wave propagation experiments could still be used to determine the transition strain which demarcates between, for each given temperature, the solid and fluid behaviour of frozen soils.

TRITIUM IN PERMAFROST AND IN GROUND ICE | H-2

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The use of tritium analysis makes it possible to establish the existence of considerable amounts of water in permafrost rocks and ground ice in the zone of annual temperature fluctuations. The moisture was found to migrate from the active layer into the permafrost, resulting in the formation of ice lenses. High tritium concentrations caused by the inflow of meteoric water under 30 years of age are inherent in the growth of wedge ice and golets ice. However tritium is absent from buried wedge ice and the lenses of primary ice. Tritium analysis offers new possibilities for studying laws governing the formation and age of ground ice in permafrost.

THE RECOGNITION OF IN SITU AND REMOULDED LATE PLEISTOCENE CLAYEY TILL MATERIALS IN WESTERN JUTLAND, DENMARK | I

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An area composed of clayey glacial tills on the southern slopes of Skovbjerg Bakkeø has been mapped at scales of 1:10,000 and 1:4,000. The area reveals a high concentration of pseudomorphs of ice-wedge polygonal patterns. In the study area apparent strength parameters for clayey and silty materials are determined by vane-tests. The glacial deposits which were preloaded by advancing Saalian glaciers will normally be rather strong and incompressible. The remoulded fossil solifluction deposits of till origin have not been preloaded by ice. These deposits are sandier than the in situ deposits. Strong and incompressible glacial tills are registered below the fossil solifluction deposits 4 meters below ground level. In situ clayey till materials can be recognized by crop-marks revealing pseudomorphs of ice-wedge polygons in orthogonal, random orthogonal hexagonal patterns. The tills inside these polygonal

patterns have high shear-strength values as measured by vane-tests. From O-3 meters below ground C_v intact varies between 100-500 kN/m^2 and c_v' remoulded between 10-200 kN/m^2, both increasing downwards. Remoulded solifluction deposits of till origin reveal stripes and deformed polygonal patterns in the crops. Low shear-strength values as measured by vane are found in these deposits. In clayey deposits below the dry crust 0-1.5 m below ground c_v intact varies between 2-80 kN/m^2 and c_v' remoulded varies between 15-40 kN/m^2. High shear strength values c_v > 580 kN/m^2 and c_v' 200-300 kN/m^2 are encountered in Saalien lodgement tills 4 meters below ground.

ICE-SOIL MIXTURES: VISUAL AND NEAR-INFRARED REMOTE SENSING TECHNIQUES — R-1

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The spectral properties of ice-soil mixtures are reviewed. Spectra of intimate mixtures of soil and ice are highly complex, nonlinear functions of the optical properties of ice and soil. Water ice has an absorption coefficient that varies by several orders of magnitude in the visual and near infrared (0.4-3µm) and has several prominent overtone absorption (at 2.0, 1.5, 1.25, and 1.04 Bin). Thus, different wavelengths can be used to probe to different depths in the surface as well as for different mineral impurity concentrations. Empirical and/or theoretical models might be used for deriving characteristic grain size of the ice or impurity minerals and for deriving abundance of the ice and rock or soil components. Quantitative analysis of remotely obtained reflectance spectra can only be performed by using the absorption features in the spectra of ice and soil and not by broadband response. This might be done by special selection of several narrow band filters in the near infrared that will adequately define the ice absorption.

GROUND ICE IN THE EQUATORIAL REGION OF MARS: A FOSSIL REMNANT OF AN ANCIENT CLIMATE OR A REPLENISHED STEADY-STATE INVENTORY?	R-1

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Various lines of morphologic evidence suggest that substantial quantities of ground ice have existed in the equatorial regolith of Mars throughout its geologic history. However, recent calculations on the stability of ground ice in this region suggest that any ground ice, emplaced earlier than 3.5 billion years ago, may have long since been lost by sublimation to the atmosphere. It is proposed that one possible explanation for the continued existence of ground ice in the equatorial regolith is that it may be replenished by subsurface sources of H20. The existence of a geothermal gradient in the Martian crust could provide the means necessary to thermally cycle H20 between a deeply buried reservoir of groundwater, similar to those found in cold regions on Earth, and the base of a near-surface layer of ground ice. Calculations indicate that a geothermal gradient of 25 K/km would be sufficient to replenish a layer of ground ice 1 km thick over the course of Martian geologic history.

DETECTION AND EVALUATION OF NATURAL GAS HYDRATES FROM WELL LOGS, PRUDHOE BAY, ALASKA	G-2

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The purpose of this study is to develop techniques for the detection and evaluation of in-situ gas hydrates from well log data and to determine possible geologic controls on the occurrence of hydrates in the North Slope region of Alaska. Several new methods of evaluation for subsurface gas hydrate were developed and incorporated with existing techniques. For each of 125 wells examined as part of this study the geothermal gradient was determined and the theoretical stability zone for methane hydrate was calculated. Among these, there were 102 apparent hydrate occurrences in 32 wells. A subsurface structural-stratigraphic framework was established to a depth of 1,000 meters. This sediment package is characterized by three deltaic depositional sequences. The high frequency of hydrate occurrences in the structurally up-dip region of the Kuparuk Oil Field suggests that upward migration of free gas preceded hydrate development in the zone of hydrate stability.

LONG-TERM ACTIVE LAYER EFFECTS OF CRUDE OIL SPILLED IN INTERIOR ALASKA | E-1

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Two experimental oil spills of 7,570 liters each were conducted' at a black spruce forested site in February and July of 1976. The long-term effects of the spills on the active layer were directly related to the method of oil movement. The winter spill moved beneath the snow, within the surface moss layer and the summer spill moved primarily below the moss, in the organic soil. The summer spill affected an area nearly one and one-half times that of the winter spill. Only 10% of the 303-m^2 summer spill area had oil visible on the surface, while 40% of the 188-m^2 winter spill had visible oil. Thaw depths in the summer spill area increased from 1977 to 1980--average thaw depth was 72 cm vs. 48 cm in the control -- and remained essentially the same in 1981 and 1982. Thaw depths in the winter spill area continued to increase until 1982 to an average of 92 cm. Summer temperatures 5 cm under the blackened moss are consistently higher than under the undisturbed surface. Presumably the change in albedo due to the surface oil accounts for the increased thaw in the winter spill area.

A MATHEMATICAL MODEL FOR THE PERMAFROST THAW CONSOLIDATION | C-2(2)

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A mathematical model is developed for temporal and spatial distribution of pore water pressure, temperature, ice content and displacements in an unsaturated thawing deformable soil. The water saturation is related to pore pressure and temperature by retention and phase composition curves respectively. The model is simplified for one-dimensional vertical permafrost thaw consolidation problem. The use of temperature-dependent theological stress-strain relations is also discussed.

THERMAL REGIME OF A SMALL ALASKAN STREAM IN PERMAFROST TERRAIN

I

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Goldstream Valley near Fairbanks, Alaska, is underlain by permafrost up to 75 n thick. The active layer is about 1 m thick, and beneath Goldstream Creek the top of permafrost is nearly 6 m deep. During winter, pressure builds up in the ground water due to constriction imposed by soil freezing. At this time, the creek overflows repeatedly, forming aufeis deposits that may exceed 2 m in thickness or about 8 times normal summer water depth. Hydrological and temperature observations were made from 1963 to 1973. Detailed data from our studies permitted calculations of the thermal diffusivity in unfrozen soil, using Fourier series, numerical step models, and differential analysis. Assuming conduction only in a homogeneous medium, diffusivities of 0.004 cm^2s^{-1} were obtained for areas away from the stream, but values exceeding 0.015 cm^2s^{-1} beneath the stream indicate non-conductive heat transfer mechanisms as well, such as groundwater movement and release of latent heat during formation of the aufeis. The net effect of this small stream, which produces so much ice, is to dent the upper permafrost surface, thus reducing the estimated thickness of 50 *m* by about 10 percent.

GEOCRYOGENIC MORPHOLOGY AT SEYMOUR ISLAND (MARAMBIO) ANTARCTICA: A PROGRESS REPORT

P-4

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At Seymour Island, 64°14′ S.L. and 56038′, Antarctica under a mean annual temperature lower than -10″C, various geocryogenic forms are observed including frost-contraction cracks and polygons, frost domes and pingos, gelifluction features, etc. These first forms require cold permafrost with mean annual temperatures below -5°C. The geocryogenic processes at both sides of the Antarctica Peninsula are compared. In the west part, geocryogenic processes of Deception are compared including sorting and gelifluction features, which formed at -2.8°C. On the east side forms requiring lower temperatures are observed, including thermal-contraction cracks and polygons, pingos and frost domes; they are formed under mean annual temperature of -10″C or lower. The mountain chain of the Peninsula works as a barrier for the cold winds of the Weddell Sea resulting in frigid conditions all along the east sector of the Peninsula. On the west side of the chain, with more prevalent anticyclonic conditions , warmer air is brought from the northeast and west producing higher temperatutres. Temperature differences about 8-9°C are observed at the same latitude on the east and west sides. The strong southwest winds with a snow and debris load produces a remarkable phenomenon: snow drift-dammed lakes. The lakes behind such dams can be of several hectares. The growth of mounds displaces drainage lines, this process and the water ponded by the snow drifts also cause continual change in the drainage systems. The fluvial system of the island is too dense for the apparently low precipitation.

PREDICTING HEAVE AND SETTLEMENT IN DISCONTINUOUS PERMAFROST I

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A model for predicting heave and settlement in discontinuous permafrost regions based on capillary stress theory has been developed. The model couples temperature change and ground water movement to or from a freezing or thawing frost front under the influence of seasonal ground surface thermal disturbances. One dimensional ground surface heave or settlement is predicted using an implicit-explicit, alternating direction, finite difference technique. The frost front, thaw front and ground surface predictions were found to be very similar to the experimentally observed values of other researchers, thus serving to validate the basic technique. The prediction of heave due to both in situ and migrating water freeze, and the subsequent settlement due to ice thaw and soil consolidation for a seasonal thermally disturbed region should be the first step for any heave or settlement studies, particularly for buried pipeline construction. This model presents one of the few attempts to link both heave and settlement predictions based on the physics of consolidation. The results of this study indicate that a viable model is possible using the techniques outlined.

PALEOENVIRONMENTAL STUDIES IN THE CRREL PERMAFROST TUNNEL	I

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The CRREL permafrost tunnel near Fox, Alaska, offers a unique opportunity for long-tern paleoenvironmental studies of perennially frozen ground. Presently accessible sediments in the tunnel represent a late Pleistocene valley-bottom fill. The oldest (lower) part of the section is tentatively dated from 39,000 to 30,000 yr B.P., and the youngest (upper) part from 14,000 to 11,000 yr B.P. Sediments from 30,000 to 14,000 yr B.P. appear to be absent. Preliminary analysis of plant and animal macrofossils from the tunnel have identified more than 50 taxa of plants and invertebrates and most are common members of modern forest or tundra of interior Alaska. Species assemblages suggest a tundra-like environment existed during much of the period represented in the section. Fluvial gravel at the base of the section supported dense thickets of willows. The subsequent period from 39,000 to 30,000 yr B.P. is represented by a thick loess deposit that includes large epigenetic ice wedges and macrofossils predominated by low shrub-open ground species. Toward the end of this period the climate warmed and meltwater ponds and other thaw features developed on the surface, associated with rich herbaceous vegetation. Woody shrubs became established by 14,000 yr B.P. and trees by 11,000, after a long depositional hiatus corresponding to the late Wisconsin glaciation.

DESIGN AND PERFORMANCE OF A LIQUID NATURAL CONVECTION SUBGRADE COOLING SYSTEM FOR CONSTRUCTION ON ICE-RICH PERMAFROST	M-1

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In 1976, personnel from the U.S. Navy's Civil Engineering Lab erected a building incorporating a subgrade cooling system on ice-rich permafrost near Barrow, Alaska. The cooling system consisted of 15 horizontal, loop-configures, liquid natural convection heat exhangers. The installation at Barrow was heavily instrumented, and data obtained over 3 years allowed calculation of the performance and efficiency of the natural convection heat transfer devices. Experimentation with forced convection (pumping) of the liquid resulted in only a minor

improvement of performance. Because seasonal freezing and thawing occurred in frost susceptible material and thawing occurred in frost susceptible material in the subgrade, cyclical settlement and heave were recorded. Since the experiment was completed, foundations incorporating subgrade cooling systems employing air ducts or inclined two-phase heat transfer devices have become increasingly common in the Arctic and subArctic. The liquid system tested compares favorably to two-phase or air duct systems currently in *use.*

LONG-TERM PERFORMANCE OF THREE BRIDGES IN THE FAIRBANKS AREA	I

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Research on bridge foundations was initiated in 1964, under a joint research program between the Alaska Department of Highways and the U. S. Army Cold Regions Research and Engineering Laboratory (USA CRREL). The purpose of the study was to evaluate and improve design criteria for piles in permafrost by (1) extending existing data and criteria on installation methods, load capacity, and frost-heave control techniques and (2) monitoring long-term thermal regime changes and movements of the bridges. Three new bridges in the greater Fairbanks area were selected for the study and periodically observed for more than 17, years. Ground temperature assemblies installed in pockets on the driven foundation piles reflected only minor changes in the thermal regime at abutments of these bridges, while at one pier on the Goldstream Creek bridge the permafrost sifted drastically beneath the streambed. Vertical movement observations indicated substantial settlement of the two midstream piers at the Goldstream Creek bridge, annual heave and subsidence at the Moose Creek bridge, and differential settlement but no heave at the Spinach Creek bridge. Severe icing at the Moose Creek bridge and the corrective actions taken to remedy the situation are also discussed. Revision to design and construction criteria are discussed in light of the performance data.

AN EXPERIMENTAL STUDY OF THE FROST-HEAVE REACTION | 1

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The existence of the frost-heave reaction has been recognized by many researchers. To evaluate frost-heave quantitatively for the design of foundations in cold regions, in situ frost-heave tests on model foundations were carried out at Jintao Field Research Station in the Da-Xinganling Mountains of northeast China from 1978 through 1980. Test results showed that the frost-heave reaction around pile foundations exhibits a triangular stress distribution. Its peak value occurs away from the foundation center at one-half of the freezing depth. Based on a simplified triangular stress distribution diagram, the authors present equations for calculating frost-heave reaction in both plane- and space-stress cases. Equations for examining frost-heaving stability and tensile strength of foundations, where the frost-heave reaction is taken into consideration, are also presented for both two- and three-dimensional problems.

AN INVESTIGATION OF ROCK GLACIERS IN THE KUNLUN SHAN, CHINA P-6

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A special form of rock glacier in the continuous permafrost zone is found at high elevations in the Qiong-Xian Valley of the Kunlun Shari of western China. These rock glaciers generally have a smooth longitudinal profile and lack longitudinal and transverse ridges and furrows. Their gradients are steeper than rock glaciers elsewhere, but their frontal slopes are only slightly steeper than their downvalley gradients. They contain permafrost below a depth of 1.5-2.0 m and have interstitial ice contents of up to 57%. These rock glaciers are on north facing slopes and flow roughly from 0.2 to 3.0 cm yr^{-1}, primarily because of slope-induced creep facilitated by subsurface water derived from springs above them. The constituent debris does not originate from rock fragments produced at mountain walls, but instead comes from till and alluvium covering a smooth, rounded ridge just under 5,000 m in elevation.

VARIATIONS OF PERMAFROST TABLE BENEATH EMBANKMENTS IN NORTHEAST CHINA	I

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Based on results from an experimental embankment and the experience of two operating railways, the author has analyzed the variation regularity of the permafrost table beneath an embankment and its influencing factors, and proposes measures to protect embankments from damage. When construction is undertaken in the thawing season, the permafrost table beneath the embankment declines to the maximum thawed depth in the same year, begins to rise again in the center of the embankment and on the shaded slope in the second year, rises overall in the third year, and reaches a stable state in 5-6 years. Variations of the permafrost table are closely related to latitudinal zonality, but they also depend on the height and orientation of the embankment, the thermophysical properties of the filling materials, the heat insulation measures adopted, the surface formation after construction, and the hydrological conditions and characteristics of the frozen soil. To protect the embankment from damage, the following measures are available: improving surface drainage, protecting the natural permafrost table near the foot of the embankment slope, and constructing a heat insulation berm.

MECHANISM AND LAWS GOVERNING THE TRANSFORMATION OF UNCONSOLIDATED ROCKS UNDER THE INFLUENCE OF REPEATED FREEZE-THAW	1

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A comprehensive procedure was used to study the mechanisms of the transformation of unconsolidated rocks as the result of repeated freeze-thaw (up to 1,000 cycles) under various external thermodynamic conditions. The latter ensured freezing of samples from both one side and from all sides and also the formation of various types of cryogenic textures. It was possible to establish trends with regard to changes in dispersivity, chemical and mineral composition of the materials, cryogenic structure, plasticity and mechanical properties, depending on their original composition and structure. It was demonstrated that a reduction in the dispersivity of clay soils occurs with an increase in freeze-thaw cycles due to an increase in the amount of secondary silt

and secondary sand particles. The most pronounced structural changes are associated with the differentiation of the frozen material into ice and mineral material, thus greatly enhancing the material's heterogeneity. This leads to the formation of a specific structure in terms of porosity and encourages changes in the content of liquid H_2O, lowers the strength and conductivity of the material and increases its susceptibility to saturation and erosion.

STREAM ICING ZONES IN ALASKA	I

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Stream icing zones are a seasonal flood phenomenon in high and alpine middle latitudes that involve water repeatedly overflowing its ice cover at sub-freezing temperatures. This results in thick accumulations of thin ice sheets and flooding beyond the stream channel. To target these problem areas the distribution of stream icing in Alaska are mapped at 1:250,000 sclae based on interpretation of multidate Landsat imagery. The maps delineate areas that are flooded during formation of the thick ice deposits and areas where residual ice deposits are present long after the spring melt. Portions of braided streams that may be susceptible to the occurrence are also mapped.

TIME DOMAIN REFLECTOMETRY DIELECTRIC EXPERIMENTS ON FROZEN SILT	I

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Dielectric properties of ice-rich frozen silt from the permafrost tunnel at Fox, Alaska, have been measured both in the field and in the laboratory, using time domain reflectometry (TDR). Undisturbed field samples obtained with a modified CRREL core barrel were placed in a specially adapted rigid coaxial line mated to the TDR unit. The volumetric water content of the undisturbed samples varied between 65 and 80%, and the sample temperature was approximately -7.0°C. The laboratory samples were reconstituted with volumetric water content between O and 55%. Temperature was varied between +25° and -25°C. The data were processed to cover the frequency range of 0.05 - 1.0 GHz. For the undisturbed samples, dispersion tended toward a maximum slightly

above 1.0 GHz. The range for the real part of the dielectric constant was 3.8 - 5.3 at the low frequency end, while the imaginary part varied between 0.01 and 0.33 for the entire frequency range. These results from the field studies agree well with laboratory observations, indicating that the TDR core barrel sampler is an effective technique for measuring dielectric properties of undisturbed samples. This method could easily be applied for in situ dielectric testing of frozen fine-grained soils and ice.

PRINCIPLES OF TERRAIN CLASSIFICATION FOR PIPELINE CONSTRUCTION	-1- I

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As a basis for designing, constructing and operating a safe system of long-distance pipelines it is essential to compile baseline assessment maps depicting engineering-construction conditions. These must take into account, on the one hand, the complete complex of environmental factors pertinent to the project and, on the other, technological and engineering peculiarities. Construction regionalization involves terrain classification on the basis of the most important environmental factors, based on classification in terms of construction and engineering geology developed by the authors.

PHYSICAL NATURE OF FROST PROCESSES AND A RESEARCH METHOD	I

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The frost process, which includes changes in temperature and moisture fields, the formation of ice layers, and frost heave, develops under certain natural conditions, forming geological and geomorphological phenomena in frozen ground regions. The quantitative study of frost processes involves three aspects: the determination of state parameters, the establishment of a mathematical model by model test or system analysis, and the resolution of the numerical or approximate solutions to the model. Based on a group of combination equations related to heat and moisture flow, the frost-heave process, and the heat-water balance at the thaw interface, and on the principles of thermodynamics and the mathematical model, the author presents approximate solutions for calculating the depth of frost penetration, the amount of migrating water, unfrozen water content, and the amount of frost heave.

A STUDY OF HORIZONTAL FROST-HEAVING FORCES] 1

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To investigate the horizontal frost-heaving forces that act on structures, an experimental and a model reinforced concrete retaining wall were constructed at the Fenghou-Shan Field Research Station on the Qinghai-Xizang Plateau in 1976. The experimental retaining wall was 15 m long and 4-5 m high, and the model wall was 3 m long and 1.2 m high. Investigations conducted during three winters (1976-7S) indicated that the magnitude and distribution of horizontal frost-heaving forces are substantially governed by the material properties of the backfill and the displacement of the walls. For clayey soil backfill, the maximum horizontal frost-heaving force was 1.4 kg/cm^2 and acted upon the middle or lower middle part of the wall, while for gravel backfill it was 0.76 km/cm^2 and acted upon the lower part of the wall. Based on the distribution of frost-heaving forces along retaining walls, the author presents three basic models for calculating the horizontal frost-heaving forces acting on structures according to the different working conditions of the structures.

DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS IN YUKON-KUSKOKWIM DELTA, ALASKA c-3(1)

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A "reaction beam" type pile load test was conducted in ice-rich silt at Kipnuk, Alaska to determine the load capacity of driven H-piles at the edge of the continuous permafrost region in the Yukon-Kuskokwim Delta. Field test results are compared to existing theories on the design of pile foundations in frozen ground. Additionally, information regarding site conditions, pile installation methods, equipment and construction problems are discussed for the pile foundations of water

tanks and auxiliary structures designed and installed in this region at the Eskimo Villages of Kotlik, Hooper Bay, Chevak, Newtok, Tuntutuliak, and Kipnuk. These water tanks ranged from 45,000 to 910,000 liters with accompanying loads of up to 115 kN/pile. Subsoil conditions varied from ice-rich organic silt, and silty sands to poorly graded frozen fine sand with low moisture content.

CREEP BEHAVIOR OF FROZEN SALINE SILT UNDER ISOTROPIC COMPRESSION | C-2(2) CANCELLED

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Isotropic compression creep tests were conducted on a prepared frozen sandy silt with a pore-fluid salinity of about 60 parts per thousand before freezing. Single-step and multi-step loadings of pressure from 70 to 700 kPa were applied to soil samples at three different temperatures (T = -15°C, -10°C, -5°C). From our results we observed the following: (1) Samples originally in equilibrium underwent attenuating creep upon compression by a superimposed hydrostatic stress; over 70% of the ultimate volume change occurred within the first few hours; a substantial portion of the volume change was not recovered upon unloading. The level of ultimate volume change indicated that volume change during creep could be a significant factor in some problems. (2) A history of loading and recovery had a strain-hardening effect on the frozen soil; so did a history of incremental loading. (3) At -5°C the saline soil was non-bonded but its response to isotropic compression did not seem to be qualitatively different from the way it behaved when it was ice-bonded. This study is part of a broader investigation into the long-term multiaxial creep behavior of frozen saline soils that simulate those beneath the Beaufort Sea.

ROCK WEATHERING BY FROST SHATTERING PROCESSES | I

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We discuss two main types of control on the weathering of rocks by frost shattering. External controls are those concerned with temperature cycling which the rocks experience together with associated moisture variations. With data from Iceland, we show conditions under which air temperatures are poor indicators of rock temperatures. Rock surfaces can be warmer than the air, even if the latter is below 0°C; or colder than the air. If snow or ice cover the rock surface, freezing intensity can be damped. A knowledge of rock properties (internal controls) is important because water may freeze at temperatures other than at 0°C. This temperature may be different for different rocks. In the pores of an Icelandic hyaloclastite, water froze at about -4°C; water in rock cracks may freeze at rather higher temperatures than this; tests in "cracks" in plastic blocks suggest about -2°C.

HYDROLOGY OF NORTH SLOPE COASTAL PLAIN STREAMS | H-1(1)

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This paper presents the general hydrologic characteristics of coastal plain streams located between the Sagavanirktok River and the Colville River on Alaska's North Slope. Data presented were gathered over the last five field seasons by the authors and others while working under contract with ARCO Alaska, Inc. Following a general discussion of the geographic and climatic setting for these streams, there is a discussion of several important hydrologic parameters which define the uniqueness of streams flowing in the permafrost environment. Permafrost is a key factor in defining drainage basins. From discharge measurements, values for typical slopes, Mannings' roughness factors, and Coriolis energy coefficients are presented. Finally, a flood frequency analysis for these streams has been developed using a Log Pearson Type III distribution in conjunction with a regional skew weighting analysis. The regional skew weighting analysis is based on station skews for all gauged streams in Alaska north of 64°N latitude, a region approximately coterminous with the region underlain by continuous permafrost.

VIBRATORY PILE DRIVING IN FROZEN SAND	C-3(I)

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Laboratory modeling of vibratory pile driving in permafrost has shown that the strength of the material at the tip has to be overcome by plastic yielding for penetration to occur. This is contrary to the view that melting of the soil at the pile tip dominates the process. Various factors influencing pile penetration have been studied and the energy balance of the pile penetration mechanism has been developed.

PRINCIPLES FOR COMPILING MAPS FOR THE PRESERVATION OF THE GEOLOGICAL ENVIRONMENT IN THE CRYOLITHOZONE	I

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The paper presents the principles and content of the maps of preservation of the geological environment in the cryolithozone, based on studies of the *laws* governing the formation of permafrost and on predictions of changes in the permafrost. The most important elements portrayed on maps are the stability of natural complexes and of the permafrost-engineering geological conditions in terms of technogenic disturbances; permissible engineering load; and recommendations on the preservation of the geological environment and optimization in terms of possible developments. Assessment of stability is preceded by a classification of technogenic disturbances to the geological environment and the assessment itself is carried out on the basis of forecasts of the permafrost-geological processes which might be provoked by these disturbances. The results of the assessment allow one to classify permafrost-engineering geological areas in terms of the permissible engineering load, which, in its turn, allows one to compile and portray on the map recommendations with regard to preservation and optimization of the geological environment and to delimit protected zones and sites. A model map of conservation of the geological environment in the cryolithozone is presented.

BIOLOGICAL DECOMPOSITION AND PLANT SUCCESSION FOLLOWING DISTURBANCE ON THE ARCTIC COASTAL PLAIN, ALASKA	E-2

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Thirty years after abandonment of Oumalik Test Well, vigorous stands of grasses (Arctagrostis latifolia, Poa arctica) and erect willows (Salix glauca, S. planifolia, S. lanata, S. alaxensis) dominate the mesic disturbed areas. We hypothesized that the existence of these communities was due to a higher nutrient availability created by greater decomposition rates in these warm, well-drained sites. Weight loss from these types of materials placed 10 cm deep in disturbed and undisturbed sites for periods of 12 and 13 months showed that decomposition rates in disturbed plots were significantly greater ($P < 0.02$) than in undisturbed plots. Stepwise multiple regression showed that the most important measured environmental factors in explaining the variation in decomposition rates were soil temperature (positively correlated with decomposition rate) and soil moisture (negatively correlated) . The greater rates of decomposition presumably indicate increased availability of nutrients, which is known to favor species with high rates of turnover such as the grasses and willows. As long as the abiotic conditions favoring high decomposition rates persist nutrient availability will stay high. We expect that the present communities will not be replaced with communities similar to those of the surrounding undisturbed tundra for several hundred years.

TRANSIENT ELECTROMAGNETIC SOUNDINGS FOR PERMAFROST MAPPING	G-2

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Over the years electrical and electromagnetic methods have been successful in napping the lateral and vertical boundaries of permafrost over the land. Offshore most electrical and electromagnetic methods cannot map top and bottom of permafrost, because of the low resistivity of the brine saturated, unfrozen sediments overlaying offshore permafrost. Transient electromagnetic exploration is a method of electrical resistivity mapping that can detect resistive layers under highly

conductive sediments. In the winter of 1983 a large survey was conducted on lines onshore and offshore in areas west of Prudhoe Bay, Alaska. Over and the bottom of permafrost which generally occurs at a depth less than 650 m (2000 ft) was mapped with good accuracy. Offshore top and bottom of permafrost was mapped under as much as 250 m of unfrozen saturated sediments. For many geoelectric sections transient EM has a higher lateral and vertical resolution than other electrical methods. For example, for a permafrost section over the land, where a resistive layer (permafrost) overlies a conductive layer (unfrozen ground) a 10 percent change in thickness of permafrost causes a 30 percent change in measured signal. Similar sensitivities are not available in direct current, magnetotelluric, or harmonic frequency methods.

OBSERVATIONS OF SOIL AND GROUND ICE IN PIPELINE TRENCH P-5 EXCAVATIONS IN THE SOUTH YUKON

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During the winter of 1980-1981, Foothills Pipe Lines (Yukon) Ltd. excavated several long sections of trench in permafrost in order to install sections of 1.22 m diameter pipeline at the Quill Creek test facility in the South Yukon. The authors directed a program of detailed logging of the different soil strata and ground ice formations encountered. A total of about 900 linear meters of trench was excavated, mostly by wheeled ditcher, to a minimum depth of 2 m. The ditch was logged by an experienced technician, and several examples of logs from these test sections are given. The variability in surface peat cover, sand and gravel strata, and seam of volcanic ash are clearly demonstrated. The ash layer was deposited at a reasonably well-defined date in the recent geological past and therefore allows some rates of deposition or growth of surface layers to be established. The large area exposed by the trench wall allowed observations of differences between visible ice and excess ice to be made for logging in coarse-grained soils. It is concluded that in these soil types it is often difficult to distinguish pore ice in the large pore spaces from what is normally considered massive or excess ice. Several photographs are presented to illustrate the location of the different soil strata and the shapes of several massive ice features. Some of the massive ice forms observed in the trench walls are believed to be relict ice wedges. The trench allowed a three-dimensional impression of the ground ice to be obtained, which is not normally possible from boreholes. Some additional observations are made relating *to* the success of wheeled ditchers in trenching the different soil types at the Quill Creek test facility.

EVALUATION OF EXPERIMENTAL DESIGN FEATURES FOR ROADWAY CONSTRUCTION OVER PERMAFROST	M-4

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The side slopes of roadway embankments in warm permafrost areas often cause particularly severe problems from long-term thaw related settlements. Soils underlying the snow-covered slopes do not totally refreeze each winter, as they normally do beneath the cleared portion of the roadway. This results in progressive settlements of the outer edges of the roadway and longitudinal cracking of the roadway surface. Experimental installations of air convection ducts, in conjunction with insulation layers and embankment toe berms, were made during 1973 and 1974 on a newly constructed 7-m high roadway embankment approximately 40 km west of Fairbanks. Performance has been monitored since that time. Results through the thawing season of 1982 are presented. No combination of features tested was totally effective in preventing long-term thaw settlements of snow-covered embankment slopes. Results indicate that satisfactory annual refreezing beneath snowcovered side slopes might be achieved by use of the air-duct method. Insulation layers were also installed at different depths in roadway cut sections in ice-rich permafrost at sites approximately 13 km west of Fairbanks. These installations have demonstrated the benefits of placing a 100 mm thick insulation layer at a depth of 1.2 m in a 3-m deep subcut, as compared to installing a similar insulation layer at a greater depth.

SOLAR SYSTEM ICES AND MARS PERMAFROST	R-2

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Infrared reflectance measurements have resulted in identification of CH4 ice on Pluto and Triton, H20 ice on satellites of Uranus, Saturn and on three Jovian satellites (one of which may harbor a liquid H_2O zone in its crust). Frozen S02 on Io and bound H20 on the largest asteroid have also been identified. Such diversity is explicable in terms of accretion conditions, degassing history and atmospheric evolution. Ground H20 ice appears abundant in ubiquitous Mars permafrost but its distribution is controversial. A key issue is how long ice which is unstable with respect to the atmosphere can be preserved

by soil cover. We calculate thermal histories for the regolith at all latitudes, depths and obliquities throughout Mars' history. Neither seasonal nor obliquity driven freeze-thaw of systems that are stable with respect to global conditions can occur unless the systems have eutectics < 23.5°K. Either this process does not occur on Mars or occurs rarely owing to unusual brines, episodic H_2O emplacement or atypical regional subsurface thermal regimes.

ON THE PHYSIOCHEMICAL PROPERTIES OF THE SURFACE OF DISPERSED ICE (SNOW)	I

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The interaction between a dispersed ice (snow) surface and toluene and hexanol solutions in a large number of organic compounds was studied. It was found that the ice surface adsorbed only substances with an ionization potential of 9.6 eV. Formation of a liquid-like layer on the ice surface occurred in 48, 15 and 2.5 hours at temperatures of -10, -5, and -2°C respectively. The volubility of carbon acids in the liquid-like layer was shown to be lower than in the water.

PINGOS ON THE ARCTIC COASTAL PLAIN, NORTHEASTERN ALASKA	I

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Approximately 300 pingos occur on the Arctic Coastal Plain in northeastern Alaska. This region is an extensive, low-lying, treeless plain, dotted with many thaw lakes. The plain generally is mantled by 1-5 m of poorly bedded to nonbedded, pebbly, silty sand and sandy silt that is underlain by sandy gravel and gravelly sand, locally more than 300 m thick. Measurements at Prudhoe Bay indicate that the permafrost is approximately 600 m thick. The mean annual air temperature is -12°C. The typical pingo in the study area is a conical-shaped hillock 10-15 m high and 65-100 m in diameter. One pingo, approximately 60 m high and 1,000 m in diameter, is one of the largest in the world. A few pingos are linear in shape, and some have collapsed because of thawing of their ice core. The pingos are formed on the floors of drained or partially drained shallow lake basins, and are closed-system pingos. After the water drained rapidly from the lake basins, the

thawed saturated sediments underlying them were subjected to freezing temperatures. The aggravation of permafrost in these sediments caused the high pore-water pressures required for the upward growth of the pingos. The fine-grained sediments that mantle the surface generally have been eroded from the crests of the pingos. This results in pingos that are large ice-cored mounds or hillocks of gravel.

SUMMER WATER BALANCE OF A HIGH ARCTIC CATCHMENT AREA WITH UNDERLYING PERMAFROST IN OOBLOYAH VALLEY, N-ELLESMERE ISLAND, N.W.T., CANADA	H-1(1)

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The water balance of Oobloyah Valley, N-Ellesmere Island, N.W.T., Canada, a high arctic catchment area underlying by permafrost was investigated during the arctic summer 1978. The following results will be presented: (1) three main hydrogeological areas with different sediments, thawing depths, and soil drainage were separated; (2) most of the winter snow cover melted until July 1 thereafter soil thawing and its drainage began; (3) the periglacial streams never had a measurable sediment load, not even during snow melt; (4) considering daily discharges, climatic changes and soil water balance the hydrologic regimes of the three investigated streams were characterized; and (5) summer water balance must include frozen soil water stored in the year (s) before; snow and rain add up to 51% of the total balance, glaciers contribute up to 48% and actual evapotranspiration is only 1%.

PHYSICAL AND ECOLOGICAL CHARACTERISTICS OF ALEXANDRA FIORD, A HIGH ARCTIC OASIS ON ELLESMEKE ISLAND, CANADA	I

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Physical and ecological features of an atypically lush high arctic lowland, on Ellesmere Island, are described. Site topography, moisture supply, drainage patterns and radiation input combine favorably to create a highly productive biological oasis amidst a polar desert setting. Growing season radiation and energy balance parameters were higher than those of sites at similar latitudes. Thirteen distinctive lowland plant communities were recognized and divided into a xeric-mesic to mesic lichen-heath-cushion plant dominated series associated with a seasonally discontinuous moisture supply, and a mesic to hydric sedge dominated series associated with a relatively continuous moisture supply. Community species composition, standing crop, and primary production reflected changes in habitat moisture conditions.

A STUDY OF THE EVOLUTIONARY HISTORY OF PERMAFROST IN NORTHEAST CHINA BY A NUMERICAL METHOD	I

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Based on the essential principles of the unity of formation and the difference of existing conditions of permafrost, the comprehensiveness of freezing processes and the relative independence of each sub-process, the continuity (irreversibility and relative stability) and

rhythm of the freezing process, the particularity of contradiction and the main contradiction of freezing processes, and the selection of parameters and mathematics models for the description of freezing processes, and taking contemporary permafrost in large blocks in Northeast China as an example, the authors quantitatively reconstruct the evolutionary history of permafrost in China. Results indicate that the average thickness of permafrost in large blocks was 120 m in the Gu Xiangtun periglacial age. Except in the northern regions, permafrost disappeared during the high-temperature period. The average thickness of contemporary permafrost is approximately 75 m. The data obtained from analyses of the paleoclimate and paleoglacial relics are identical to the data obtained from current field explorations. This method may also be used for other types of permafrost and regions. As long as the change of air temperature is given precisely, the development of permafrost can be successfully predicted.

ULTRASONIC VELOCITY IN FROZEN SOIL | I

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The propagation velocities of ultrasonic dilatational and shear waves in frozen Lanzhou medium sand and frozen Tibet clay samples were measured at different water contents and temperatures using the SYC-2 sonic wave detector. The variation of sonic velocity with water content and unit weight substantially depends upon the type of soil. In coarse-grained frozen soil, the sonic-wave velocity consistently increases with increasing water content, while in frozen clayey soil, in the low water content range, it decreases with increasing water content, then starts to increase with a fluctuation, and finally increases steadily up to the ultrasonic velocity in ice. Tests indicate that the ultrasonic velocity increases with decreasing temperature. Based on this investigation, the authors consider that ultrasonic detection techniques can be used to determine the physical and mechanical properties of frozen soils, such as water content, density, elastic modulus, and Poissonts ratio.

THE PORE-WATER PRESSURE PROFILE IN POROUS ROCKS DURING FREEZING	I

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The frost shattering of rocks was explained by frost heave mechanisms with coupled flows of heat and moisture in porous rocks during freezing. The pore-water pressure profile of the freezing rock was obtained using tensiometers. Pore-water pressures of porous rocks during freezing were monitored by the transducers connected to tensiometers. The profiles of both temperature and pore-water pressure were obtained simultaneously. From pore-water pressure measurements ahead of the freezing point, the large negative pore-water pressure is suggested as the major driving force responsible for water uptake in porous rocks.

CONTROLS AND RATES OF MOVEMENT OF SOLIFLUCTION LOBES IN THE EASTERN SWISS ALPS	P-5

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Rates and processes of present-day movements of solifluction lobes in the Swiss National Park are compared to Holocene movements established by radiocarbon dating of buried soils in solifluction lobes. At a depth of 50 cm, corresponding to the depth of most of the buried soils, movement below vegetation was less than the limit of detection (< 0.1 cm/yr). Under vegetation-free surfaces, movements varied from 0.0 to 0.7 cm/yr (average 0.05 cm/yr). In contrast to present-day rates of movement at depth the length of solifluction lobes range from 0.5 to over 3.0 cm/yr in periods of peak activity during the last 5,000 years. The results of the study of present-day solifluction at the two test sites show that movement is controlled by vegetation cover and by the depth to which the soil freezes during the fall and winter. Thus the comparatively larger rates of movement in past periods of peak activity could be explained by a change in the climate with colder temperatures and winters with less snow cover, which would reduce vegetation cover and promote gelifluction.

GERMINATION CHARACTERISTICS OF ARCTIC PLANTS | I

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Germination traits of many arctic plants are similar to those of Eriophorum vaginatum. Eriophorum seeds have the following characteristics: they are wind-dispersed, have weakly developed or non-existent dormancy mechanisms, show optimal germination at 20-30°C when tested at constant temperatures, germinate over a wide range of temperatures in the light, germinate only at greater than 15-22°C in the dark, and remain dormant while buried in organic soil to depths of 0-30 cm. These characteristics probably contribute to the colonizing ability of many arctic species.

METHODOLOGY FOR USING AIR PHOTOS AND SATELLITE IMAGERY IN PERMAFROST SURVEYS | R-1

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The basic principles of a method for using air photos and satellite imagery in permafrost surveys are presented. It is based on the principles developed by V. A. Kudryavtsev and his school for studying rock conditions, the temperature regime and other permafrost characteristics. The method was tested in the compilation of geocryological maps for various permafrost areas in the USSR. A section of a permafrost map for an area in the Central-Yakutian lowland is presented; it was compiled on the basis of laboratory interpretation of multiband satellite imagery taken from the "'Soyuz-22° spacecraft. The efficacy of the method is assessed with regard to the north of Western Siberia, and Central and Southern Yakutia.

THE THERM-AL REGIME OF PERMAFROST SOILS IN THE USSR | G-1

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The author has compiled maps of the heat flux through the ground surface and its relationship to the radiation balance during the thaw season. The correlation between the radiation balance and the heat flux is slightly higher in permafrost areas. Thus, in the arctic regions the ratio is 20% but in areas of seasonal freezing of the gound it is less than 10%. A ratio of 12.5% corresponds approximately to the southern limit of the continuous permafrost, a ratio of 10% to that of the discontinuous zone and one of 7.5% to that of sporadic permafrost. The total heat flux through the ground surface is greatest in the continental northeastern region of the USSR reaching 200 MJ/m^2. Northwards, westwards and southwards it decreases to 100 MJ/m^2. This does not mean, however, that the greater heat flux results in a greater depth of thaw. Here a considerable amount of heat is being expended on warming the ground from extremely low winter temperatures up to 0° and on the ice-water phase change.

MAPPING OF ARCTIC LAND COVER UTILIZING LANDSAT DIGITAL DATA I

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The United States Geological Survey, with the assistance of several other agencies and institutions, has been mapping vegetation and other land cover in arctic Alaska as a base for assessing development issues. Landsat earth resources satellite imagery in digital form were processed by using algorthims that partitioned the data into spectral classes. Field work supported the later association of these spectral classes with actual land cover types and the construction of a classification system compatible with Landsat data and responsive to the needs of resource managers. Problems of classification incompatibility between adjacent Landsat images were solved by careful designation of classes and editing procedures. After an initial investigation within the National Petroleum Reserve in Alaska further development of the techniques was achieved in the region around the Prudhoe Bay oil fields and in the adjacent Arctic National Wildlife Refuge. Landsat was initially proposed as a mapping data source for this region because of cost and time factors and research has demonstrated that it is

extremely well adapted to the task. Not only are the mapped classes comparable to what could be obtained through conventional interpretation of aerial photographs, the resulting data are digital and consequently directly useable in geographic information systems.

PERMAFROST CONDITIONS AT THE WATANA DAM SITE | I

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The propose Watana development, consisting of a 270 m (885 ft) high dam and underground powerhouse, is the fist phase of a two-dam scheme on the upper Susitna River in Alaska, approximately 225 km (140 mi) south of Fairbanks. Extensive geotechnical investigations were conducted at this site to confirm the feasibility of the project. The extent of permafrost throughout the reservoir areas was mapped through the use of air photos, and the effect of thawing on reservoir slope stability was evaluated. Permafrost conditions are an important consideration at the Watana site. Lying in a broad glaciated region, the Susitna River at the Watana site flows east to west in a deep valley cut into the surrounding plateau, which lies above elevation 700 m (2300 ft). The river valley is more than 244 m (800 ft) deep and approximately 150 m (500 ft) wide at river level. At the site, the north-facing slope contains permafrost to depths exceeding 60 m (200 ft), mostly in rock, while the south-facing slope with favorable exposure is relatively permafrost free. The permafrost in the rock lies within l°C below freezing. Temperature data suggest that the average annual air temperature is close to the freezing isotherm, suggesting that permafrost, although extensive at the site, is in a state of delicate equilibrium. On the relatively flat terrain above the valley rim the permafrost is more sporadic, with extensive but discontinuous permafrost to varing depths. Although most of the permafrost in the overburden is relatively ice free, there exists at one location several miles downstream of the Watana site a large flat-lying lens of ground ice in the valley slope in excess of 3.0 m (10 ft) thick.

THERMAL PERFORMANCE OF A SECTION OF THE MACKENZIE HIGHWAY | M-4

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The thermal performance of a shallow road embankment constructed on permafrost in the discontinuous zone of the Mackenzie Valley was monitored over a 5-year period. The shallow (1.2 m) embankment consisted of clean borrow material end-dumped on a right-of-way which had previosly been cleared of trees. The road was never opened up to general traffic; consequently snow removal was minimal. Measurements included hourly ground temperatures recorded with a data logger operating unattended. Settlements were monitored and thermal conductivity probes were installed to yield information on seasonal trends within the embankment and in the various natural materials comprising the active layer. The data indicate that degradation of the permafrost is under way and provide information on the relation between road surface temperatures and climatic factors for this region.

ROCK GLACIERS IN THE MOUNTAINS OF CENTRAL ASIA | I

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There are about 10,000 active rock glaciers in the region. Their total area is of the order of 2,000 km^2, and they contain 20-30 km^3 of detritus and approximately 20 km^3 of ice. The aptitudinal range of active rock glaciers in the northern part of the area is 2,300-3,500 m, and in the southern part 3,300-4,500 m. The largest attain a length of 4.4 km and the rate of advance in certain years is 1.3 m per year. It is surmised that catastrophic movements of some rock glaciers have occurred in the past. Active and inactive rock glaciers represent two generations from the late Holocene. The latter (forms now inactive) started to develop during the period of mountain glacier retreat, approximately 2,500-3,000 years ago, when the firn line was no more than 100 m lower than at present. The beginning of formation of active rock glaciers occurred during the penultimate stage of glacier retreat (1,500 years ago) when the firn line was approximately at its present altitude. The absence of any rock glaciers older than 2,500-3,000 years indicates that when the firn line was 300-400 m lower than at present, conditions were unfavorable for their development since the rock slopes were covered with ice. As the firn line rose they emerged from the ice cover and became the source of the detritus which went to form the rock glacier. Development of the rock glaciers was thus out

of phase with stages of glacier expansion. The present advance of rock glaciers occurs during a period of general retreat of the region's glacier. Hence rock glaciers are to some degree the converse of mountain glaciers and by studying them one may make some judgement as to the retreat stages of mountain glaciation.

A THEORETICAL MODEL FOR PREDICTING THE EFFECTIVE THERMAL CONDUCTIVITY OF UNSATURATED FROZEN SOILS	I

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The model assumes the soil as a cubic space with a centered cubic solid grain. The hypotheses of parallel isotherms and heat flux lines in the determination of the effective thermal conductivity are discussed. The comparison with several experimental results on saturated two phase media indicates that the assumption of parallel isotherms gives a good agreement. The unsaturated frozen soils are investigated taking into account phenomena of adsorption and capillarity. The predictions of the present model are finally compared with experimental data on unsaturated frozen soils available in the literature. The model gives better agreement to the data than that found using the expressions of Johansen and Frivik (1980) and the electrical conductivity analogy of De Vries (1963). Some characteristic results are presented for soils studied by Kersten (1949) and Penner et al., (1975).

EVIDENCE FOR RECENT PERMAFROST WARMING IN ALASKA	I

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During the past century, the mean surface temperature has warmed about 1.8°C in northern Alaska. Since 1976, the winters in interior Alaska have been substantially warmer than normal. The most recent warming may have increased the mean ground surface temperature thus affecting t'ne thermal regime of the permafrost. The question of whether or not the ground surface temperature has warmed is exceedingly complex involving the effects of the timing, depth, and duration of the snow cover, vegetation, moisture content of the active layer etc.

A variety of data, primarily active layer thicknesses and shallow borehole temperature data have been examined to document the effect of the last seven warmer than normal winters on the permafrost. Active layer thicknesses have increased by as much as 0.22 m at several sites near Fairbanks. Shallow temperature profiles in permafrost in the Fairbanks area show a warming of several tenths of a degree Celsius. Near Deadhorse Airport, Permafrost temperatures at the 23 m depth have warmed by 0.5°C over a four year period. Shallow temperature profiles in subsea permafrost near Norton Sound in the Bering Sea and near Barrow in the Chukchi Sea show what appears to be a slight warminng. Additional data which are presently being obtained at Kotzebue, Glennallen, Prudhoe Bay and Fairbanks will be presented to document the effects of this climatic warming on the permafrost.

GAS PERMEABILITY OF AND EMISSIONS FROM PERMAFROST | I

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A description of some in situ experimental work on gases in permafrost in the Barrow and Fairbanks, Alaska areas will be described. Both naturally occurring and artificially induced trace gases were used in the work. Practical problems, calculation difficulties, and aberrations in the data apparently due to physical factors will be outlined. Values for gas permeability vary from about 10^{-10} to 10^{-5} $cm^2\ s^{-1}\ atm^{-1}$ depending on moisture and salt content of the soil. Gases in the thaw zone are highly variable and at times are emitted in quantities large enough to be regionally significant to the lower temperatures.

A REPORT ON A QUARTER CENTURY OF PERMAFROST RESEARCH AT SCHEFFERVILLE | I

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The past quarter century has seen a wide variety of permafrost related research projects in the Schefferville area. Open pit mining of iron ore and problems encountered in the extraction process has provided the general stimulus for most of the research which has been carried outby researchers from both the Iron Ore Company of Canada and from the McGill Subarctic Research Station at Schefferville. In addition to papers and other publications a large number of notes and unpublished reports have been produced and a considerable body of knowledge, often hard earned from costly mistakes, has been created. Recently, a grant was obtained to collate and synthesize permafrost information from the Schefferville area and to produe in computer compatible form thermocable data and other ground thermal data. The purpose of the present paper is to disseminate to a wider audience information contained in the numerous unpublished reports, to evaluate the current state of the art and to discuss possible avenues for future research.

A GEOCRYOLOGICAL ASPECT OF THE PROBLEM OF ENVIRONMENTAL PROTECTION	E-1

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A system of mapping areas of permafrost in the USSR on the basis of surface stability following the removal of vegetation and soil is proposed. The lowest degree of stability is typical of areas with high ice-contents, fine-grained deposits, and abundant moisture at the surface; here minimal disturbance will lead to the development of thermokarst. Five levels of surface stability in permafrost areas are mapped: 1A - severely unstable; 1B - very unstable; 2 - unstable; 3 - slightly stable; 4 - relatively stable. Some recommendations for monitoring permafrost phenomena are made.

PERMAFROST, FIRE, AND THE REGENERATION OF WHITE SPRUCE AT TREE-LINE NEAR INUVIK, NORTHWEST TERRITORIES, CANADA	I

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Adjacent burned and unburned upland stands were studied at the southwest corner of the 1968 Inuvik burn. Shallow active-layers are poorer habitat than are deep active-layer sites for white spruce because of a slower rate of thaw (effective growing season length), lower seed dispersal capacity, lower cone production, and poor seeedbed creation (because of the depth of the Of) by fire. Fire delimits the range of white spruce by restricting it to areas where the probability of surviving fire is high, e.g., the steeper valley sides and the most deeply incised or sinuous perennial creeks. Areas where survival through fire is likely also tend to possess deep active layers. Although such sites are not uncommon, nany remain uncolonized because of the poor seed dispersal capacity of those white spruce stems.

AN INVESTIGATION OF MIDLATITUDE ALPINE PERMAFROST ON NIWOT RIDGE, COLORADO ROCKY MOUNTAINS, U.S.A.	P-3

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A broad ridge in the Colorado Front Range is the site of a detailed permafrost investigation based on freezing and thawing indices. A 30-year record of temperature data from a station at 3,750 m above sea level is used along with a set of representative lapse rates to determine mean daily temperatures for 12 hypothetical stations on the ridge at different altitudes and with different aspects. Freezing and thawing indices computed for these sites indicate that continuous permafrost may be found down to 3,600 m on south-facing slopes and 3,550 m on north-facing slopes. The discontinuous-sporadic boundary was found to lie at 3,300 m on south-facing slopes and 3,200 m on north-facing slopes. These boundaries are somewhat lower than those proposed in a previous study. It is possible that the freezing and thawing indices used in higher latitude alpine settings as representative of the lower limits of the permafrost zones may overestimate the presence of permafrost in midlatitudes because of higher daily maximum temperatures .

ENGINEERING PROPERTIES AND FOUNDATION DESIGN ALTERNATIVES IN MARINE SVEA CLAY, SVALBARD	C-3(2)

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A new coal mining plant is under planning in Svea, central Spitsbergen, Svalbard. A major part of the plan area is underlain by a marine clay containing ice in vertical cracks. The cracks, 10-20 mm wide, are parallel at a spacing of about 50 mm. This paticular structure of the marine clay encountered at the area is related to the geologic history of the region. With a water content of 50% and a high salt content, the engineering properties are extremely poor. At mean annual surface temperature, -6°C, about 40% of the pore water is unfrozen. The long term strength of the clay is determined by creep tests under unaxial and triaxial conditions. For example, at a temperature of -4°C, the long term strength is as low as 80 kN/m^2 for a design life of 10 years. Based on field and laboratory data, three viable foundation alternatives are investigated. Spread footings, ventilated gravel pad, and slurried pile foundations are evaluated and typical design solutions are given.

A HIGH RESOLUTION TECHNIQUE FOR MEASURING MOTION WITHIN THE ACTIVE LAYER	I

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We have developed an instrument based upon the principle of electromagnetic induction to measure the three-dimensional position of a sensor. This sensor can be buried in the active layer of periglacial patterned ground. This system is sensitive to sensor displacements of 1 mm, a very high resolution rleative to anticipated heave rates. The present system is effective at ranges of up to 1 m, and this range could be easily extended. Laboratory tests show the system to be insensitive to variations in temperature, and calibration results are independent of the state of the soil, whether frozen or thawed.

ZONATION AND FORMATION HISTORY OF PERMAFROST IN QILIAN MOUNTAINS OF CHINA	I

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Alpine permafrost underlies 91,000 km^2 in Qilian Shan, and its distribution shows obvious latitudinal and longitudinal zonation. The lower limit of the permafrost is at *3700-3900* m a.s.l. in the south and at *3494-3650* m in the north. As the latitude increases by 1°N, the permafrost lower limit descends 123.7 m; as the longitude increases 1°E, the permafrost lower limit descends 56.6 m. In the insular permafrost zone, the permafrost is generally 25-35 m thick, with a mean annual ground temperature of 0° to -1.5°C. In the discontinuous permafrost zone, it is 35-95 m thick and the mean annual ground temperature is -15° to -23*C. Temperature inversions, which become stronger northwards, affect permafrost distribution; a maximum thickness of 139.3 m occurs in the Mu Li and Tuo Lei Basins. Permafrost on north-facing slopes is *30-50* m thicker than on south-facing slopes. Qilian Shari has undergone several ice ages, but the existing permafrost was formed around 3000 yr B.P., because during the interglacial period of the Pleistocene and the post-glacial stage at the beginning of the Holocene temperatures were too high for permafrost preservation.

A COMPARISON OF REMOTELY SENSED SURFACE TEMPERATURE AND BIOMASS ESTIMATES FOR AIDING EVAPOTRANSPIRATION DETERMINATION IN CENTRAL ALASKA	R-1

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Aerodynamic surface roughness, an important parameter controlling the evaporation rate, is related to the biomass. Previous work indicated that temperature variations in the Heat Capacity Mapping Mission (HCMM) satellite data were related primarily to evaporation differences for similar albedo values. LANDSAT-derived estimates of the biomass were related to HCMM-derived estimates of the surface temperature for an area of the Alaska sub-Arctic for which contemporaneous LANDSAT and HCMM data existed. It was found that the relationship showed some

scatter, the correlation coefficient being only -.62. Thus, land cover data are not good substitutes for remotely sensed thermal infrared data in this area at this time of year, but these data have ancillary uses for situations in which high spatial resolution data are needed to improve coarse resolution thermal infrared data.

FIELD TESTS OF A FROST-HEAVE MODEL	I

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A one-dimensional mathematical model of frost heave based upon a nodal domain integration analog is compared to data collected from a Winchendon, Massachusetts, field site. Air and soil temperatures, pore water pressures, and ground-water level data were collected on test sections containing six different soils during the winters of 1978-1979 and 1979-1980. The soil samples were evaluated in the laboratory to determine soil moisture characteristics, hydraulic conductivity as a function of pore water tensions, density, and other parameters. The parameters were used together with assumed thermal parameters in a one-dimensional model that calculates the distributions of temperature and moisture content as well as the amount of ice segregation (vertically lumped frost heave) and thaw consolidation. Using measured air and soil surface temperatures as input data, the simulated frost heave and thaw consolidation agreed well with measured ground surface displacements that resulted from ice segregation or ice lens melting.

PERMAFROST-GLACIER RELATIONSHIPS IN THE SWISS ALPS-- TODAY AND IN THE PAST	P-3

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A conceptual model is proposed to explain the geographical distribution of permafrost and glacier phenomena in high altitude/low latitude mountains. The concept centers around the fact that the vertical distance between the lower boundary of permafrost distribution an the equilibrium line on glaciers is related to the mean annual air temperature at the equilibrium line. This temperature term strongly depends on the continentality of the climate and can be empirically linked to thermal conditions in ice and permafrost, and also to glacier activity. Conditions in the Swiss Alps both today and in the past are used to illustrate the concept and to demonstrate its use for paleoclimatic reconstructions. In the humid marginal zones of the Alps, where permafrost is restricted to rock outcrops in the accumulation area of glaciers, active, temperate glaciers are dominant; on the other hand, less active, partially cold glaciers and creep phenomena in perennially frozen sediments (such as rock glaciers and push moraines) are abundant in the sheltered interior regions today. Partially warn-based, cold glaciers of extremely low activity within continuous permafrost were typical for the coldest period of the last ice age. In agreement with palynological reconstructions this indicates that precipitation was greatly reduced at this time.

STRATIGRAPHIC DISTRIBUTION OF PERIGLACIAL FEATURES INDICATIVE OF PERMAFROST IN THE UPPER PLEISTOCENE LOESSES OF BELGIUM	P-2

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Among the various types of periglacial features known within the loesses of Belgium, only ice-wedge casts and tundra gleys, mainly those associated with an ice-segregation structure, may be considered as indicative of permafrost. The distribution of those features in the upper Pleistocene loesses of Belgium implies that the most widespread episodes of permafrost formation took place at intervals, between 33,000 and 20,000 years B.P., before and during the sedimentation of the late Weichselian loess cover. Permafrost conditions did also occur at the beginning of the middle Weichselian (around 60,000 years B.P.) and during the second half of the late Weichselian (around 15,000 years B.P.}.

PERIGLACIAL PHENOMENA IN ARID KEGIONS OF IRAN	P-6

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Field work in the Shir-Kuh Mountains (cl. 4,055 m) of central Iran included studies of periglacial phenomena as well as of the present and Pleistocene limits of patterned ground and the snow line. The climate is semi-arid. Average annual precipitation is about 200 mm at 2,000 m and about 400 mm at 4,000 m. Precipitation occurs almost exclusively in winter in the form of snow. The summer months are characterized by low cloud cover, and thus high solar radiation. All of the mountain area possesses Pleistocene glacial landforms down to 1,900 m, as well as present periglacial forms above 2,000 m. Four groups of periglacial features are distinguished: (1) On the Shir-Kuh summit plateau at 4,055 m stone circles, stone stripes and solifluction lobes occur, comparable to alpine forms. Stone circle diameters are 50-100 cm. Limestone frost debris is upturned and well oriented. (2) Between 3,400 and 4,000 m, smooth slopes ("Glatthange") cut across limestone strata. Slope inclinations are between 35° and 40°. They are interpreted as periglacial forms. (3) At the foot of limestone outcrops, between 3,000 and 3,400 m, there are frequent occurrences of vegetation garlands of periglacial origin. Stone stripes are also common and extend down to 2,500 m. (4) Occurrences of patterned ground are found as low as 2,100 m. With the exception of those on very suitable substrates they appear to be convergence forms due to wetting and drying of clays and salts. There is some evidence for progressive divergence of the snow line and the lower limit of patterned ground towards the arid zones.

QUANTITATIVE ANALYSIS OF THE RECOVERY OF BURNED AREAS IN ALASKA USING REMOTE SENSING	I

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Forest and tundra fires are common in Arctic and sub-Arctic Alaska during the summer months. Extensive efforts are often necessary to control these fires. In addition to the danger associated with fire, the effects of fire on tundra and forested areas in the Arctic and sub-Arctic remain ambiguous. Following a fire, recovery patterns vary greatly depending upon many factors including severity of burning and type and amount of vegetation available. The role of satellite remote sensing for analysis of post-fire recovery is explored in this paper. Fires in the Seward Peninsula and central Alaska are analyzed using Heat Capacity Mapping Mission (HCMM) and NOAA visible, near-infrared and thermal infrared data, along with available conventional meteorological data. The relative vigor of the remaining vegetation following a fire can be estimated by measuring the evapotranspiration in the burned area. The evapotranspiration may be estimated using an energy and moisture balance model designed to accept remotely sensed data. The albedo and surface temperature may be estimated using HCMM and NOAA satellite data. These values are then input to the model which calculates the components of the energy balance equation and evapotranspiration. The summer of 1977 was time in which forest and tundra fires were common in northern and western Alaska. HCMM and/or NOAA data of the study areas are available from 1978 through 1981. These data are used to monitor the evapotranspiration (estimated using the model) in burned and surrounding unburned areas during the study period. Increases in albedo were found in the years following the burning, thus indicating considerable vegetative regeneration. (However, the type of vegetative regrowth is not considered here.) For example, between July of 1979 and August 1980, the albedo in a portion of one burned area increased from 13 percent to 16 percent while the albedo in a surrounding, unburned area decreased from 21 to 19 percent. Three other burned areas were analyzed as well. This method thus represents a quantitative method of estimating vegetative regrowth in remote areas.

THE BREAKDOWN OF ROCK DUE TO FREEZING: A THEORETICAL MODEL P-7

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Frost wedging -- the breakdown of rock due to freezing -- is viewed as a manifestation of slow crack propagation in rocks due to ice growth in cracks. Frost wedging is modeled through a synthesis of Gilpin's (1980a) analysis of freezing in porous media and well-established principles of fracture mechanics. The model predicts most rapid breakdown at temperatures that range from -5° to -15°C for most rocks. At higher temperatures, ice pressures sufficient to produce significant rates of crack propagation are not thermodynamically possible. At lower temperatures the rate of ice growth is greatly reduced because water mobility and, hence, the flux of water necessary to sustain crack growth decrease considerably. The model clarifies

the dependence of frost wedging on lithology, temperature, and moisture conditions. Four important rock properties figure in the analysis: pore size, permeability, average crack length, and fracture toughness. Crack growth rate has a complex dependence on temperature and is proportional to temperature gradient. The moisture content of rock can strongly affect frost wedging rates primarily by controlling the pore water pressure. Solutes are inferred to influence crack growth rates in several distinct ways.

ALASKA HIGHWAY GAS PIPELINE PROJECT (YUKON) SECTION THAW SETTLEMENT DESIGN APPROACH	C-1

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The Alaska Highway Gas Pipeline will traverse permafrost terrain for much of the route through the Yukon Territory. In the predominantly frozen ground, the pipeline will operate in the "cold" mode. Where the terrain is predominantly unfrozen, the pipe will operate in the "warm" mode requiring mitigative design for thaw settlement in some frozen terrains. The results of the thaw settlement tests carried out for the project are presented as well as other data available in the literature. Statistical methods were used to arrive at correlations between thaw settlement and moisture content or density. The thaw settlement predictions were based on a computerized Borehole Data Bank containing simplified borehole logs and a computerized thaw settlement program. The thaw settlement predictions were applied to the pipeline design by assuming that the predicted thaw settlement could occur as a differential settlement over a relatively short length of pipe. The various mitigative designs are presented.

VESICLES IN THIN SECTIONS OF PERIGLACIAL SOILS FROM NORTH AND SOUTH NORWAY	I

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Micromorphological investigations of *silty* sand soils from a solifluction slope in Okstindan, North Norway, revealed vesicles apparently identical to those encountered in samples from the centers of sorted

circles at Gråsubreen, Jotunheimen, Norway. Vesicles appeared in thin section as smooth-walled spherical voids. Walls were clean with no evidence of alluvial silt linings. Other elements of the micromorphology were disrupted by vesicles, including silt coatings on sand grains and silt droplet fabrics. On the basis of simple laboratory experimentation and field observation it was concluded that vesicles resulted from the following conditions: (1) low initial bulk densities during thaw of ice-rich soils; (2) high moisture contents, but air present in larger pores; (3) disturbance of the sensitive soil due to thaw-consolidation, or to the process of sampling. Disturbance caused repacking of grains, reduction in void ratio, increase in pore water pressures and liquefaction. Air in larger voids and pores became bubbles, forming the vesicles observed in thin section.

COMPARISON OF THE CLIMATIC AND GEOMORPHIC METHODS OF PREDICTING PERMAFROST DISTRIBUTION IN WESTERN YUKON TERRITORY

G-1

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Drilling and ground temperature measurements along the Dempster Highway demonstrate that continuous permafrost is at least twice as extensive in Western Yukon Territory as previously shown on maps. An extensive belt occurs in the foothills below the St. Elias Range west of Destruction Bay, while continuous permafrost extends south to the North Fork Pass along the Dempster Highway. Between the zones of continuous permafrost are areas of discontinuous permafrost in lowland areas, with 30-80% of the landscape underlain by permafrost. The climatic predictive method is reasonably successful at predicting the permafrost distribution on small scale maps but tends to slightly underpredict the distribution in montane valleys. Cold air drainage is widespread and very marked in these areas, and may cause the anomalies. Groundwater movement is undoubtedly also important locally. The geomorphic method based on the distribution of zonal permafrost landforms is of little use in mapping the permafrost boundaries. It was the evidence used to augment the sparse ground-temperature data available to previous workers.

PALEOCLIMATE IMPLICATIONS FOR ARCTIC ALASKA OF THE PERMAFROST AT PRUDHOE BAY	I

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The permafrost onshore at Prudhoe Bay contains paleotemperature information on several time scales. On the scale of 1000 years information is contained in the permafrost temperature profile; it has been analyzed in terms of a climate warming over the last century or so by Lachenbruch. Infromation on a much longer time scale, tens of thousands of years, is contained in the present permafrost thickness, given the geothermal heat flow and thermal properties as recently determined by Lachenbruch and others. We have analyzed these data to obtain a temperature amplitude for several paleotemperature models going back to the Sangamon. We find that the pre-Holocene temperatures were not greatly different, within 1 or 2"K, from those existing in the last century. The limitations on this estimate due to uncertainties in the goethermal data, in the relation between ground surface and air temperature, and in the geologic history of the Prudhoe *Bay* area, will be described. None of these factors seems to be too serious given present knowledge, although a change in present ideas of the history of the shoreline position could change the interpretation.

THE ORIENTATION AND EVOLUTION OF THAW LAKES, SOUTHWEST BANKS ISLAND, CANADIAN ARCTIC	P-5

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On southwest Banks Island, the melt-out of ice within unconsolidated permafrost sediments has led to the formation of numerous thaw lakes. A majority of basins are oriented perpendicular to prevailing winds and possess a D-shaped outline which is in equilibrium with wind-generated geomorphic processes. In particular, a strong relationship exists between lake morphology and the storm wind regime during the summer period of open water conditions. Thaw lakes in this area cannot be interpreted within the traditional "thaw lake cycle"' and appear to represent quasi-equilibrium landforms. Shoreline erosion results in asymmetrical expansion rather than a lateral migration of the basin. Lake drainage occurs primarily by catastrophic outflow, following basin capture or truncation by coastal retreat.

RELATIONSHIPS BETWEEN ESTIMATED MEAN ANNUAL AIR AND PERMAFROST TEMPERATURES IN NORTH-CENTRAL AMERICA | I

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Mean annual air temperatures (MAAT) are estimated for a transect from central to northern Alaska. The estimated MAAT are compared to mean annual ground temperatures (MAGT) representative of upper permafrost temperatures. The estimation of MAAT for the remote and topographically complex transect area was based on trend surface estimates of numerous short-term (l-7 years) temperature records obtained from climatic stations operated by research projects and longer records from existing National Weather Service stations. The standard error of the estimated MAAT falls within a degree (C) of observed MAAT for stations with long-term records. The MAGT are based on subsurface thermistor measurements made at construction sites and are therefore from disturbed terrain, but data were selected to minimize the effects of disturbance. MAGT measurements ranged from -7.5°C in the north to -0.7°C near Fairbanks. Predicted MAAT ranged from -11.5°C at Prudhoe Bay to -4.5°C in the Fairbanks area. A simple regression relationship showed MAGT to average 3.6°C higher than MAAT. This study suggests that, based on estimated MAAT and MAGT values, the boundary between the zones of continuous and discontinuous permafrost is located at or slightly north of the continental divide at Atigun Pass.

STABILIZATION OF SINKHOLES ON THE HUDSON BAY RAILWAY | C-4

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Embankment settlements have presented a long-term track maintenance problem where the Hudson Bay Railway crosses extensive peatlands of northern Manitoba. Localized zones of settlement, termed sinkholes, typically consist of short sections of track that settle about 100 mm each summer. Field studies have verified that subsidence is caused by

thaw at the unstable transition between unfrozen fen and permafrost-cored peat plateaus. In 1978, five test sections were constructed on the railway to study techniques for stabilizing the roadbed by stopping permafrost degradation. A total of 40 two-phase heat pipes were installed along the toe of the embankment at four of the sites. Ground temperatures, track movements and surface settlements were monitored from October 1978 through March 1982. A well-defined group cooling trend was evident at all of the test sites and settlements were substantially reduced after the first year of operation. The research program successfully demonstrated that heat pipes provide a viable means of arresting localized thaw settlement for embankments constructed on peatlands where permafrost is warm and discontinuous.

BUILDING FOUNDATIONS ON PERMAFROST	I

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To examine the applicability of various foundations to cold regions, the massive concrete foundation, earth-padded ventilation foundation, reinforced concrete strip foundation, and column and pile foundations were tested at Zhaohui and Jingtao field stations in northeast China, where the mean annual air temperatures are -5° and -5° to -6°C, respectively. The ground temperature fields, thawing settlement, and tangential frost-heaving forces of subsoils were measured from 1972 through 1980. Test results showed that the distribution of ground temperature beneath structures depends upon the type of foundation, and that the ihawing depth under foundations is governed by the building's heating system. The formation of cracks in buildings not only depends upon the settlement of foundations, but is also influenced by air temperature. In designing the ground floor of buildings, thermodynamic calculations must be made according to the type of foundation.

PROBLEMS IN THE CARTOGRAPHY OF GROUND ICE: A PILOT PROJECT FOR NORTHWESTERN CANADA	I

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A new permafrost map of Canada is being proposed, emphasizing the occurrence and distribution of ground ice. The key element is the extreme variability of ground ice both horizontally and with depth. Problems include the development of a suitable classification scheme and the quality and variability of the source data. Previous work on ground ice classificaiton and mapping is reviewed and a new, morphological classification of ground ice bodies is proposed. The main classes are: ice crystals in voids, equidimensional ice masses, layers or sheets of ice (horizontal, vertical, diagonal) and networks of segregated ice. These classes are subdivided on the basis of the regularity of the shapes of ice masses and whether their occurrences are simple or multiple. A qualitative classification of the amount of ground ice is proposed: low, moderate, high, very high and extreme. Selected geomorphic features, such as pingos, will be shown by symbols. A pilot study map of northwestern Canada, using these classifications is being prepared.

VEGETATION MAPPING FOR HABITAT AND WETLAND ASSESSMENT ALONG PROPOSED MINE TRANSPORTATION ROUTES, NORTHWESTERN ALASKA	I

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A proposed lead-zinc mine 145 km north of Kotzebue, Alaska (67°N, 163°W) would require about 96 km of rail line or haul roads to the coast near Kivilina. Vegetation mapping was instigated in 1982 to identify important habitats and obtain information on terrain conditions as indicated by vegetation. A specific objective was to identify wetlands and areas of critical habitat for routing considerations and permitting requirements. Map units were delineated along several corridors using 1:60,000 false color infrared aerial photography and then transferred to a 1:63,360 based after gound-truthing. Vegetation of the area consists mainly of dwarf shrub and tussock tundra types, but includes 12 of Viereck et al. (1981) level three categories. Species composition, soils and hydrologic data were collected at sites representing plant community types for each map unit. These data were used for wetland determinations according to U.S Army Corps of Engineers guidelines and for habitat assessment. Relationships between active layer depths, soil conditions and vegetation map uits are analyzed to help delineate sensitive areas or units that could be problematic for construction.

DESIGN OF BURIED SEAFLOOR PIPELINES FOR PERMAFROST THAW SETTLEMENT

I

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Computer simulations were performed to model the mechanical and thermal behavior of pipelines buried in the seafloor above ice-bonded permafrost. Conditions typical of the Alaskan Beaufort Sea were used, and the study was directed at water depths greater than 2 m (6 ft). Maximum pipe diameter, operating temperature, and cover depth considered were 61 cm (24 in), 93°C (200°F), and 3.0 m(10 ft), respectively. A few cases considered two parallel pipelines instead of a single isolated pipeline. Allowable permafrost settlement was determined by modeling the mechanical interaction beween the pipeline and settling soil. If the top of ice-bonded permafrost was within about 9 m (30 ft) of the seafloor, then the allowable permafrost settlement was only about 0.3 m (1 ft). However, the allowable settlement increased rapidly as the depth to ice-bonded permafrost increased. For example, doubling the depth to ice-bonded permafrost more than tripled the allowable settlement. The soil thermal regime was modeled to develop guidelines for preventing excessive thaw and and settlement. Where the ice-bonded permafrost was below a depth of about 27 m (90 ft), thaw was acceptable for all situations considered. For ice-bonded permafrost depths of about 14-27 m (45-90 ft), insulation was used to limit thaw. If the ice-bonded permafrost was at a depth less than about 14 m, then restrictions on operating temperature or changes in burial geometry were sometimes also necessary. These guidelines can change depending on the specific application but are useful for planning future studies. Salt transfer in the thawed soil was identified as a significant factor in calculating thaw depth because it controls the permafrost thawing temperatures.

PHENOMENA OF FOSSIL PERMAFROST IN SANDY DEPOSITS OF THE LAST GLACIAL IN BELGIUM

I

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The northern part of Belgium was situated in a periglacial area during the Last Glacial (Weichsel or Wurm Glacial). The late Pleistocene drainage pattern of the Scheldt and its tributaries were deeply

scoured into the Eocene substratum, consisting of monoclinal alternating sandy and clayey layers dipping northwards to the Dutch subsidence basin. The deepest incision related to a low glacial sea level resulted in a pattern of thalwegs up to -30 m below actual sea level and formed a large valley system called "'Flemish Valley". Sandy and gravelly coarse sandy deposits wth loam, peaty loam and peat layers colmatated this valley system due to an anastomosing braided river system and buried young Pleistocene terraces. In many excavations different phenomena of frozen ground and periglacial features could be studied. The most common secondary sedimentary structures are frost wedges, sand wedges, ice wedges, cryoturbations, drop tails, diapyrs, involution and small melting depressions. An attempt is made to order these phenomena in a stratigraphical succession, based on palynological data and absolute C14 datations.

THAW SETTLEMENT AND GROUND TEMPERATURE MODEL FOR HIGHWAY DESIGN IN PERMAFROST AREAS	M-2

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Highway roundness produced by the differential settlements of thawing permafrost is probably the major problem for highway engineers in permafrost regions. A one-dimensional finite element model was developed to estimate thaw depths and subsequent settlements of an embankment on permafrost terrain. The computer program accepts basic soil parameters in an interactive manner making its use relatively simple. Soil parameters input to the model are limited to test results normally available to the highway engineer and thermal properties that may be measured or estimated from suitable correlations. Climate data may be input as daily or monthly air temperatures along with suitable n-factors. Results have been compared with theoretical calculations and several measured temperatures under insulated and uninsulated road test sections. Comparisons indicated that the model is capable of giving very good results under a variety of conditions provided that accurate estimates of dry densities and water contents can be obtained.

PHYSICAL, BIOLOGICAL, CHEMICAL, AND HYDROLOGIC CHARACTERISTICS OF A SUBARCTIC STREAM SYSTEM	1

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Stream system quality is monitored in the 110 km^2 Caribou-Poker Creeks Research Watershed, in the Interior Alaska taiga. The multidisciplinary program provides comprehensive data on baseline conditions prior to experimental landscape treatments (streamside clearing, logging, fire). Based on one season's data, 50% of annual surface water yield from a permafrost-dominated first-order basin is produced during the spring melt period, compared to 7% during winter and 43% during the ice-free summer. Spring runoff is critical to calculating sediment and chemical loadings in the subarctic. Summer streamflow data from paired basins show that a first-order catchment dominated (53% of area) by permafrost has more pronounced hydrologic response to storm events and greater sediment and turbidity load than does a similar-sized permafrost-free (3% of area) first-order catchment. Physical, chemical, and biological data confirm that water quality characteristics such as turbidity, element and nutrient concentration, and stream biota are affected by permafrost and respond in a manner consistent with a hypothetical stream continuum. Species composition, periphyton standing crop biomass, and accumulation rates on natural and artificial substrates are related to stream order, while species diversity apparently does not change from low to higher order sites.

APPROXIMATE SOLUTIONS FOR MILLER'S THEORY OF SECONDARY HEAVE	M-5

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Quasi-static approximations for the temperature and pore water pressure profiles are used to describe the one-dimensional freezing of a saturated noncolloidal soil. Using the energy and mass conservation equations the problem is reduced to the solution of two ordinary differential equations. The theory includes a criterion for the initiation of lenses and a simple numerical procedure is used to describe the growth of a lens, the frozen fringe and the initiation of a new lens. Some numerical results are given that are in general qualitative agreement with other studies.

HYDRAULIC CONDUCTIVITY FUNCTIONS OF FROZEN MATERIALS — M-3

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A constant-volume permeameter/dilatometer apparatus was used to obtain data for unfrozen water content and hydraulic conductivity for eight materials, including four natural silts, as a function of temperature in the range 0° to -0.35°C with pore water pressure held near zero gauge. After seeding with ice, samples were first chilled and then rewarmed by small steps. Hysteresis effects were extremely large in the first freeze-thaw cycle for all materials but were small in the one natural silt subjected to a second cycle, suggesting possible malfunctions of the seeding procedure in the first round. Typically, hydraulic conductivities fell from values of the order of $10^{-8}\ m \cdot s^{-1}$ before freezing to values in the range 10^{-12} - 10^{-13} at temperatures near -0.3°C. After thawing, hydraulic conductivities were higher than before freezing of the thoroughly remolded materials by factors ranging from 1.1 for a natural silt to 60 for a stock sample of Illite.

COMPARISON OF TWO-DIMENSIONAL DOMAIN AND BOUNDARY INTEGRAL GEOTHERMAL MODELS WITH EMBANKMENT FREEZE-THAW FIELD DATA — M-2

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The time- and position-dependent locations of the O"C isotherm were calculated using two modelling strategies: a domain method and a boundary integral method. Simulations were made for the runway embankment at Deadhorse Airport near Prudhoe Bay, Alaska. The same thermal properties, initial conditions, and boundary conditions were used in both models. Sinusoidal surface temperature variations, dependent upon surface type and exposure, were used in the simulations rather than measured surface temperatures. The positions of the O"C isotherm determined by the boundary integral method near the time of maximum thaw penetration were essentially the same as those determined by the finite element method, and results from both models agreed closely,

within a few centimeters over a total freezing depth of about 2.5 m, with the measured positions. The largest differences between measured and computed positions occurred early in the freezing and thawing seasons. Tine primary advantge of using the boundary integral method for problems specifically of the type considered herein is that it requires only a few nodal points, so computer simulations can be completed rapidly on a micro computer. If the two-dimensional thermal region is necessary, the finite element method is most suitable.

DETERNINATION OF CRITICAL HEIGHT OF RAILROAD EMBANKMENTS IN THE PERMAFROST REGIONS OF THE QINGHAI-XIZANG PLATEAU | I

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Based on analysis of data obtained from the observation of a railroad embankment in situ, the author presents mathematical formulas for calculating the lower and upper height of railroad embankments. The lower height of the embankment is the least height that does not affect the natural permafrost table in the subgrade; it can be determined by two empirical formulas: the first expresses the maximum thawed depth in relation to the natural permafrost table, and the second expresses the elevated height of the natural permafrost table in relation to the height of the clay soil embankment. The upper critical height of the embankment is the maximum filling height for the freezing connection of the body of embankment to the natural permafrost table in the first cold season; it can be determined by an empirical formula that expresses the upper height of the embankment in relation to the time of disappearance of frozen ground with temperature of −0.5°C.

GEOPHYSICAL METHODS FOR PERMAFROST SURVEY IN CHINA | I

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Direct-current electric prospecting has been used for permafrost investigations since the end of the 1950's, and remains a major prospecting technique. It has proved to be a useful method for locating the distribution of permafrost and taliks, mapping ground ice, and

determining permafrost thickness. Recently, computers have been used to process data from electrical soundings. Experiments in seismic prospecting show that the first arrival refraction can be used to measure the depth of the permafrost table, and shallow reflection can be used to measure the thickness of noncompacted sediments. D.C.-induced polarization, dipole array potential-drop ratio, and radon emanation techniques have been tested and applied to permafrost surveying. The conductivity, acoustical properties, and dielectric constants of frozen soils have also been studied in the laboratory. Future tasks include (1) further research on the characteristics of ground electrical sections of permafrost, to increase the accuracy of quantitative interpretation of V.E.S. curves and to perfect computer data processing, (2) further research on electrical and acoustic properties, and (3) further study of the dynamic characteristics of seismic waves in permafrost.

DOWNSLOPE CREEP OF UNSTABLE FROZEN GROUND	I

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A relatively fast mode of creep may develop in sloping frozen ground when a steep bank is cut along the foot of the slope. This conclusion is based on field studies of downslope creep into a crater produced during the 1970 volcanic eruption on Deception Island, Antarctica, and from laboratory creep studies of frozen ground performed by Russian scientists in 1962. These field and laboratory studies show that ice-cemented frozen ground ranging from volcanic ash to clayey soil to sandy loam has a creep behavior that is nearly plastic flow. When creep is nearly plastic, strain rates become partitioned between slow creep rates at low shear stresses and fast creep rates at high shear stresses. This partitioning gives an unstable character to downslope creep of frozen ground, particularly when roadcuts and erosion of river banks cause abrupt increases in boundary stresses. These dangers can be readily assessed, because the downslope creep behavior of frozen ground can be accurately predicted from maps of the surface slope and measurements of the plastic yield stress and frozen thickness along the steeply cut bank.

SOME SPATIAL ASPECTS OF CLIMATE-DEPENDENT MECHANICAL WEATHERING IN A HIGH ALTITUDE ENVIRONMENT

P-7

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Mechanical disintegration on mountain walls in alpine tundra of the San Juan Mountains, Colorado is related in a general way to the mesoscale distribution of insolation: fractures are more closely spaced at sites having higher insolation. This conclusion is based on analysis of fracture data from 111 small, scree-producing cliffs in volcanic rocks. The sites vary widely in orientation and exposure, and are located between 3,700 and 4,100 m elevation. North facing sites average 27% fewer fractures than south facing sites, and 19% fewer than both east and west facing sites. The correlation of insolation and fracturing ($\underline{r}$ = .399) is highly significant (<.001) yet the regression equation is a poor predictor. It suggests that sites having the most insolation average 50-70% more fractures than those having the least. Sixteen percent of the total variation in fracturing is explained by insolation alone, but results are modified by elevation and orientation: more variation is explained for (1) sites facing south and east, and (2) sites above the average site elevation (3,900 m). Greater seasonal ranges and higher average insolation on southerly facing sites must influence the shattering process and cause them to have more fractures.

SOIL WEDGES ON SPITSBERGEN

P-1

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In the Van Mijenfjorden, in the western part of Spitsbergen, the author found non-sorted polygons composed of fine shale debris. Although these polygons were clearly a result of frost cracking, no ice wedges were in the permafrost (to a depth of 1.2 m). The soil wedges found were active-layer soil wedges, similar to the soil wedges known from Siberia. The Spitsbergen findings indicate that such soil wedges can develop in an oceanic periglacial climate. The hypothesis that soil wedges occur only in continental periglacial zones may be incorrect.

FROST HEAVE MITIGATION AND PERMAFROST PROTECTION FOR A BURIED CHILED-GAS PIPELINE	M-1

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The problems of frost heave and thaw settlement are analyzed for a gas pipeline buried across discontinuous permafrost terrain. First, possible operating temperatures are evaluated, and chilling the gas below the freezng point is concluded to be the best way to minimize geotechnical problems. Next, a reasonable lower limit for the gas temperature is determined. This temperature is then used to calculate freeze bulb sizes for insulated and uninsulated pipe in initially thawed, frost-susceptible soil. The results for insulated pipe demonstrate that the additional heat input caused by the construction surface disturbance can prevent formation of a permanent freeze bulb, and therefore, preclude significant heave. However, if the soil is initially frozen and thaw-unstable, and the gas temperature is near the freezing point, or the pipeline is insulated, then the surface disturbance can also cause thaw settlement. This can be prevented by using a row of heat pipes along both sides of the pipeline. The heat pipes can keep initially frozen ground frozen, and freeze initially thawed ground "without causing heave.

AN ANALYSIS OF PLANT SUCCESSION ON FROST SCARS 1961-1980	E-2

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Plant succession on frost scars was studied at Ogotoruk Creek, Alaska. In 1961, 326 frost scars were marked for long-term study. The initial physical and biological measurements were repeated several times. In 1965, four transects were established and later revisited to learn if new frost disturbance is occurring. Frost scars at Ogotoruk Creek are convex, primarily oval areas of fine-grained soil with a modal size of about 1 m in diameter. They occur on surfaces of from 1-3° and cover up to 50% of the ground surface. Many frost scars show surface activity due to frost action, but repeated mapping of them indicates that they neither expand nor contract laterally. Repeated measurements along fixed lines suggest that new frost scars are not being formed at present. Plants invade bare areas at Ogotoruk Creek

by seeds or vegetative reproduction. Plants growing on frost scars are subject to frost heaving, uplift and disruption from needle ice formation, and wind erosion and desiccation. A direct relationship exists between plant cover on frost scars and soil moisture surrounding the scar. During the 20 years of the study both positive and negative changes in plant cover were recorded. A consistent pattern of plant succession was not detected.

RECOVERY AND ACTIVE LAYER CHANGES FOLLOWING A TUNDRA FIRE IN NORTHWESTERN ALASKA

E-2

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An upland tundra fire, started by lightning, burned 48 km^2 near the Kokolik River (69030'??, 151°59'W) in northwestern Alaska during late July and early August 1977. Permanent plots were established to monitor recovery of severely, moderately, and lightly burned areas as well as unburned tundra. During the following 5 years the original permanent plots and other portions of the burn were observed annually. Vegetative recovery was most rapid and active layer effects were least on the moist sedge-shrub tundra. Recovery was slower on a high-centered polygonal area and on severely burned tussock tundra. By August 1979 the sedge-shrub vegetation had largely recovered while both the polygonal ground and the tussock tundra were still readily recognizable as burned areas. Accelerated hydraulic erosion had occurred on some slopes, exposing massive bodies of ground ice. Active layer thicknesses averaged 27 cm in the unburned areas and 35 cm within severely burned areas in August 1977 and reached a maximum at all sites in August 1979. Depth of thaw decreased between 1979 and 1982 in the sedge-shrub tundra and in the lightly burned shrub tundra and remained at the same increased level through 1982 at all other sites.

PERFORMANCE OF AN INSULATED ROADWAY ON PERMAFROST, INUVIK, N.W.T., CANADA	M-4

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In 1972 four insulated and two uninsulated test sections were installed and instrumented on the Mackenzie Highway (a gravel-surfaced, all-season road) near Inuvik, N.W.T., to evaluate the use of extruded polystyrene board insulation in controlling permafrost degradation. Two test sections were insulated with a 90-mm layer of insulation, another with a 50-mm layer, and a fourth with 115 mm. Preliminary analysis had indicated that an optimum insulation thickness of about 90 mm would be required. Ground temperature and settlement observations over a 6-year period showed that permafrost aggraded under all insulated test sections, whereas under the uninsulated (control) sections it receded by as much as 60 cm. Approximately 60 cm of settlement was experienced by the control sections, about 30 cm by the 50-mm insulated section, and little or none by the sections having 90 and 115 mm of insulation. The 90 mm of insulation was shown to provide adequate protection against thawing; 50 mm of insulation was not sufficient.

THE FROST SUSCEPTIBILITY OF GRANULAR MATERIALS	I

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The frost susceptibility and suction characteristics of fifteen granular materials ranging from silty soils to crushed rock sub-base aggregates were determined by the British Transport and Road Research Laboratory (TRRL) test and an osmotic suction technique, respectively. The test specimens were prepared at a number of standardized gradings and compacted to their maximum density at optimum moisture content. The heaves after 250 hours ranged from 2 to 50 mm so that both frost susceptible and non-frost susceptible materials were included. The results for all but one of the materials lay on a single curve relating frost heave to $\theta_{2.5}$, the total volumetric water content at a suction of pF 2.5 (31 kPa). Using the segregation potential approach it appears that there is a characteristic suction that controls the average permeability of the frozen fringe. For most of the materials considered, this suction approximates to pF 2.5. Materials with $\theta_{2.5}$

less than 9% were non-frost susceptible, but tests are required on many more materials to establish whether this relationship has general validity.

DEFORMATION BEHAVIOR OF FROZEN SAND-ICE MATERIALS UNDER TRIAXIAL COMPRESSION	I

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Deformation behavior and strength of frozen sand-ice materials containing O to 0.6 weight fraction of sand were studied by testing the samples at -11°C in compression under hydrostatic pressures varying between 0.1 and 85 MPa. The peak strength increased with increasing hydrostatic pressure, reached a maximum for confining pressures around 25 MPa, and decreased for further increase in pressure. The results are compared with those obtained earlier in pure polycrystalline ice and frozen saturated sand.

PERMAFROST-RELATED TYPES OF LARGE-SCALE DISSECTION, DEGRADATION, AND DEFORMATION OF MARTIAN LANDSCAPE	I

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Aureoles, mega-aureoles and chaotic terrains are among Mars' most significant permafrost-related surface structures. In areas of high relief the melting of a proposed layer of underlying permafrost led to downslope sliding of overlying rigid material. The results were aureoles with a maximum diameter up to about 1,600 km which surround the largest volcanoes (Olympus Mons, Elysium lions). Large-scale downslope sliding on the flanks of very large updomings led to the development of mega-aureoles with a diameter up to about 6,000 km. In areas of low relief the melting of underlying permafrost led to the origin of much smaller arcuately bordered depressions with maximum diameters up to about 300 km, the chaotic terrains. Most depressions of this type are related to the Chryse Planitia by large outflow channels. All these features seem to have no counterparts on Earth.

ELECTRICAL THAWING OF FROZEN SOILS | I

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Electrical thawing of frozen soil is applied mainly in earthwork, highway, pipeline and foundation engineering, and for stripping of overburden in quarries and at construction sites. The electrical method of thawing is effective enough for loosening up of small volumes of soil to facilitate excavation of such soils. Electrical thawing *is* a convenient and expedient method for its application to small, dispersed structures, especially in built-up areas during cold periods of the year. The temperature T of the soil to be thawed at a radial distance x from the heat source (electrode) on any horizontal plane is calculated by means of the Gauss' probability integral. The main advantages and disadvantages of electrical thawing of frozen soils are pointed out. Methods of electrical thawing; electrodes; electrical resistance of frozen soils; thermal calculations; and advantages and disadvantages of electrical thawing are discussed.

TEMPORARY AIRFIELDS IN NORTHERN ALASKA | I

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Special engineering studies were conducted from 1977 to 1982 in the National Petroleum Reserve, Alaska (NPRA), in support of the U.S. Geological Survey's petroleum exploration program. These studies in-elude roads, airfields, drill pads, and foundations. Shallow exploratory wells, which could be drilled in 2-4 months during the winter, employed airstrips on nearby frozen lakes or ice runways constructed directly on the frozen tundra. Conversely, deep wells that took more than a year to drill, required uninterrupted access by aircraft and used all-season airstrips constructed from gravel, rock, or dredged material. When quantities of gravel were limited or the source was remote, insulated runways were constructed. The construction of temporary airfields on frozen lakes and tundra and the construction and performance of gravel-surfaced airfields , with and without insulation, are discussed in this paper. Data on the thermal regime beneath insulated runways show insulation can preserve the frozen conditions almost indefinitely, thus avoiding the necessity for thick (1.5 to 2.5 m) gravel sections.

MATHEMATICAL MODEL OF TEMPERATURE-MOISTURE FIELDS IN FREEZING-THAWING SOIL	I

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Based on mathematical and physical analyses of dynamic and continuity conditions of energy and mass transmission and the phase transition between water and ice, the author establishes a simultaneous partial differential mathematical model applied to the temperature-moisture fields in freezing-thawing soil, and gives its definite conditions, including initial and boundary conditions. The time-varying coefficients of heat and moisture transmission are considered to be initial quasisteady values, and the time-varying correction factors of equivalent conductivity are introduced. To realize the numerical solution of the mathetmatical model, a time-space discretization expression is presented, taking the central difference for the space coordinate and the backward difference for the time coordinate, and its definite conditions. The solution of this model provides the time-space integrated state of ice, moisture, and heat in the physical field in soil during freezing and thawing, and the amount of frost heaving may be calculated. The stress state of freezing and thawing soil may be analyzed with definite parameters, such as the ice parameters.

FIELD EVIDENCE OF GROUNDWATER RECHARGE IN INTERIOR ALASKA	H-2

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Increased utilization of groundwater resources in discontinuous permafrost regions requires that we develop a better understanding of the system and its processes. This paper discusses the mechanics of one of the processes, groundwater recharge. Two distinctly different soil conditions exist; generally permafrost inhibits drainage and these areas are poorly drained, whereas nonpermafrost areas are better drained for the *same* soil type. Field studies near Fairbanks, Alaska, show that the infiltration and hydraulic conductivity properties for frozen and unfrozen soils vary substantially. Freezing of a soil reduces the infiltration rate becuse of the existence of ice in soil pores. Further, frozen soils with high ice contents have lower infiltration properties than frozen soils with low ice contents. Frozen but relatively dry soils behave in a manner similar to unfrozen soils. Therefore, substantial infiltration can occur in seasonally frozen soils

from snowmelt. Our field studies have shown that most of the groundwater recharge occurs during the snowmelt period in nonpermafrost areas. This is partly because of the soil condition and partly because of the large quantity of water available. Recharge during the summer is limited by the pattern of summer precipitation coupled with the ongoing process of evapotranspiration.

LAWS GOVERNING THE COMPACTION OF THAWING SOILS TAKING DYNAMIC PROCESSES INTO EFFECT	I

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Comprehensive compression investigations of the deformation properties of thawing sandy soils were carried out under static (up to 0.4 MPa) and dynamic (up to 4000 mm/s^2) loading. The experiments were made with the artificially prepared samples of frozen sand whose porosity ratio varied between 0.544 and 1.046. The samples were 113 mm in diameter and 45 mm high. Maximum compaction of the thawing soil occurred in the early stages of vibration with vibration accelerating from 0 to 1000 mm/s^2 and from 1000 to 2000 mm/s^2. The impact of the static load is significant. Extremely intense compaction occurs under the static loads of up to 0.05 MPa. There is a linear relationship between the static load and the critical vibration acceleration. The amount of settling of thawing sandy soils under dynamic loads is greatly affected by the grain-size composition and other soil conditions (e.g. compactness, moisture content). It is suggested that settlement of thawing soils under dynamic loading may be estimated on the basis of the soil compaction coefficient when subjected to vibration, the thickness of the soil layer involved and the values of the vibration acceleration both actual and critical. Taking into account both static and dynamic loading the amount of settlement in a thawing soil layer was calculated to be the sum of the settlements due to thawing and compaction under static loading, and of compaction settlement due to vibratory action. Settlement of foundations may be determined by summation of settlements in individual soil layers down to foundation depth within each of which the values of dynamic actions and the compressibility characteristics may be considered to be constant.

PERIGLACIAL FEATURES AND PALEOENVIRONMENT IN THE FLAGSTAFF REGION, NORTHERN ARIZONA | I

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Sand-filled wedges, averaging 15 cm wide at the top, 50 to 80 cm deep and spaced about 1.4 m apart were recently discovered at 2263 m (6900 ft) in Flagstaff, Arizona (35°N latitude). The wedges occur in a 1 m thick, strongly developed Typic Argiboroll soil which is developed in alluvium of the Rio de Flag River and which is buried by two Mollisol soils, also developed in alluvium. The wedges are considered probably sand wedges, although they could possibly represent seasonal cracking and frost heaving. The sand wedge interpretation implies that mean annual temperatures in this region were at least 12.6°C colder than today's (7.6°C) and that treeline may have been depressed by some 1000 or even 1500 m from today's position at about 3773 m to near Flagstaff. Pollen found in alluvial and lacustrine deposits below the wedge soil supports this reconstruction and suggests the region was once an open parkland near or slightly above treeline (Hevly, pers. comm.). Pollen includes mostly grasses, sedges, Artemisia, and cheno-ams; arboreal species include Douglas fir, Engleman spruce, white pine and bristlecone pine, the latter of which occurs near treeline today. A former periglacial environment in this region is also suggested by patterned ground on the rim of Walnut Canyon at 2257 m (6880 ft), inactive rock glaciers and blockfields at 2600 m (7925 ft) on Kendrick Peak and "Illinoian" till at 2756 m (8400 ft) on the San Francisco Peaks.

APPLICATION OF ELECTROMAGNETIC INDUCTION MEASUREMENTS TO PERMAFROST TERRIAN | I

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A large number of electromagnetic induction surveys have been conducted throughout Alaska over a wide variety of terrain types usually containing permafrost. These shallow induction surveys include studies defining the thaw bulb around hot springs, mapping ground ice conductivity anomalies on proposed highway routes, airstrips and building sites, delineating gravel deposits for use in construction, locating formerly habitable cavities in rock closed by silt at an archaeological site and determining seasonal effects on near-surface conductivity. The noncontacting electromagnetic induction method has proven to be extremely useful in reconnaissance surveys for providing rapid mapping of near-subsurface conductivity. Thus, it can be used in a cost-effective way to define the location of any material which has a reasonably large conductivity contrast from that of surrounding materiale.; such knowledge is especially useful in the construction and mining industries. Some of the surveys will be discussed in terns of subsurface geology, soil temperatures and other factors. In particular, the induction measurements at an air strip site in Marshall, Alaska are compared with extensive ground truth. This comparison shows the practical limits in the induction measurements. A detailed study is also made of seasonal effects in the induction measurements over an artificial ice mass showing permafrost temperatures must always be considered in interpreting these data.

CONTINUOUS GEOPHYSICAL INVESTIGATION FOR MAPPING PERMAFROST DISTRIBUTION, MACKENZIE VALLEY, N.W.T., CANADA	G-2

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A continuous inductive conductivity survey using a 10 m station interval was carried out over a distance of 868 km along the Interprovincial Pipe Line route in the Mackenzie River Valley, N.W.T. The work reported herein was done as part of a contract for Interprovincial Pipe Line (NW) Ltd. The study provides a useful case history for delineating frozen ground along a route that traverses a zone of scattered discontinuous permafrost and a zone of widespread discontinuous permafrost. Terrain conductivity meters were used to measure apparent conductivities along the entire proposed pipeline route. Air photo interpretation was used to map the terrain type distribution along the pipeline route. This information was correlated with vegetation, topographic, and geophysical data to delineate the boundaries of frozen ground. This interpretation was checked by boreholes drilled at an average spacing of 1 borehole every 4 km. The interpreted results provide information useful for the design of the pipeline and substantially reduced the number of boreholes that would normally be required. Statistical analyses were obtained between the occurrence of frozen ground and different terrain types. The results of the analyses indicate that soil texture is a major controlling factor in the occurrence of frozen ground.

THE REDISTRIBUTION OF SOLUTES IN FREEZING SOIL: EXCLUSION OF SOLUTES

M-3

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The redistribution of "non-reactive" solutes during ground freezing has been studied. The combination of field studies, laboratory experiments, and theoretical analyses lead to the conclusion that exclusion of a solute by an advancing freezing front may not be a particularly significant mechanism for solute redistribution. However substantial redistribution due to convective transport during the process of ice lens formation does occur.

LATE GLACIAL PALEOTEMPERATURES AND PALEOPRECIPITATION AS DERIVED FROM PERMAFROST: GLACIER RELATIONSHIPS IN THE TYROLEAN ALPS, AUSTRIA

I

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Numerous fossil rock glaciers in the Alps, situated 450-550 m below the presently active rock glaciers, can be correlated with the Egesen Stadial cold phase (11,000 to 10,000 BP). Fossil rock glaciers of Daun and Senders age (probably older than 13,000 BP) are situated 650 m below the active rock glaciers. From the lowering of the Egesen rock glaciers, a lowering of the mean annual air temperature on the order of -3.5°C against modern values is inferred. The lowering of the summer temperature, as inferred from the lowering of timberline, was on the order of -2.5°C during this period. For the Daun and Senders Stadials, a lowering of the MAAT on the order of -4.5°C is estimated. With the help of a permafrost-glacier-precipitation relationship, paleoprecipitation is estimated. During the Egesen Stadial, precipitation was reduced by 30% in the sheltered valleys of the Tyrolean Alps, whereas precipitation was about equal to present-day values along the northern slope. During the Daun and Senders Stadials, precipitation was reduced by 40% and 25% respectively in some valleys of the northern slope.

SOME ABIOTIC CONSEQUENCES OF THE CANOL CRUDE OIL PIPELINE PROJECT, 35 YEARS AFTER ABANDONMENT

E-1

L

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The Northwest Territories portion of the CANOL No. 1 crude oil pipeline has been abandoned since 1945. A number of terrain disturbances were initiated by the construction and operation of this pipeline that are comparable to those associated with contemporary developments in northern environments. Abiotic alterations include the removal, compaction, or burial of the often peaty soil surface layers. In all cases there as less organic matter at the surface than in undisturbed areas. Disturbance subsurface temperatures were warmer than controls, and it was the amelioration of this ecologically limiting factor that led to the rapid rate of organic matter accumulation (e.g. up to *98%* of control values). Subsurface moisture was less for most disturbance types except where depressions resulted from compaction or thermal subsidence in organic cryosols. Biological and geomorphological processes continue to respond to the initial surface disruptions and have as yet not stabilized, although the degree of "recovery" varies with the type of disturbance and the terrain in which it occurs.

MECHANICAL STABILIZATION AND FROST SUSCEPTIBILITY

I

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Stabilization has been suggested as a means of controlling frost action in soils. Mechanical stabilization involves blending two or more soils to produce the desired engineering properties and its relative simplicity makes it particularly suitable for road construction. In this investigation, the basic soil matrix was classified as highly frost susceptible when subjected to the TRRL frost heave test. Three types of coarse particle - slag, basalt, limestone - were used as the stabilizing agent, each being subdivided into two particle groups - 20 to 3 mm and 40 to 20 mm. The introduction to the matrix of up to 50 percent of the selected coarse aggregates produced various non-frost susceptible mixtures. The influence of the coarse aggregates was very dependent on aggregate type, with aggregate size being less influential. The data have been examined to assess the role of the individual characteristics of these coarser particles in the freezing process. This investigation clearly demonstrated the role of mechanical stabilization and was supported by the results of additional

freezing tests on natural soil. Heaving pressures are reported and are examined in relation to frost heave, aggregate content, aggregate type and particle size. The addition of coarse aggregate to the matrix is shown to reduce the measured heaving pressures.

SITE INVESTIGATION AND FOUNDATION DESIGN ASPECTS OF CABLE CAR CONSTRUCTION IN ALPINE PERMAFROST AT THE "CHLI MATTERHORN", WALLIS, SWISS ALPS | C-3(2)

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The construction of the uppermost section of the cable car leading from Zermatt (1,600 m a.s.l.) to the "Chli Matterhorn" ("little Matterhorn", 3,884 m a.s.l.), Wallis, Switzerland, posed several geotechnical engineering problems related to the presence of alpine permafrost. One important pylon had to be designed to withstand the creep pressure from a perennially frozen historical moraine, rich in ice. The site was investigated by geoelectrical D.C. resistivity soundings, core drillings, and geodetic measurements of creep displacements. Pits excavated for the foundation of the pylon were filled with pure ice. This ice has first to be squeezed out by creep of the frozen moraine before the full creep pressure can be exerted onto the pylon. In the rocks of the summit stations (with a mean temperature of about -12°C), the anchorage of heavy cables had to be effected in a purely mechanical way, in tunnels which were specially excavated for this purpose. Attention was given to the thermal insulation of buildings in order to avoid any melting of ice in cracks and joints. Deformation of the rock mass is being measured periodically and has remained small.

ROAD CONSTRUCTION IN PALSA FIELDS	I

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Palsa is an important feature of the discontinuous permafrost regions of Northwestern Quebec. Because of the hydro-electric complexes along the La Grande and Great Whale Rivers, the road network will be expanded with the addition of two thousand kilometers of road, many sections of which will cross palsa fields. In this paper, problems related to the design, construction and maintenance of roads in palsa fields are identified and described. The observations are mainly based on the performance of a test fill built on a large palsa 3 years ago and that of a road, paved in 1976, which cut through several palsa fields. The following topics are discussed in the paper: occurrence and distribution of palsa fields in Northwestern Quebec, description of a palsa field, datation of palsa's ice, formation of a palsa, detection of palsa, description of physical characteristics of a typical palsa, temperature regime in the palsa, performance of an instrumented test fill 3 years after construction, performance and maintenance history of a 6 year old paved road which crossed several palsa fields, predicted versus observed rate of settlement of an embankment. Based on the results of all these investigations, recommendations are given on the design and maintenance of roads that are required to cross palsa fields.

SELECTION OF PRINCIPLES FOR THE USE OF PERMAFROST MATERIALS AS A FOUNDATION FOR BUILDINGS AND STRUCTURES	c-3(2)

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In designing buildings and structures in the North two principles are applied in using permafrost materials as a foundation (the permafrost materials are used either in a frozen state or in a thawed state). The choice of one of these construction principles represents a sophisticated technical and economical problem. It is made on the basis of optimization of the reliability of the foundation in terms of cost* Calculations of the reliability of the foundation and the costs involved were made by computer using an algorithm developed by the author and construction of a design nomogram that interrelates foundation reliability, costs involved , and the controlling parameters of

the foundation. Then the nomogram was used to select one of the principles for using permafrost materials, the foundation depth and the depth of preliminary thawing or freezing of foundation materials.

ACOUSTIC VELOCITIES IN STRUCTURE I AND II HYDRATES BY BRILLOUIN SPECTROSCOPY	I

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Brillouin spectroscopy involves the scattering of light from (hypersonic) acoustic waves which are thermally induced and arise spontaneously within a sample. By measuring, with Fabry-Perot interferometry and photon counting methods, the frequency shift between the incident and scattered laser light, the velocity of sound can be accurately evaluated. This technique has, for the first time, been used to determine the acoustic velocities in clathrate hydrates. The longitudinal velocity (at -10°C) of, structure I, methane and xenon hydrates and, structure II, ProPane hydrate was determined. The samples were artificially grown, polycrystalline, and in many cases somewhat opaque. In addition, both the longitudinal and transverse velocity (at 0°C), of, structure 11, tetrahydrofuran hydrate was determined from high quality transparent single crystal samples. Calculated values of density and index of refraction, for about 98% cage occupancies, were used and the acoustic velocities are presented as a ratio with respect to the velocity in ice at the above quoted experimental temperatures - structure I: methane hydrate 0.88, xenon hydrate 0.76 and structure 11: propane hydrate 0.97, THF hydrate 0.96. Particularly noteworthy is the similarity in velocities of the structure II hydrates and the excellent agreement with Whalley's theoretical calculation of 0.95.

HIGH MOUNTAIN PEWROST IN SCANDINAVIA	P-3

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In the vicinity of the highest elevations of northern Europe the Kebnekaise Massif in northern Sweden (peak of Kebnekaise is 2,100 m a.s.l.) and the Jotunheimen area in southern Norway (Galdhöpiggen and Glittertind reach about 2,470 m a.s.l.), extensive permafrost occurrences could be proved. Two test areas, the Tarfala Valley

(67°55'N, 18°35'E) and the Leirvassbu/Juvasshytta area (61°40'N, 8°20'E), have been investigated in detail by means of ground temperature measurements, hammer seismic soundings, dc-geoelectric soundings, and studies of snow depth and snow temperature (BTS values). In both areas a permafrost thickness of more than 100 m could be proved above 1,500 and 2,200 m, respectively. A continuous alpine permafrost zone seems to exist here. Additional information concerning the Sognefjell and Rondane/Dovre area and the Lyngen Alps is given, and a model of alpine permafrost zonation for the central parts of the Scandinavian high mountains is derived from these findings. Cross sections through the high mountains of Scandinavia show that large areas underlain by widespread and patchy discontinuous permafrost must exist and help explain the rich periglacial morphology well known from Scandinavia.

FOUNDATION STABILIZATION OF CENTRAL GAS INJECTION FACILITIES, PRUDHOE BAY, ALASKA | I

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The importance of the Central Gas Injection Facilities at Prudhoe Bay, Alaska, prompted a detailed study of its adfreeze pile foundation when differential settlements were noticed in some piles. As a result, an extensive data gathering program was initiated to monitor pile movement, subsoil temperatures, and microclimate temperatures beneath the facility. The data gathered indicated that pile settlement was occurring and that settlement was not related only to the magnitude of applied load. Studies indicated that settlement was more related to soil temperature and the creep characteristics of soil near the pile. A theoretical analysis successfully predicted observed settlement rates on those piles showing the most settlement. The theoretical model assumed the piles were embedded in ice or ice-rich soils. Remedial measures were undertaken to control and limit the pile movement. The ground surface beneath the entire facility was insulated, many piles were converted to thermosyphons, exposed pile surfaces were painted white to increase their reflectivity, and an impervious membrane was installed over the insulation to control moisture and contaminant infiltration. These remedial measures appear to have controlled pile movement to an acceptable level and to within the accuracy of survey measurements.

ANALYSES OF CORES TAKEN FROM THE UPPERMOST LAYER IN TUNDRA AREAS	I

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Expeditions were conducted in the summers of 1974, 1977, 1980 and in the winter of 1981 in tundra areas at Barrow, Alaska, as well as Tuktoyaktuk, Mackenzie Delta, Canada. They had the main purpose of studying the relation of soil water behavior in the uppermost layer to the physical and biological environment in the tundra area. This paper reports the results of core samplings as part of their studies. Core samples of 5 cm in diameter were collected from the surface to the depth of 100-150 cm in the fields. Analyses were made of their layer structures, soil types, soil colors, densities, permeability, acidity and other physical properties. *When ice* cores were obtained, analyses were made of their crystal structures and isotopic oxygen concentrations. From these results the growth mechanism of polygons and pingos are discussed.

THE PROCESS OF NALED (ICING) FORMATION IN THE TROUGHS OF THE PACIFIC MOUNTAIN BELT	H-2

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The formation and existence of belts of icings are predetermined by the geology and evolutionary history of the regions during the Pleistocene and Holocene. These belts *are* related geomorphologically to the activities of former and contemporary glaciers. The action of the latter has led to the formation of moraine-and-riegel complexes, series of which have resulted in the icing belts. Icing formation occurs within the moraine-and-riegel complexes. A definite interrelationship exists between the icings and sub-icing taliks. The dimensions of the moraine-and-riegel complexes of the icing complexes regularly decrease with altitude. There may be several separate taliks, or a single extensive one, but they are always smaller in area than the area occupied annually by icings. The number of icings corresponds to the number of talik basins, which in turn coincides with that of the erosional valleys draining the sides of the troughs. Freezing of the taliks and icing formation *always* begin from the upper part of the area affected by the icing and the freezing barrier migrates from higher to lower altitudes.

THE EFFECTS OF GRAVEL ROADS ON ALASKAN ARCTIC COASTAL PLAIN TUNDRA	E-1

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Gravel roads on the Alaskan Arctic Coastal Plain may induce considerable habitat alteration through snowbanks, flooding, and dust. An integrated sampling approach is taken to delineate the magnitude and extent of these impacts on the tundra communities along the West Road at Prudhoe Bay, Alaska. After 1 year of monitoring, minor vegetation changes are noted. Snowbanks within 10 m of the road are 5-10 times deeper than the natural snowpack. Unlike roads with heavy winter traffic where dust on the snow surface decreases albedo which hastens snowmelt, the West Road receives no winter traffic and snowbanks persist for many weeks after the natural snowpack melts off. These snowbanks block culverts which causes extensive early summer flooding which is the predominant impact of the road, inducing greater depth of thaw and greening of the vegetation. The level of dust fallout along the road is relatively low, only about one-third of that measured along other roads in the area. A matarix of predicted impacts is presented and certain mitigative measures are suggested for gravel road construction and maintenance.

RECLAMATION OF FIRE CONTROL LINES ON PERMAFROST SITES IN INTERIOR ALASKA	I

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Forest fires are a dominant force in the taiga of Alaska. Fires on permafrost sites rarely cause major erosion problems, but methods used to control the fires can cause more visible changes in the landscape. Firelines built with tractors were located where line could be constructed most rapidly. Slope, aspect, and soil condition on the routes were considered primarily in relation to fire suppression rather than permafrost, potential erosion, or reclamation problems and solutions, some firelines built in ice-rich soils during the 1960's rapidly eroded into 2 m deep ditches. Ten years of observations on methods used to locate, construct, and rehabilitate firelines to prevent serious erosion problems suggest that fireline erosion in Interior Alaska

can be largely prevented in two ways: 1) By providing proper water control, such as water bars and diversion cuts. 2) By replacing the vegetation or organic mat and associated developed soils that were removed during construction, Replacing the organic layer and the developed soil appears very important to revegetation. The material is a source of roots, seeds, and rhizomes. The organic material also serves to insulate the ground, acts as a mulch to prevent sheet and rill erosion, holds moisture, and provides a variety of microclimates.

ALPINE PLANT COMMUNITY COMPLEX ON PERMAFROST AREAS OF THE DAISETSU MOUNTAINS, CENTRAL HOKKAIDO, JAPAN	E-3

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On the summit area in the Daisetsu volcanic mountains, the existence of permafrost is recognized. In this area an alpine plant community complex is distributed widely. It is composed of alpine windblown herb-heath, an alpine stony desert plant community, and two kinds of Salix (Salix pauciflora and Salix yezoalpina), which are thought to grow in a humid habitat. To clarify the cause of this complex, the depth of the active layer in mid-July, vertical changes of soil temperature, and the depth of the water table were examined. It became clear that the depth of the water table was the only factor controlling the distribution of the two species of Salix, though there were no relations between the distribution of windblown vegetation and these three conditions. Salix is limited to the humid places of the shallow water table, less than 35 cm in mid-July. They do not emerge in the dry places of the low water table. Owing to the rise of the water table caused by the permafrost, two species of Salix are thought to have mixed in windblown vegetation, which is ordinarily a dry type plant community. And as a result, the alpine plant community complex is formed.

COVER SANDS IN SOUTHERN JUTLAND (DENMARK)	P-2

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Investigations in southern Jutland (Denmark) have revealed the presence of Older and Younger Cover Sands. By means of pollen analysis and stratigraphic comparisons with neighboring countries, it is suggested that the Upper Pleniglacial is represented by the Older Cover Sand I and II, with a phase of fluvial activity, deflation, and frost action in between. There is a Late-Glacial succession of Younger Cover Sand I, peat of Allerød age, and Younger Cover Sand 11 on top of the Older Cover Sand 11. Holocene peat is found on top in some areas. Within the area glaciated during the Weichselian, diamicton is locally overlain by cover sand while west of the glaciated area a period of cold climate is reflected within the cover sand sequence. It is suggested that the conditions for the accumulation of cover sands are: a flat or very gently sloping relief in the area of deposition, (short?) vegetation to catch and retain the sand and silt, winds, and a sandy-silty source area without protective vegetation cover.

RECOVERY OF PLANT COMMUNITIES AND SUMMER THAW AT THE 1949 FISH CREEK 'TEST WELL 1, ARCTIC ALASKA	E-1

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The Fish Creek Test Well 1 site on the Arctic Coastal Plain (70°18'36"N, 151°52'40"W) has been abandoned since its construction in 1949. The plant communities which developed on the disturbed site are all successional. The degree of community recovery has differed with the habitat/vegetation type and corresponded to the degree of recovery of the habitat. The average depth of thaw *was* greater in recovering than in undisturbed habitats, particularly in mesic uplands. Marshes have recovered much faster than mesic uplands, which are more resistant to disturbance, are less resilient, and show less fluctuation and narrower ecological range on some environmental gradients such as depth of thaw. The time of recovery of mesic upland ecosystems at the Fish Creek site is estimated to be 600-800 years and that of marshes, 100-200 years. In more general features the resulting communities will probably resemble the surrounding undisturbed complex communities.

A THEORY OF DESICCATION OF UNCONSOLIDATED ROCKS IN AREAS WITH NEGATIVE TEMPERATURES

M-3

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The article presents the results of theoretical and experimental investigations of the process of desiccation in unconsolidated rocks in areas with negative temperatures. On the basis of a thermodynamic assessment of the phase equilibrium of water in the rocks it was demonstrated that the desiccation process occurs through sublimation and resorption of ice as well as through the combined effects of these processes, and occurs in two forms: voluminal and surficial. The instability of the surficial form is attributed to the presence of ultrapores. A capillary model of the process is proposed, based on an arbitrary subdivision of moisture present in the rock into three categories, which provide a qualitative description of the kinetics of desiccation rocks of different composition and structure and under different ambient conditions. This scheme forms the basis of a system of equations for a three-zone model describing desiccation in a moisture-filled rock mass. Results of a comparison between solutions of a simplified system of equations for a quasi-isothermal case with the experimental data are presented; they indicate a satisfactory agreement between t'ne two. Peculiarities of applying this solution in cases where the process is occurring in non-saturated rocks are discussed.

GEOCRYOLOGICAL MONITORING OF PIPELINES

C-1

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Long-term geocryological-geological investigations along the route of an arctic pipeline revealed environmental disturbance during both construction and operation and also corresponding changes in the permafrost condition. The impact of cryogenic processes on pipeline operation was-studied; causes of breakdowns were revealed; and possible ways of improving operation were pinpointed. The conclusion was reached that geocryological monitoring must be included in the design, construction and operation of pipelines in permafrost zones, as well as permafrost surveys and forecasts. The term monitoring implies systematic field observations of the dynamics of permafrost conditions along the route of the pipeline as the natural environment evolves under the technogenic influences imposed on it. The scientific and procedural aspects of geocryological monitoring are described. Its

aims and practical applications at the various stages of exploration, construction and operation are defined. It is noted that the monitoring data are necessary for revealing trends in the formation and development of permafrost conditions along the pipeline, and for developing, checking and streamlining forecasts of changes and means of modifying permafrost conditions to ensure optimum conditions for pipeline operation consistent with environmental protection.

THE CRYOGENIC EVOLUTION OF MINERAL MATTER (AN EXPERIMENTAL MODEL)	P-7

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An analysis of existing hypotheses as to the interaction between water and minerals in connection with their crystal and chemical properties allows one to present a theoretical model for the existence of minerals in the zone of cryogenic weathering. According to this model, the destruction threshold depends on the peculiarities of the surface energy of the minerals, which is a function of the crystallochemical properties of the surface, the characteristics of the ground solution, and the degree of dispersion. Tine threshold of cryogenic destruction was established experimentally for different groups of minerals and for different temperature regimes. It was established that the degree of mineral disintegration was two to three times higher in the case of temperature oscillations across the 0°C threshold than in the case of oscillations entirely beneath that threshold.

FROST SUSCEPTIBILITY OF SOILS IN TERMS OF THEIR SEGREGATION POTENTIAL	M-5

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Recent studies have shown that the segregation potential, which is the ratio of water intake velocity to temperature gradient near the frost front, provides a basis for coupling mass flow with heat flow in a freezing soil. Since the segregation potential depends upon the composition of the soil system and the externally applied load, it appears to be an effective parameter for classifying frost susceptible soils. Moreover, it can be obtained readily for various applied

pressures from a one-dimensional freezing test and can be used directly to estimate frost heave in the field versus time, provided that the solution to the corresponding thermal problem can be obtained. Data is presented and practical cases are described that illustrate the use of the segregation potential for determining frost susceptibiltiy with respect to various project requirements.

HYDROTHERMAL PROPERTIES OF PERMAFROST SOLONCHAKS IN CENTRAL MONGOLIAN ARID-STEPPE ZONE	I

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A three-layer, unstable system exists within the permafrost solonchak profiles of the dry-steppe zone in the southern part of the central Gobi Peneplain. It is subject to deformation due to hydrostatic pressure and low temperature. The action of the latter factors results in the formation of characteristic continental mud boils on the lower parts of the slopes. These are perennial features and lack frost segregation.

THERMAL INTERACTION BETWEEN PIPELINES AND THE Environment	M-1

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Aspects of thermal interactions between large-diameter underground pipelines and the environment are considered. Consideration of this topic is necessary for achieving design solutions under northern conditions. Criteria of choice are formulated. A classification of various methods for pipeline laying is developed for northern regions and appropriate operating conditions are discussed, Numerical simulations have been carried out with the aim of determining the permissible negative temperature of the external surfaces of underground pipelines from an ecological point of view. The influence of water migration on the rate of freezing around the pipe is evaluated. Soil expansion during the transport of chilled gas has also been evaluated. It has been shown that the actual thermodynamic properties of the gas make a significant contribution to the level of gas cooling at compressor stations. A method for determining the optimal thickness of insulation along the length of a gas pipeline is suggested with due consideration of environmental protection. Generalized relationships for heat transfer in underground gas pipelines are given, in the case of both

constant and variable temperature (where apparatus for air cooling is used). Results obtained were applied to the design of gas pipelines in the Soviet North.

ERODIBILITY OF UNCONSOLIDATED MATERIALS IN PERMAFROST	I

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Mechanisms and laws governing the erosion of unconsolidated rocks in permafrost are examined. Four types of erosion, distinguished on the basis of the interaction of water flow with the rock, are identified. The most typical for the erosion of frozen rocks are the thermoerosional and extreme-thermoerosional types. It was established that the intensity of erosion increases with increasing stream discharge (in the case of the erosional and thermoerosional types) and with increasing water temperature (in the case of the extreme-thermoerosional type). It was shown that the composition, cryogenic structure, ice content and density of the rocks are basic factors indicating their erodibility. Indices of erodibility of permafrost materials which reflect the mechanical, thermal and physical aspects of erosion as well as methods of determining them are proposed. A scheme is developed for subdividing permafrost materials on the basis of erodibility, which might be used for assessing and mapping permafrost and seasonally-frozen materials within the Yamal Peninsula. Much of the peninsula is composed of deposits susceptible to catastrophic and rapid erosion, with the percentage area of such deposits increasing from south to north.

PERMAFROST AND PERIGLACIAL INDICATORS ON THE TIBET PLATEAU FROM THE HIMALAYAN MOUNTAINS ON THE SOUTH TO THE QUILIAN SHANS ON THE NORTH	I

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Pingo and ice wedge polygons occur between 5100 - 5500 m in north Tibet and at 4650 m in the Quen Lun. They are 100 - 500 m above the lower limit of permafrost. The findings of these permafrost indicators at the periglacial level of subtropical mountains proves the global uniformity of the periglacial region. The lower limit of permafrost is at 5000 m at the southern border of Tibet; is at 4200 m in the Animachian and Quen Lun mountains; and at 3300 m in the northeast Quilian

Shari. The periglacial region extends 1500 - 1700 m below the permafrost level reaching 3300 - 3500 m at the Inner Himalayas. In northeast Tibet the lower limit of solifluction is only 700 - 100 m below the permafrost level. The lower limit of patterned ground is 200 - 400 m higher than these limits. At the southern border of Tibet a level of optimal formation of patterned ground occurs between 4900 - 5200 m, near the lower level of permafrost. The size of the patterned ground decreases until an upper limit of patterned ground is reached at 5600 - 6000 m. Here the ground remains frozen throughout the year and the sorting of materials stops. In northern Tibet, however, the level of optimal formation of patterned ground is combined with firn and ice cover; an upper limit is not reched. The higher rate of precipitation in north and northeast Tibet is the reason for this difference. With the formation of an upper limit of patterned ground, a qualitative indication for an "arid*" periglacial zone occurs. The area between lower limit and level of optimal formation of patterned ground is located in the zone of persistent unfrozen ground. Here the frost penetrating the ground causes sorting. Above the lower limit the depth of the frost change layer is the greatest. Here the zone of optimal formation of patterned ground is developed.

DILATOMETER TESTING IN THICK CYLINDERS OF FROZEN SAND	C-2(1)

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The borehole dilatometer method of in situ determination of creep properties of frozen soils, introduced initially by Ladanyi and Johnston (1973), has since been used with reasonable success in several field investigations in frozen soils and ice, the results of which have been reported in several previous papers. However, since the method has not yet been tested under controlled laboratory conditions, it was decided to carry out a series of dilatometer creep tests in confined thick cylinders of frozen sand, using the conventional field equipment. This paper presents and discusses the results of a series of stage-loaded medium- and long-term creep tests carried out in these cylinders with the Menard pressuremeter and gives the whole theoretical interpretation of such tests, which appear to be an interesting alternative method for determination of creep parameters of frozen soils under plane strain conditions.

THE EXTENS1ON OF PERMAFROST IN WESTERN EUROPE IN THE PERIOD BETWEEN 18,000 AND 10,000 YEARS B.P. (TARDIGLACIAL): INFORMATION FROM SOIL STUDIES

P-2

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Soils developed since the beginning, or during the Tardiglacial (±18,000 to 10,000 years B.P.), are compared with "Holocene"' soils. The area covers the loess and coversand belts of NW France, Middle Belgium, and The Netherlands. Eight major kinds of Tardiglacial soils are recognized. All of these except one have a consolidated horizon which is present regardless of the texture and drainage class. This horizon has a particular structure and porosity fabric, shows relict pseudo-gley properties, and is not observed in the Holocene soils. The formation of the consolidated horizon either by freeze-thaw cycles or by permafrost is discussed. It is concluded that only the permafrost hypothesis can explain the complete set of properties. Consequently, permafrost would have been at least once continuous during the Tardiglacial in the studied area.

NUIQSUT AIRPORT DREDGE PROJECT

C-4

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The unique Nuiqsut Airport Dredge Project is the first dredged fill placed over permafrost on the Alaska North Slope. The specially designed 45.7 cm diameter suction dredge capable of being air or truck transported, was used to unify the steps of mining, transporting and placement of the runway embankment fill material. This technique has the advantage of minimizing damage to the fragile tundra and ice-rich permafrost. The need for large on-shore borrow pits and long haul roads was eliminated. Approximately 152.911 cubic meters of sand and gravel was hydraulically placed along the 1554.0 meter long runway right-of-way. The predicted depth of thaw beneath the fill and the amount of thaw consolidation in the natural soils compared well with measured values. The direct placement of dredged fill material on permafrost with controlled and limited thawing of the subgrade has proved *to* be a rapid, ecologically sound, and cost-effective technique.

GROUND ICE IN PERENNIALLY FROZEN SEDIMENTS, NORTHERN ALASKA	P-1

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The distribution and volume of ice in perennially frozen sediments beneath three unglaciated sites in northern Alaska vary with the grain size and depositional origins of the sediment, thermal history (permafrost aggravation and degradation), and age of the terrain and deposits. Substantial lateral variation in near-surface ice volume exists between and within each site, but reasonably consistent trends in ice content with depth were measured beneath individual landforms. Primary deposits, those deposited and frozen without postdepositional thermal or sedimentologic modification, contain the highest volume of ice at each locality. Sediments that have undergone thawing or resedimentation typically contain much less excess ice. Thaw lake, slope, or fluvial processes modify ice contents and produce sedimentary sequences with a spatial distribution of ice determined by these depositional processes and the subsequent thermal history.

DEFORMATION OF FREEZING, THAWING AND FROZEN ROCKS	I

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The paper examines the deformation of earth materials during the processes of heat- and mass-exchange while undergoing freezing, thawing, and in the frozen state. Study of the deformation of the materials during the processes of freezing and thawing has shown that variously directed *and* nonuniform strains develop in unconsolidated materials. Shrinkage strains are directed downward due to migration of water toward the freezing front. Heaving strains are directed upwards due to the 9% increase in the volume of pore water on freezing and due to the accumulation of segregation ice at the expense of water which has migrated from the unfrozen zone. The accumulation of segregation in enhancing the upward deformation of the earth materials was also found in thawing soils where there was a frozen zone in a gradient temperature field. During a comprehensive study of the deformation of frozen

materials in an isothermal temperature field, the samples were tested for uniaxial compression with and without possible lateral expansion. Investigations revealed hi-axial relationships between the pattern of deformation, the final magnitude of deformation, the composition and structure of the materials and the magnitude of the deforming load and rate of deformation.

EROSION BY OVERLAND FLOW, CENTRAL BANKS ISLAND, WESTERN CANADIAN ARCTIC	H-1(2)

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Process studies carried out at runoff plots on Banks Island emphasize the importance of solute erosion by overland flow, rather than suspended sediment removal. Rates are low, despite the influence of permafrost in promoting surface runoff. Observations of feedback within the slopewash system suggest that these trends may not be universal. In tundra zones, vegetation is thought to be more protective than in the transitional zone of Banks Island, In polar semi-desert and desert zones, where vegetation cover in snowbed locations is limited, removal of sediment particles by overland flow may be more significant.

PERMAFROST STUDY AND RAILROAD CONSTRUCTION IN PERMAFROST AREAS OF CHINA	PRC

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Field investigation, laboratory experiments, and engineering practice during the past 30 years has given China a great deal of information on railroad construction in permafrost regions. The thermal and mechanical properties of soils both in frozen and thawed states were determined, several formulas for predicting the natural and artificial permafrost table were developed, four distribution maps of permafrost at different scales were compiled, and a principle for selecting railroad routes was presented. In the area of foundation design of railroads, bridges, and culverts, methods for constructing foundations in sectors of thick layer ground ice have been studied, along with measures to prevent freezing of blind drain outlets and avoid thaw damage to embankment foundations. Raft and wood-reinforced culvert foundations were successfully used in the permafrost regions in the Great Hinggan Mountains, reinforced concrete pile foundations were tested, and a method of rapid construction of foundation pits for small bridges and culverts was developed. In tunnel design and construction a sluiceway drainage sytem was used. A set of design principles and methods has been developed for buildings, pipelines, and pavement, In addition, two kinds of low-temperature construction materials, have been developed for reinforced concrete-poured pile foundations and culverts.

PERIGLACIAL SLOPEWASH AND SEDIHENTATION IN NORTHWESTERN GERMANY DURING THE WURM (WEICHSEL-) GLACIATION	I

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The older morainic landscape of the Northwest German Lowland has a very subdued relief. This was caused by Weichsel periglacial processes, partly of a solifluidal but mostly of an ablual kind. The latter encompasses all eroding sheetwash processes on slopes and accumulation of fine sandy material in basins. Abluation and solifluction were processes during cold periods in the foreland of central European glaciation; erosion and sedimentation occured mainly during the end of interstadial phases. The most impressive incision happened at the very

EFFECT OF SURFACE-APPLIED PRUDHOE BAY CRUDE OIL ON VEGETATION AND SOIL PROCESSES IN TUSSOCK TUNDRA	E-1

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Prudhoe Bay crude oil was applied as a 20 liter m^{-2} surface spray on Eriophorumus vaginatum tussock tundra at Eagle Summit, Alaska, in August 1979. Oil caused a significant reduction in mycorrhizal root numbers and root respiration rates in Betula nana, but not in Eriophorum vaginatum root tips which had grown through the 5- to 15-cm-deep oil-contaminated sil. Significant changes did occur in leaf

senescen patterns of B. nana and the tillering index of E. vaginatum. Soil cellulase and phosphatase enzyme activities both declined in the oiled soil horizons but were unaffected in horizons immediately below visibly contaminated organic matter.
end of the last interglacial.

IDENTIFICATION AND EVALUATION OF ACTIVE FAULTS IN GLACIAL AND PERIGLACIAL LANDSCAPES	I

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The polar landscape poses distinct challenges to geologists attempting to assess the seismic hazard for lifelines and critical facilities. Our recent work in east-central Alaska has deomonstrated the need for great care in interpreting geomorphic features in terms of seismic activity. Solifluction rapidly degrades fault scarps and frost action quickly obliterates many fault-related features sought in trenching studies. Coarse-grained glacial and glaciofluvial sediments do not promote the production or preservation of many features commonly associated with active faults. Dense tundra and boreal forest vegetation often compounds the problem. Our experience has demonstrated the critical value of false-color infrared and large-scale low-sun-angle aerial photography to seismic geology studies in the polar regions. There is no landscape more demanding of the use of low-sun-angle observations and photography than is the glacial and periglacial terrain of Alaska. These tools, in combination with a helicopter-based field program, are necessary to the conduct of a quality seismic hazard assessment in such areas. Finally, we strongly advocate the use of probabilistic assessment techniques to deal with the many uncertainties inherent in the identification and characterization of active faults in glacial and periglacial landscapes.

CALCULATION OF FROST-HEAVING FORCE IN SEASONALLY FROZEN SOIL	C-3(2)

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The mechanical properties of frozen soil differ considerably from those of unfrozen soil. The author proposes that the soil beneath foundations on seasonally frozen ground be considered as a double layer, composed of a layer of frozen soil and a layer of unfrozen soil. Based

on the linear elastic theory, the author proposes a method for calculating stress distribution at the freeze/thaw interface in soils under foundations. Analyzing the characteristics of stress distribution during the frost process in a double-layer subsoil, the author has presented a method for estimating the normal and horizontal frost-heaving forces in frost-susceptible subsoils. According to field test results, a nomograph for determining normal and horizontal frost-heaving forces in various frost-susceptible soils is also presented. To demonstrate the application of double-layer calculations to foundation design, several examples for examining foundation stability are given.

FROST SUSCEPTIBILITY OF SOILS	M-5

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The fabric of soil significantly influences all aspects of its behavior including frost susceptibility. While the arrangement of solids in a soil is very difficult to quantify, the size distribution of pores may be simply accomplished by techniques of mercury intrusion porosimetry. The resulting frequency distribution may be characterized in any convenient statistical manner, and related quantitatively to other variables. A conventional technique of relating frost susceptibility to grain size distribution has a serious intrinsic deficiency in that a soil has a <u>single</u> grain size distribution, but a multitude of pore size distributions. It is, of course, the pore size distribution which controls the movement of fluids under all gradients. This has been demonstrated experimentally by producing a wide variety of frost heaving rates for a single soil; in all cases, the heaving rates were related to the pore size distributions in the soil. Pore size distribution has also been related to suction and hydraulic conductivity values. It is an appropriate substitution for (1) direct determination of the water characteristics curve and (2) measurement of permeability, in fine grained soils, since it requires but a fraction of the time required for these tests. Examples of all correlations cited above are contained in the paper.

BASIC CHARACTERISTICS OF PERMAFROST IN NORTHEAST CHINA — P-2

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There are two kinds of permafrost in northeast China: high-latitude permafrost and alpine (high-altitude) permafrost. The high-latitude permafrost is distributed mainly in the Da-Xiao Hinggan Ling and occupies an area of about 38,000 km^2, while the alpine permafrost is only sporadic. From south to north in Northeast China, the mean annual air temperature drops from 0°-1°C down to -5° or -6°C, and the landscape changes from forest-steppe, through mixed coniferous and broad-leaf forest, to coniferous forest, and the permafrost varies correspondingly in continuity, temperature, and thickness. In the south, there is insular permafrost, 5-10 m thick, with a mean annual ground temperature of 0"C. In the north, the large-patch continuous permafrost has a mean annual ground temperature of 0" to -2.5°C (and in some places even lower than -4.2°C) and is 80-100 m thick. Between these two extremes there is a transitional permafrost zone with insular taliks. The southern limit of permafrost descended to the upper course of the Liao He River during the last glacial period. The existing permafrost is the sum of relic permafrost formed in the Late Pleistocene and younger permafrost formed in the last 3000 years.

PERMAFROST ON MARS: POLYGONALLY FRACTURED GROUND — R-2

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Newly discovered martian polygons of 50–300 m diameter have random orthogonal patterns and are similar in size and shape to terrestrial unsorted polygons in permafrost terrain. The martian polygons occur at 47°N, 346°W where conditions are favorable for ice-related fracturing processes; ice is in equilibrium with the atmosphere and could remain in the ground for extended periods. Desiccation of ground ice due to astronomically forced climate cycles or thermal contraction due to seasonal cycles could have fractured the ground. The desiccation hypothesis has uncertainties concerning the temperature regime and the exchange of water between the atmosphere and the ground. An origin by seasonal thermal contraction is compatible with the size and

shape of the polygons, with a seasonal cooling rate of -60°C, and with the availability of seasonal frost. Both sand wedges and ice wedges could have filled the polygonal fractures. Crispness of the fractures suggests that they are only slightly degraded and thus relatively young, but local ground collapse indicates that they are probably not forming actively today.

THAWING BENEATH INSULATED STRUCTURES ON PERMAFROST	M-2

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The problem of thawing beneath heated structures on permafrost (or cooled structures in nonpermafrost zones) must be addressed if safe engineering designs are to be conceived. In general there are no exact solutions to the problem of conduction heat transfer with phase change for practical geometries. The quasi-steady approximation is used to solve the phase change problem for insulated geometries including infinite strips, rectangular buildings, and circular storage tanks. Analytical solutions are presented and graphed for a range of parameters with practical importance.

LATE WISCONSINAN PATTERNED GROUND IN THE SAGINAW	I

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More than 930 km^2 of patterned ground have been delimited within the Saginaw Lowland of east-central Michigan. The patterns consist of high-centered , non-sorted nets which formed primarily on somewhat poorly drained loam or silt loam drift. The morphostratigraphic relationship of these micro-relief land forms to the Port Huron Moraine and preglacial Lakes Warren I and Elkton suggest that active pattern formation began sometime later than 13,000 years B.P., may be younger than 12,730 years B.P., and ceased by 12,400 years B.P. The nonsorted nets are attributed to thermal contraction - cracking and ice wedge development in discontinuous periglacial permafrost. Mean annual air temperatures in this part of Michigan were on the order of -1°C to -6°C during this interval. Favorable microclimatic conditions are postulated to account for these cold temperatures during the waning Port Huron Stadial.

RESULTS OF LOAD TESTS ON TEMPERATURE-CONTROLLED PILES IN PERMAFROST	C-3(2)

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Eight temperature-controlled pile load tests have been made at three sties representing typical Alaskan permafrost subsurface conditions. The loads were applied in increments, and accurate displacement histories were obtained for each increment. Direct results of these tests and evaluations based on primary creep and ultimate strength are presented in this paper. It is believed that these tests represent an extremely valuable data base to the profession to evaluate the load-carrying and settlement characteristics of slurried piles in permafrost.

EVIDENCE FOR SEASONAL VARIATION OF NEARSHORE SUBSEABOTTOM PERMAFROST TEMPERATURES IN THE CANADIAN BEAUFORT SEA	I

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Over the past few years, the Geological Survey of Canada has drilled five onshore-to-offshore lines of holes into the seabottom during the springtime. These lines were spaced along 200 km of coastline from Garry Island to Atkinson Point. Temperature cables were installed in each hole to depths up to 30 m below bottom and equilibrium temperature-depth profiles were obtained. The results indicate subzero bottom temperatures in water depths as shallow as 4 m. All lines indicate a warm (yet below O"C) bulb at depths of 6 to 10 m below bottom which is interpreted to be the effect of the previous summer Mackenzie River water outflow. This effect attenuates with increasing water depth and is absent beyond the 12 m isobath where sub-bottom temperatures of approximately -l°C are observed. It is suggested that the warm Mackenzie River water (>0°C) reaches the 12 m isobath in summer and is replaced by cold sea water during the winter

months. One one line, seabottom sediments sampled indicated the presence of interstitial ice which is probably seasonally formed.

LAND USE CONTROLS AND ENVIRONMENTAL PROTECTION ON PERMAFROST TERRAIN IN N.W.T., CANADA	I

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All of the Northwest Territories (N.W.T.) fall within the zones of continuous and discontinuous permafrost, including a wide range of terrain and ground thermal conditions. Greater than 95% of the land area, about 1.2 million square miles or 3.2 million square kilometers, is Federal Crown Land admininstered by the Northern Affairs Program of the Department of Indian Affairs and Northern Development. Land use activities are administered as set out in the "Territorial Land Use Regulations", through terms and conditions placed in land use permits. Knowledge of general and specific site conditions such as surficial geological and engineering properties of soils varies with location in N.W.T. but may be limited in many locations. In general permitters are encouraged to use the minimum amount of area practicable and to limit such activities as off-road vehicle use to months of the year when the ground is protected by snow cover. Where a particular mode of operation is not feasible, and or where uncertainty exists whether a particular operation, such as summer off-road vehicle use, might be conducted in an area in an environmentally acceptable manner, special experimental conditions for monitoring and for joint government-industry research are incorporated into the land use permit. Examples of some of these experimental programs will be illustrated. The experience gainedin the experiments are used to develop and illustrate guidelines for future operations.

PINGO GROWTH AND SUBPINGO WATER LENSES, WESTERN ARCTIC COAST, CANADA	P-4

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Field surveys of hydrostatic (closed) system pingos which are growing in the bottoms of drained lakes have been carried out along the western arctic coast, Canada, from 1969 to 1982. The water pressures beneath the pingo are derived from pore water expulsion in saturated sandy lake bottom sediments during permafrost aggravation. A subpingo water lens develops when the pore water pressure uplifts the pingo overburden and intrudes water beneath it. Three growth patterns have been identified for the pingos with subpingo water lenses. (1) Constant year-to-year growth suggesting a balance between water supply and freezing of the water lens. (2) Decreasing year-to-year growth suggesting a freeze-through of the subpingo water lens. (3) Erratic *year-to-year* growth with periods of increasing height, followed by pingo rupture, water loss, and pingo subsidence. The freezing point of the water in a subpingo water lens is depressed slightly below 0°C by a combination of hydrostatic pressure and the concentration of solutes rejected during freezing.

FROST CELL DESIGN AND OPERATION	I

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This paper presents the design and recommended operation of a frost heave cell for use in conducting laboratory frost heave experiments. Specific features of the design include split barrel construction for easy assembly, controlled top and bottom temperatures, well-insulated sides, simple thermistor installation for temperature measurement, and new heat exchanger details for top and bottom plates. Tests can be performed on undisturbed samples, remolded cohesive coil, or remolded cohesionless soil. Details of sapmle preparation are presented for each sample type. Test duration depends on soil type and amount of heave, and generally ranges from 1 to 3 days. Tests can be conducted at various overburden pressures. Test results are interpreted using the Konrad-Morgenstern segregation potential concept of frost heave.

PHYSICAL AND NUMERICAL MODELING OF UNIAXIAL FREEZING IN A SALINE GRAVEL

C-2(1)

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Laboratory model studies were conducted to study the freezing process and the distribution of salt during advancement of a freezing front through a seawater saturated column of granular soil. The freezing front in a saline soil may be described as a zone of partially frozen soil. The strength of the frozen soil in the freezing zone is visually waeaker than for soils above the freezing zone. The salt concentration and the unfrozen water content in the partially frozen zone decreases toward the colder temperature. It is shown that conventional analytical modeling of freezing front penetration will underpredict the rate of freezing when no account is made for the effects of salinity. The rate of advance to a given depth of freezing increased with increasing salinity. The paper presents a discussion based on the results of 17 laboratory freezing column tests in which the effects of salinity on the freezing front advance and the redistribution of solutes was observed. Comparisons between observed behavior an computer simulations of three tests are given to demonstrate difficulties associated with analytical modeling freezing front penetration in a saline soil.

A MECHANISTIC APPROACH TO PAVEMENT DESIGN IN COLD REGIONS

I

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A mechanistic approach to pavement design in continuous permafrost areas is examined. Typical material, environmental and loading conditions are evaluated for Barrow, Alaska. A presentation of typical pavement response parameters is made and used to evaluate several possible pavement structural sections.

MIGRATION OF ELEMENTS IN WATER IN TAIGA-PERMAFROST LANDSCAPES

H-l(2)

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The peculiarities of the migation of elements in water in the main taiga-permafrost landscape-types in Northeastern Yakutia are examined. Zonal and azonal classes of geochemical landscapes associated with permafrost and bioclimatic peculiarities are distinguished on the basis of the conditions of migration of elements in water. Differing intensities of the migration of elements in water as between permafrost and non-permafrost zones were demonstrated. Both surpluses and deficits of certain elements were identified and also paragenic associations of elements characteristic of specific geochemical landscapes.

METHODS FOR DETERMINING THE TIME-DEPENDENT FAILURE OF FROZEN SOILS

c-2(2)

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Various methods are available for determining the strength characteristics of soils; and, as numerous investigations have demonstrated, the values of the parameters being determined depend on the conditions and type of testing. The article discusses the problems of the impact of the test conditions and type of test on the value of the time-dependent failure characteristics of frozen soils. The tests were carried out to determine time-dependent failure and to compare the experimental data from uniaxial compression tests with constant loading, with those derived with a constant rate of deformation and a constant rate of loading and under conditions where the operation stress was relaxed. These investigations revealed the mechanisms whereby the soil strength decreased under various types of tests and demonstrated the possibility of determining extremely long-term values for the strength of frozen soils from the various tests.

OBSERVATIONS OF MARTIAN FRETTED TERRAIN | I

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Fretted terrain is one of several lowland landscapes found on Mars that suggest intense geomorphic activity. Fretted terrain was formed initially during a period of heavy cratering and possibly fluvial activity early in martian history. Subsequent modification processes have been active in the "recent" past, and may still be active today. Evidence of the process that formed the fretted terrain is generally lacking because of subsequent modification. The location of the terrain along the boundary between heavily cratered uplands and sparsely cratered lowlands that extends around the planet, and the orientation of portions of the terrain along structural trends associated with the boundary, suggest a tectonic origin in part. Subsidence through ground ice melting or sublimation may then have led to progressive deterioration of the relatively incompetent rock units. Modification of the surfaces has been widespread; most severely altered are valley floors and walls , and aprons surrounding mesas. Lineations on the surfaces of aprons resemble leveed channels, whereas those on valley floors, though superficially similar to medial moraines and other indicators of longitudinal flow, most likely reflect differential degradation by subsidence and eolian action. Measurements of the aprons show some similarities to certain terrestrial gravity-induced and gravity-driven mass flows.

REVEGETATION OF FOSSIL PATTERNED GROUND EXPOSED BY SEVERE FIRE ON THE NORTH YORK MOORS | E-2

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Severe fire in 1976 ignited large areas of blanket peat on the North York Moors. Direct combustion, conversion to ash, and subsequent erosion have exposed a dense system of patterned ground at Rosedale. Disoriented mineral material and exhumed sorted stone hummock-hollow terrain indicate periglacial activity dating to the Late Devensian or possibly immediate postglacial times. Geometric and chemical characteristics of the patterned ground are outlined. Revegetation by a succession of bryophyte species has been observed since 1976. Early colonization by Ceratodon purpureus and lichens (Lecidia spp.) has given way to a clear pattern adjusted to moisture conditions involving

Polytrichum piliferum (dry humock microsites) and *Polytrichum commmune* (moist hollow microsites). Factors influencing colonization on the fossil hummocks are examined and compared with patterns of mature vegetation in contemporary periglacial environments.

INVESTIGATION OF THE DEFORMATION OF CLAYEY SOILS RESULTING FROM FROST HEAVING AND THAWING IN FOUNDATIONS DUE TO LOADING | I

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The relationships between the deformation of clayey soils beneath loaded foundations and the number of freeze-thaw cycles, soil composition, pressure, depth of the foundation footing, and ground water levels with respect to the depth of freezing were demonstrated. When the pressure on the foundations increases, heaving begins at the maximum depth of freezing penetration beneath the foundation footing. Intensity of heaving decreases. An increase in the depth of the foundation within the freezing zone reduces the impact of heaving at the ground water level with respect to the depth of freezing. Loaded clayey foundation materials whose settlement had stabilized prior to freezing experienced additional settlement after further cyclical freeze-thaw in the materials. Additional compaction of the soils, as a result of repeated freeze-thaw in the loaded foundation materials, leads to reduction in the deformation.

PILE DRIVING AND LOAD TESTS IN PERMAFROST FOR THE KUPARUK PIPELINE SYSTEM | c-3(1)

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Drilled and slurried piles have been used at the North Slope of Alaska. These tests were conducted for the determination of a faster pile placement method in permafrost. Ultimately this refined, thermally-modified pile driving method was selected by ARCO Alaska, Inc., in 1980 in its construction of the aboveground Kuparuk Pipeline.

CYCLING OF N-15 THROUGH TUSSOCK TUNDRA ECOSYSTEMS

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The objective of this research was to evaluate the effect of plant species, time, and site on cycling of tracer levels of N-15 through tussock tundra ecosystems in Alaska. Sites were located at Eagle Summit, Cape Thompson (two sites), and at Old Man, Toolik, and Sagwon along the pipeline haul road. Generally, plant compartments were most heavily labeled the year of application; an exception was above-ground current vascular tissue which reached a maximum at 1 year. The N-15 recoveries (% of added) at the end of two months were : litter (19%) > messed (18%) > vascular plants (15%); the N-15 recoveries at the end of two years were: litter (9.5%) > mosses (6.8%) > vascular plants (3.6%). Fine roots were highly labeled after two months (9.8%), but lightly labeled after 2 years (0.25%). The different sites showed comparable labeling in the various ecosystem compartments. The few site differences were attributable to differences in biomass pool sizes.

GEOMORPHOLOGICAL MAPPING AND ENVIRONMENTAL PLANNING IN PERMAFROST REGIONS

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With the help of the geomorphological map of Oobloyah Bay, Ellesmere Island, N.W.T., Canada, the applicability of the legend, developed in a priority project of the German Research Foundation, in permafrost regions is demonstrated. In addition, possibilities for the practical applicability of geomorphological information like this are presented. For the user who is informed about the terminology used in geomorphological maps, different levels of information (e.g., slope angles, subsurface material, etc.) can be printed separately. For those not informed about the terminology, the geomorphological information can be prepared with ecological evaluation on the basis of a stability test, which allows direct use for nongeomorphological problems.

THE INFLUENCE OF SURCHARGE LOADS ON FROST SUSCEPTIBILITY	I

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When a frost susceptible soil is frozen and the heave is restrained, either partially or completely, heaving pressures will also be generated. The work reported in this paper describes a laboratory study of the interactions between heave, heaving pressure, and surcharge pressure. The tests were performed on a highly frost susceptible mixture of sand and ground chalk to which various amounts of coarse aggregate were also added to produce a range of granular mixtures. The frost heave and heaving pressures were determined for these materials. To quantify the effects of surcharge, several levels of loading were applied to the freezing specimens, with either dead loads or an air-diaphragm system, to produce surcharges between 3 and 1230 kN/m^2. Freezing behaviour was clearly modified by the application of surcharge loads, and for each material a hyperbolic relationship was established between frost heave and surcharge. Although the complete elimination of frost heave was not achieved, the application of low surcharges produced large reductions in heave. The surcharge required to render each material non-frost susceptible was dependent on heaving pressure rather than frost heave, as demonstrated by the ratio between surcharge pressure and heaving pressure. Typically, a 5% ratio was sufficient to achieve a 50% reduction in heave.

AN INVESTIGATION OF TRANSIENT PROCESSES IN AN ADVANCING ZONE OF FREEZING	M-3

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Studies have indicated a relation between subfreezing temperature in a fine-grained soil and pressure (moisture tension) in the film water adjacent to an ice lens. During the experiments reported here, concurrent measurements were obtained of temperature and pressure in the liquid water phase of a freezing silt soil. Freezing was from the top down utilizing an open system, with the water table held at the base of a specimen 30 cm long. The freezing front advanced into the specimen at a generally decreasing rate from 20 mm/day to 5 mm/day. The tests utilized a special tensiometer developed at CRREL that

continues to measure moisture tension below a temperature of O°C as long as continuity with the unfrozen water is maintained. Moisture tensions were registered continuously up to 75 kPa (0.75 atm), after which the tension remained constant or decreased slightly. Temperature corresponding to the maximum tension was -2.0°C; the tensiometers were unfrozen at this temperature. Atmospheric pressure was indicated in the soil water until the local temperature was colder than about -0.45°C. Combining the pressure-temperature data with data on unfrozen water vs. temperature resulted in an apparent moisture characteristic for the unfrozen water phase that is dependent on temperature.

BENEFITS OF A PEAT UNDERLAY USED IN ROAD CONSTRUCTION ON PERMAFROST	M-4

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In 1973, two adjacent experimental road sections incorporating peat underlays were constructed on a permafrost foundation site near Fairbanks, Alaska. The project's objective was to determine if the theoretical advantage of such a design technique would in fact prevent thawing of the thermally unstable foundation. Because the thermal conductivity of peat is much lower in a thawed condition than when frozen, it should act as a summertime thermal barrier while allowing considerable winter refreeze to occur. Field studies have continued through 1982 in order to estimate the long term consequences of this construction method. Results indicate that a 0.75 m thick layer of consolidated peat can provide significant protection against permafrost degradation under at least the central portion of a road embankment in a warm {-1*C) permafrost area. However, side slope and ditch area thawing and settlement problems, which result primarily from the insulating effects of snow cover, were not prevented by the installation of the peat underlay.

A TECHNIQUE FOR MEASUREMENT OF VOLUMETRIC UNFROZEN AND FROZEN SOIL MOISTURE CONTENT | I

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A solid-state, durable inexpensive radio frequency sensor (RFS) has been developed and laboratory-tested. The RFS uses a Wien bridge circuit to measure a change in soil impedance when changes in soil moisture occur. Both electrical conductance and capacitance are measured at differing moisture contents. The dielectric constant of the soil moisture is proportional to the measured capacitance and is approximately linear with respect to percent moisture. Due to the simple readout system, the RFS has the potential to be interfaced with a data collection system for data acquisition from remote areas. A laboratory experiment was conducted, varying texture and density, to determine the accuracy of the RFS for measurement of volumetric soil moisture content. The values of the capacitance and thus of the dielectric contant of the moist soil obtained with the RFS compare favorably with the values recorded in the literature. Preliminary tests on the temperature effect of the RFS accuracy have shown that volumetric water content can be obtained by the RFS over a wide range of temperatures. Since the RFS is solid state, it can be placed in remote areas and can monitor soil water content to within ± 0.5% by volume.

USE OF SEASONAL WINDOWS FOR RADAR AND OTHER IMAGE ACQUISITION AND ARCTIC LAKE REGION MANAGEMENT | I

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This paper introduces regional remote-sensing data and methods that can provide arctic lake basin characterizations for economical site-specific management decisions. It also illustrates conditions and time periods, hereafter referred to as "windows," that can reduce natural-resource/human-activity conflicts and enhance remote-sensor acquisition of aquatic resource inventory data. Most oil exploration activity can be completed in a cost-effective manner with the least environmental disturbance during the winter surface use window. Lakes, rivers, and wetlands can be managed much like a terrestrial environment during the long arctic winter. Lakes, ponds, and hydroscopic soils

cover most of the Arctic Coastal Plain and support an active flora and fauna that are susceptible to disturbance during the short summer. Some seasonal land management factors to be considered are overland and ice-road travel, avoidance of critical habitats during periods of high wildlife use, and water withdrawal from lakes. Data useful for regional inventory, classification, and management of acrctic lake resources are April radar images, ice thicknesses, and summer aerial photographs and satellite images. April radar images of arctic lakes may be used to interpret isobaths separating three ranges of water depth (approximately O-2 m, 2-4 m, and >4 m).

PERMAFROST DYNAMICS IN THE AREA OF THE VILUY RIVER HYDROELECTRIC 'SCHEME	C-4

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During 14 years of operation of the hydroelectric installation the permafrost in the flooded zone has thawed to a depth of 15-17 m and to a depth of 20-50 m in the base of the dam. During the construction phase and during the first few years of operation freezing of the taliks below the river bed to a depth of 10-20 m was observed as a result of the drainage of the construction site, the systematic disturbance of the snow cover and to intense air convection in the rock fill. The permafrost layer which had formed had thawed almost completely by 1982. The temperature field of the dam is characterized by extremely low mean annual temperatures; however, the spatial characteristics of the zone of negative temperatures differ significantly from those forecasted using a stationary model. The formation of temperature anomalies within the body of the dam is due to use of highly gas-permeable materials ($k \approx 1 \cdot 10^{-7}\ m^2$) in its construction.

ARTIFICIAL ICE MASSES IN ARCTIC SEAS	I

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Natural climatic conditions in the arctic seas create preconditions for extensive use of ice and frozen ground as construction materials for creating artificial islands and structural foundations in areas of shelf. Experiments were carried out off the Kaya Sea coast into the formation of ice masses both by freezing layers of sea water and by sprinkling. The rate of ice formation by means of repeated flooding was up to 12 cm daily. The rate of ice formation by the sprinkling method was about 0.7 cm per hour at an air temperature of -15°C, and 1.1 cm per hour at -30°C. In the laboratory, the rate of freezing of layers of water at -20°C was from 0.2 to 0.55 cm per hour depending on the wind velocity. Ice formed by the sprnkling method possessed higher porosity and salinity as compared with ice formed by the freezing of layers of water or with natural sea ice, and its compressive strength was only half that of natural sea ice.

ISOTOPE VARIATIONS IN PERMAFROST WATERS ALONG THE DEMPSTER HIGHWAY PIPELINE CORRIDOR	H-2

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Oxygen-18 contents of permafrost waters have been determined for representative core samples from the proposed Dempster Highway pipeline route. Many samples contain water with an isotopic content ($\delta^{18}O$ = -20 to -23°/..) similar to modern precipitation which suggests significant groundwater migration near surface. Samples from the unglaciated northern Yukon have ^{18}O contents ranging from -14 to -27°/oo which are suggestive of climatic changes since the late-Wisconsinan. Superimposed on these variations are 2 - 2.5°/oo fluctuations formed by isotope fractionation during freezing.

BEHAVIOR OF CONCRETE STRIP FOUNDATIONS ON THAWED LAYER OF CLAYEY PERMAFROST	I

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This paper reports on laboratory and field investigations into the behavior of thawed layers of clayey permafrost under strip plate loads. The aim was to study the load-settlement relationships of unfrozen as well as thawed soil layers. Such relationships were found to be nonlinear and were expressed in terms of a maximum load and a parameter dependent on the soil layer thickness, the foundation shape, and soil properties.

APPLICATION OF MICROWAVE ENERGY FOR ACCELERATING EXCAVATION?/ IN FROZEN SOILS	I

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The paper examines the heating of frozen ground by means of microwave energy in order to determine the most rational thawing regimes where frozen masses are being prepared for excavation by formation of local thawed zones or by thawing of a slope in layers. The derived equation of the advance of the thawing front created by the absorption of microwave energy by the rocks as well *as* experimental data revealed that the main critical parameters for thawing frozen rocks by microwave energy are the depth of penetration of the electromagnetic field, the area of formation of a thawed zone at the surface through which the electro- and thermo-physical properties of the rock exert an influence on the thawing and also the frequency and strength of the microwave energy flow. It was shown that when operating under optimal conditions, typical depths of microwave thawing depending on the frequency and type of rock; are 0.1-0.6 m with a consumption of microwave energy of 20-30 kWt-hr/m^3

WELL CASING STRAINS DUE TO PERMAFROST THAW SUBSIDENCE IN THE CANADIAN BEAUFORT SEA	I

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Permafrost sediments will experience local melting and thaw subsidence with the prolonged extraction of 60° to 85°C hydrocarbons through production wellbores. Design concerns include the settlement of topside production systems and the potential detrimental effects of the displacement-controlled loading of production casings. A total stress analysis, assuming undrained loading, was employed in parametric, single-well studies to assess the influence of the composite thaw subsidence loading mechanisms -- thaw strain and stiffness reduction. The thaw strain results from the potential 9% pore-ice to porewater volume reduction in ice-bonded permafrost. The stiffness

reduction strain is due to the increase in the soil's undrained compressibility with the melting of the pore ice. The validity of the undrained approach to thaw subsidence analysis has been supported by a major field investigation and monitoring program performed during the drilling of the Tarsiut N-44 exploratory well in 1981-82.

FROST FEATURES IN THE KARST REGIONS OF THE WEST CARPATHIAN MOUNTAINS	I

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The action of freezing and thawing on limestone near cave entrances in the high mountains in Czechoslovakia produces modification of rock walls, rock shelters, debris ramparts, and sorted polygons and stripes in the frost-weathered debris on cave floors. Debris ramparts, about 1 m high and wide, form near cave entrances. They are the result of intense frost action caused by the outside freezing air entering the cave and contacting the moisture-soaked, jointed limestone walls. Frost-weathering debris on the cave floors near the entrances is sorted into small polygons and stripes by frost action.

GEOPHYSICAL MEASUREMENTS OF SUBBOTTOM PERMAFROST IN THE CANADIAN BEAUFORT SEA	G-3

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Early marine seismic refraction interpretations on the Canadian Beaufort Sea shelf have indicated the widespread occurrence of ice-bearing sub-seabottom sediments. A large area of the shelf is underlain by coarse-grained high velocity (> 3000 m/s, typical of ice-bonded sand and gravel) Cenozoic sediments. Recent data have reaffirmed the subdivision of this area into two major seismic layers, a deep thick continuous layer with the upper surface generally greater than 100 m below the seabottom, and a thin discontinuous layer at depths of 5 - 50 m below the seabottom. High resolution multichannel refraction seismic surveying has provided detailed structure on these layers.

THE UTILITY OF REMOTELY-SENSED DATA FOR PERMAFROST STUDIES — R-1

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The presence of permafrost determines to a large degree, the capability or suitability of land for development. Many environmental factors which influence permafrost can be studied through the analysis of remotely sensed data. This paper discussed the utilization of remotely sensed data in the development of derivative maps and data layers based on associations among vegetation and terrain factors and permafrost conditions. An approach will be presented for deriving data layers from an existing data base to illustrate their potential contribution to predictive permafrost modeling.

THE ROLE OF PRE-EXISTING, CORRUGATED TOPOGRAPHY IN THE DEVELOPMENT OF STONE STRIPES — P-6

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An experiment was conducted to explore the role of small-scale topography in the development of stone stripes. The surface of a silt loam with a homogeneous admixture of gravel was shaped into sinusoidal corrugations with wavelengths ranging from 0.05 to 0.8 m. The soil was then subjected to both diurnal and storm-length freeze-thaw cycles. Surface heave and subsurface temperature were monitored electronically. Sorting was measured by displacement of marker stones and changes in gravel concentration in soil samples. The volume concentration of gravel increased in the soil underlying troughs. Marker stones tended to move toward the nearest trough. Stones close to the surface in more steeply inclined regions traveled the greatest lateral distance with several stones moving as far as 40 mm. Sorting related to topography was apparent only under the larger corrugations. Heave records indicate that significant heave occurred in troughs during the thaw portion of the temperature cycle. Residual differences in heave between the crests and troughs of sinusoids on the order of 1 mm per storm-length freeze-thaw cycle tended to accentuate relief through time.

BIOGEOGRAPHIC SIGNIFICANCE OF STEPPE VEGETATION IN SUBARCTIC ALASKA	E-3

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Fossils in late-glacial deposits of Beringia suggest a dry grassland or steppe was a fundamental part of the periglacial vegetation mosaic. This is consistent with the expected effect of the Bering Land Bridge on climate during glacial maxima: colder and drier overall, possibly with shorter and warmer summers when deeper seasonal thaw created soils suitable for steppe plants but inimical to the dominant taxa found here today. Remnants of that vegetation may persist today in Siberia and the continental interior of Alaska and adjacent Yukon Territory on steep, dry south-facing bluffs and terraces. We reconnoitered the steppe flora and its communities on steep, dry south-facing bluffs and terraces along the Yukon, Tanana, Copper, and Porcupine rivers examining both glaciated and unglaciated areas and surfaces of Tertiary, Quarternary, and Holocene ages. These steppes are comparable to those of the upper to middle Yana and Indigirka drainages and the upper Kolyma River in western Beringia. Steppe vegetation of Alaska and Yukon is to a significant degree composed of vascular plants that are either the same species or close relatives (vicariants) of Siberian species. Others are American taxa either endemic to eastern Beringia or the same as or vicariants of taxa found in continental western North America. The mosses and lichens are mostly members of a widely distributed, although often disjunct and rare, flora and arid and semi-arid regions. The Asian taxa presumably arrived in eastern Beringia via the Bering Land Bridge, some perhaps as early as late Tertiary. The American contribution to the modern steppes might be both ancient and recent, since the present mix of species could also reflect contributions from a postglacial warm interval. These taxa became restricted to their present sites during the Holocene by the expansion of taiga and mires.

SOIL-WATER DIFFUSIVITY OF UNSATURATED SOILS AT SUBZERO TEMPERATURES	I

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The soil-water diffusivities of soils containing no ice were determined at -1°C by an experimental method recently introduced. The theoretical basis of the method is presented. The measured diffusivities of three kinds of soils are found to have a common feature in that the diffusivity increases with increasing water content, attains a peak, and increases again as the water content increases. This common feature of the soils at the subzero temperature is discussed in comparison with unfrozen soils. The experimental data appear to indicate that the basic transport mechanism of water in soils containing no ice at the subzero temperature is essentially the same as that in unfrozen soils containing a small amount of water.

SEISMIC VELOCITIES AND SUBSEA PERMAFROST IN THE BEAUFORT SEA, ALASKA	G-3

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The distribution of high-velocity material was used as an indicator of ice-bonded permafrost. Observations from ice survey and marine seismic records, coupled with control from a small number of drill holes, suggest that ice-bonded permafrost is extremely widespread in the Beaufort Sea. Large areas of high-velocity material at shallow depths, 10-40 m below the seabed, were observed near Prudhoe and Harrison Bays. In some cases these zones extended up to 35 km from shore. It was also common to find that depths to high-velocity material increased with distance from the shore. Observed depths were as great as 150-230 m below the seabed. Velocities also commonly decreased with distance from shore to a point where it was no longer possible to identify ice-bonded horizons. Reflection analysis revealed several deep near-horizontal reflectors that recurred along segments of the coastline from Harrison Bay to the Canadian border. Reflectors at approximately 200 m and 450 m could be permafrost-related, although no control exists for an evaluation of this interpretation. Locally these reflectors may extend out to the shelf edge to approximately the 100 m water depth.

PREVENTING FROST DAMAGE TO RAILWAY TUNNEL DRAINAGE DITCHES IN COLD REGIONS | I

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Cold weather and permafrost usually have an adverse effect on the drainage system of a railway tunnel. Based on several years' experience in railway construction and operation in the Great Xingan Mountains of China, the author discusses the effect of drainage ditches, deeply buried seepage ditches below tunnels, thermo-insulated drains, heated drains, etc., on the prevention of frost damage by using actual engineering examples. His conclusion is that, in cold regions where underground water is presumed to exist in winter, the drainage ditch is still preferable, even though it is difficult to construct and increases project costs. The seepage ditch is applicable only in regions where the frost depth is 2.7-4.8 m, because the ditch can affect the stability of the sidewalls if it is buried too deeply below the center of the tunnel. The thermo-insulated ditch and the heating ditch are more convenient and cheaper to construct, but should be used on only an experimental basis until more research can be done.

CRYOGEOTHERMAL PROBLEMS IN THE STUDY OF THE ARCTIC OCEAN | I

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One of the most notable geological-geophysical features of the Arctic Ocean is the presence in any sea-bed section of a cryolithozone, involving frozen sediments and ground ice. The stages of its evolution in shelf areas correspond to cyclic regressions and transgressions in the Arctic Basin. This involves an oscillation from unfrozen submarine sediments through a newly formed submarine frozen zone to a frozen terrestrial zone, and then back through a relict submarine frozen zone to an unfrozen submarine zone. Sedimentation on the sea bed on the shelf is closely related to the evolution of the cryolithozone. Widespread occurrence of ice-rich lacustrine-alluvial deposits on the Arctic shelf in the late Pleistocene is inferred on the basis of peculiarities of sedimentogenesis in the course of thermal abrasion of the sediments during the transgressive phase of development of the Arctic Basin. Submarine lithogenesis is accompanied by unique changes in the fluid phase, viz., salinization of pore water and the formation of gas

hydrates. It is possible to outline possible gas hydrate-bearing-areas on the basis of cryogeothermal reconstructions. Submarine permafrost also dictates a number of peculiarities in the geophysical fields especially the mobility of the thermal fields; this is extremely critical in the case of formation and degradation of frozen and/or gas hydrate-bearing strata.

DYNAMICS OF THE CRYOLITHOZONE IN THE NORTHERN HEMISPHERE DURING THE PLEISTOCENE	P-2

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During a study of deep freezing of the lithosphere in various parts of the Earth, the concept of an extremely old cryolithozone (namely 2 roil. years old) was adopted. It was shown, that the last phase of deep freezing of the lithosphere in the mountains of Northern Siberia and Alaska started in the Early Pleistocene (600-700 thousand years BP) and has continued from that time. During the last 50 thousand years four stages can be identified in the development of these frozen strata; during these stages the dynamics of the cryolithozone were closely linked to the progress of glacial events. Summarizing the information on traces of the past distribution of permafrost, the author has compiled a map of its maximum distribution. On the basis of the trends derived from this, a prognosis of the evolution of the cryolithozone for the next 100 years has been attempted. However, it is emphasized that man's industrial activities are starting to exert a critical impact on the course of natural processes.

A FROST INDEX FOR SPATIAL PREDICTION OF GROUND-FROST ZONES	G-1

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Recent investigations of the relationship between the minimum and maximum mean monthly air temperatures along the trans-Alaska pipeline route indicate that good estimates of freezing and thawing degree days at a site can be obtained from these two extreme monthly mean values. The dimensionless ratio between the Stefan solution for the annual frost and thaw depths at a site can be obtained from the degree-day estimates, winter snow-cover data, and estimates of site thermal properties. The ratio of Stefan estimates of frost to thaw depths is termed the "frost number". Its value is much larger than unity in regions of continuous permafrost and descends to unity at the equatorward limit of the discontinuous permafrost zone. A preliminary mapping of the frost number in northwestern North America shows a very high spatial correspondence with observed permafrost distribution. The frost number can also be mapped using climate data in successive years, which yields information useful for correlation with such geomorphic processes as palsa growth and thermokarst development.

CRYOPEDIMENTS IN THE BIGHORN CANYON AREA, SOUTHCENTRAL MONTANA	I

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At least four levels of gently sloping erosional surfaces, representing at least four periods of sedimentation, occur in the Bighorn Canyon area of southcentral Montana. The truncated bedrock surfaces are irregular in detail, with many interfingerings between broken, disaggregate bedrock from subjacent formations and the overlying thin (1 to 3 m) veneer of diamicton. The diamicton is very poorly sorted, containing erratic blocks up to several meters in diameter, which have moved up to 6 kilometers from their sources. Most of the fine-grained portion of the diamicton originated from subjacent formations. Formerly much more active frost wedging and frost churning are indicated by the wide size range and angularity of the erratic blocks, fragmentation and disaggregation of subjacent formations, and the thorough mixing of erratic material with material from subjacent formations. Frost wedging of subjacent formations is thought to have been the main process of pedimentation; no evidence of prior planation was found. The movement of the diamicton is interpreted to have been by gelifluction, as indicated by the extensive, sheet-like geometry of the deposits, downslope and cross-slope block orientations, the presence of diamicton lobes, and transportation of huge blocks several kilometers on slopes between 2° and 11°. The major conclusion drawn from data and interpretations presented in this paper is that the pediments in the Bighorn Canyon area are cryopediments, developed through processes of intensive frost action in a periglacial environment.

THAW STRAIN DATA AND THAW SETTLEMENT PREDICTIONS FOR ALASKAN SOILS	C-2(2)

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To aid design of the trans-Alaska pipeline, a method was developed to predict thaw strain from correlations with simple frozen soil index properties. Laboratory thaw consolidation tests were made on about 1,000 representative soil samples recovered during subsurface exploration programs along the pipeline alignment. The test results were then grouped by sample soil type and landform profile. Various relationships among the soil index properties (frozen dry density and moisture content, specific gravity, gradation) and thaw strain measurements of samples within each category were examined to empirically determine a "best fit" equation by multiple variable regression analysis of the data. A computerized analysis-procedure determined the set of regression coefficients to yield a unique equation for each soil category to predict thaw strain of a frozen soil sample with only borehole index property values. These estimated thaw strain values could be multiplied by stratum thickness and summed over an anticipated thaw depth to predict thaw settlement.

SHORELINE EROSION AND RESTABILIZATION IN A PERMAFROST-AFFECTED IMPOUNDMENT	I

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In 1976, an 850 m^3/s river diversion was constructed through 300 km of permafrost-affected landscape in northern Manitoba. The diversion as accomplished by raising the level of a 1,977 km^2 riverine lake on the Churchill River (Southern Indian Lake) until the water spilled across a terrestrial drainage divide into a series of small valleys tributary to the Nelson River. Over 400 km^2 of permafrost-affected backshore area surrounding the lake were flooded. The mean annual temperature at Southern Indian Lake region is -5°C. Three repeated phases of shoreline erosion in permafrost materials were

observed; melting and undercutting of the backshore zone, massive faulting of the overhanging shoreline, and removal of the melting and slumping debris. At erosion monitoring sites in fine-grained frozen silts and clays rates of retreat of up to 12 m/yr were measured. The index of erosion based on the wave energy impinging on the shoreline was 0.00035 m^2/tonne. After 5 years of erosion, restabilization of the shoreline has occurred only where bedrock has been encountered by the retreating backshore. Clearing of the forested backshore prior to flooding did not affect the erosion rates. The rapidly eroding shorelines have increased the suspended sediment concentration in Southern Indian Lake water and have triggered degradation of the commercial fishery.

GEOTHERMAL DESIGN OF INSULATED FOUNDATIONS FOR THAW PREVENTION	C-3(2)

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As development in the North American Arctic proceeds to more northerly remote regions, the demand for reliable and thermally acceptable foundations for heated structures on permafrost will increase. In subarctic areas, or regions where the permafrost ground temperatures are close to melting, some method of ventilation or heat removal is necessary to provide a stable, frozen subsoil condition for support of the structure. However, in more northerly areas, communities or new energy developments are located where the mean ground temperatures are colder than 5°C or so, and another foundation alternative is available to the designer. It is possible using insulation alone, to retain the melting isotherm above the thermally unstable permafrost layer. In some cases, a distinct economic advantage may exist (particularly for smaller structures) to placing the foundation on a thicker layer of insulation, and omitting any active form of heat removal altogether. In this way, the capital costs of an elevated structural floor, or costs for ventilation or other heat removal systems can be omitted. In many remote northern areas, regular maintenance cannot be relied upon, and the use of a pure insulated foundation system does not require any long-term maintenance, and may have more than simply economic advantages. A thermal analysis for rectangular insulated structures is reviewed, and a new solution for a heated circular insulated structure is presented. A convenient chart allows the designer to select the insulation thickness that will prevent the 0°C isotherm (or any other isotherm) from entering the permafrost subsoil. In addition, an available solution for an insulated buried pipe in permafrost is reviewed for comparison.

DRIVEN PILES IN PERMAFROST: STATE OF THE ART | C-3(1)

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Pile driving techniques in permafrost have developed rapidly over the last 5 years, to a point where the driven pile method using thermally modified drilled pilot hole now offers a fast and economical solution to many frozen foundation problems. Most types of piles, including H-shape, pipe, and sheet piles , now can be driven, assuming that there is a knowledge of soil conditions and that the correct procedure is followed. Presented in this paper are the latest research, testing, and production pile driving developments in Alaska. Current proposed pile design approaches will be discussed as related to short-term loading and long-term creep. The scope of this paper is based largely on actual practical experience with about 5,000 piles recently driven in cold and warm permafrost soils; as well as recent laboratory work and field testing experience on a large number of driven piles. The proposed criteria presented in this paper are primarily addressed to the practicing design engineer, including design and construction considerations. As more research and experience accumulate, factors presented in this paper may change.

PERMAFROST ON MARS: DISTRIBUTION, FORMATION, AND GEOLOGICAL ROLE | R-2

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Temperature data for Mars suggest the existence of global permafrost. Due to the low pressure of water vapor in the Martian atmosphere the frost lies at about 198K. Consequently, ground ice can only be in diffusive equilibrium with the atmosphere at relatively high latitudes (poleward of about 400). Slow diffusion rates through fine-grained regolith, however, may permit ground ice to have existed for billions of years anywhere within the permafrost zone. The climatic changes on Mars, on time-scales of millions of years, appear to be directly controlled by astronomical variables. Climatic changes on time-scales of billions of years are probably of geological nature. It appears likely that an early phase of intense out-gassing could have produced global temperatures considerably in excess of those at present. Probably more than 100 m of precipitable water was released during this early phase of out-gassing. The water may have charged a

global ground water system which subsequently froze during a period of cooling climate. The downward progression of the freezing front may have increased the pressure of the underlying ground water system. Locally, the artesian pressure could have exceeded the lithostatic pressure, fractured the ground ice seal and released water at enormous discharges. Alternatively, the pressure build-up in the confined aquifers could have liquified subsurface unconsolidated materials leading to fracturing of the overlying ground ice layer. Both mechanisms would explain the large channels as results of catastrophic discharge. Smaller-scale morphologic features indicative of deterioration of near-surface ground ice occur over vast areas on Mars.

CLIMATIC AND ADAPHIC INFLUENCES ON TREELIMIT, UPPER ALATNA RIVER DRAINAGE, CENTRAL BROOKS RANGE, ALASKA	I

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The ecology and vegetation dynamics , associated with white and black spruce, Picea glauca (Moench) Voss , and Picea mariana (Mills.) B.S.P., have been investigated in eight side-tributaries to the Alatna River Drainage, Central Brooks Flange, Alaska. At this temperature sensitive latitudinal and elevational limit of spruce an anomalous situation has been observed; in the Arrigetch Creek tributary (deglaciated 11,500 years B.P., post-Walker Lake Glacial Event) both white and black spruce are represented at treelimit. Sexual and asexual reproduction exists. In the other valley tributaries (deglaciated 40,000 years B.?., post-Itkillik I Glacial Event) white spruce is the only conifer species at treelimit. Black spruce is encountered 10-15 km down-valley. These spruce populations have good sexual reproduction. It is suggested that historical and extant abiotic factors play a role in the present day spruce distribution within the Alatna Drainage. Atmospheric factors (i.e. maritime vs continental) and edaphic factors (i.e. acidic vs basic bedrock, drainage conditions, and depth of thaw to permafrost) have considerable influence on the aptitudinal position of treelimit. These factors also influence development of the associated vegetation assemblages.

PRACTICAL APPLICATION OF UNDERSLAB VENTILATION SYSTEM: PRUDHOE BAY CASE STUDY	I

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When designing buildings at grade on permafrost, consideration must be given to maintaining the frozen subgrade. One foundation system cools by ventilating ambient air through ducts in the subgrade. This paper responds to the need for documented results correlating performance of underslab ventilation systems to theoretical thermal analysis for operating facilities at Prudhoe Bay, Alaska. Experiences from the design and construction of a 7200 sq. ft. Fabrication Shop in Prudhoe during the 1981 summer construction season are the basis for the discussion. Design criteria recommendations are presented for slab-on-grade underslab ventilation systems for thermal analysis and system design. Aspects of construction specifications which contribute to ensuring good systems performance are highlighted. The article concludes with a case study for Sohio's Fabrication Shop. Thermal analysis calculations to determine ventilation rates which contrast F.J. Sanger's method to J.F. Nixon's approach using the Fabrication Shop's design criteria are appended. Instrumentation data is tabulated for intake and exhaust duct temperatures, and subgrade temperatures over an eighteen (18) month period covering initial freeze-back, winter operation, and summer thaw. From information presented, correlations are made on how well theoretical analysis approximates actual performance of a slab-on-grade underslab ventilation system.

UNIAXIAL COMPRESSIVE STRENGTH OF ICE SEGREGATED FROM SOIL	C-2(1)

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Segregated ice (ice lens), which was columnar grained, was subjected to uniaxial compression tests. Specimens of such ice (5 cm in diameter and 9 cm in height) were prepared by freezing a soil composed of a frost-susceptible clay collected in Tokyo. The main factor thought to influence the strength of frozen clay is either unfrozen water or segregated ice. Therefore, the strength of segregated ice constitutes an important element in the clarification of the strength of the frozen clay. When a load is applied in the direction of ice

growth, the uniaxial compressive strength increases with decreasing temperature, giving values of 18.6 Mega Newton/m^2 at -10°C and 24.5 MN/m^2 at -20°C. When it is applied perpendicular to the growth direction, the uniaxial compressive strength, which is about 4.9 MN/m^2 at -20°C, is approximately equal to the strength of commercial ice. When the loading angle ranges between 20° and 90° to the growth direction, the strength is nearly constant and decreases at -10″C to one-fifth of the strength in the growth direction.

WATER MIGRATION DUE TO A TEMPERATURE GRADIENT IN FROZEN SOIL	I

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Closed soil columns at an initially uniform total water content were subjected to a nearly linear and constant temperature gradient along their length. At various times, the columns were sectioned and water content as a function of position was determined gravimetrically. Unfrozen water content vs temperature curves were also determined with a nuclear magnetic resonance technique on separate samples of the same soil at the same dry density. It *was* found that the water migrated from the warm to the cold end, two zones developed in each of the tubes, one that contained only liquid water and the other containing ice and water. The boundary between the two zones also migrated toward the cold end as the experiment progressed, and the water content of the zone containing only water fell while that of the zone containing ice and water increased. The free energy of the liquid water was calculated as a function of position, assuming the validity of a form of the Clausius-Clapeyron equation. Hydraulic conductivity coefficients were then calculated from the free energy gradients and water migration data. Values ranged from 4.5 x 10^{-12} m/s at -0.3°C to 3.5 x 10^{-13} m/s at -2°C for the Morin clay soil tested.

HYDROLOGIC CHARACTERISTICS OF SMALL ARCTIC-ALPINE WATERSHEDS, CENTRAL BROOKS RANGE, ALASKA

H-l(2)

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A hydrologic investigation of six watershed was conducted during three summer runoff seasons (1978, 1979, and 1980) in the central Brooks Range. The orographic effect produced by the Brooks Range significantly affects both summer and winter precipitation patterns and consequently stream runoff characteristics. Summer precipitation north of the continental divide is normally greater than that to the south, which is reflected in the volume of runoff per surface area for the small watersheds near the divide. The largest percentage of seasonal runoff takes place from breakup to early summer and is attributed to snowmelt and to the significant proportion of summer precipitation which occurs during this period. Precipitation discharge calculations suggest that the major portion of annual precipitation becomes stream discharge, representing a large water yield in proportion to total precipitation. These yields are attributed to low evaporation rates and to the presence of continuous permafrost.

THERMAL REGIME OF SUBSEA PERMAFROST

I

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Temperature measurements have been made in shallow, small-diameter boreholes in the Beaufort, Chukchi and Bering Seas off the Alaskan coasts since 1975. The maximum depth reached was about 50 m below the sea bed. Most of the measurements were made in shallow water within a few kilometers of shore although some were made up to ≃ 20 km offshore where the water depth was ≃ 17 m. Additional temperature measurements have been made on offshore islands. The measured temperature profiles have been used for a variety of purposes including determining the existence of subsea permafrost, thermal gradients, depth of ice-bonded permafrost, permafrost thickness, the nature of the heat and salt transport processes, thermal parameters, ice content, shoreline stability and, ultimately, to develop models of subsea permafrost and its distribution. The paper will review recent and past temperature data obtained in the course of this investigation and the published temperature data obtained by other investigators (e.g. CRREL and USGS). A comparison of the measured thermal regime with that predicted by thermal models will also be made and the current state of the analyses of the temperature data will be discussed.

INVESTIGATIONS INTO THE COMPACTION OF THAWING EARTH MATERIALS	M-2

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The author has developed a method for solving one- and two-dimensional problems concerning the compaction of thawing earth materials. The method was used to investigate the impact of the thawing regime, the depth of the layer being thawed, and its compaction properties on trends in the process of compaction of the thawing material. The results achieved are presented as nomograms which allow one to predict the degree of compaction of various types of thawing and recently thawed materials at any point beneath the foundations of buildings or structures at a given point in time. They may be used to resolve specific practical problems in location and design.

FIELD MEASUREMENT OF ELECTRICAL FREEZING POTENTIALS IN PERMAFROST AREAS	I

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Electrical potentials developed during freezing of natural soils have been measured in two permafrost areas: one in a saturated sand in a drained lake (Illisarvik) on Richards Island where permafrost was aggrding downward 5.65 m below ground; the other, in a mud hummock in the active layer at Inuvik. Peak potentials of up to 1350 mV were measured on electrodes located on the advancing freezing front at Illisarvik. At Inuvik, maximum freezing potentials of up to 700 mV were measured as the active layer froze in winter. There was also evidence of downward water migration and freezing as the ground started to thaw at the surface in spring.

MEASUREMENT OF UNFROZEN WATER CONTENT OF SALINE PERMAFROST USING TIME DOMAIN REFLECTOMETRY	I

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Time Domain Reflectometry has been previously used to determine volumetric unfrozen water contents, θ_u, in frozen soils. This paper presents laboratory results which indicate that the technique can be extended to use in saline permafrost samples. TDR determined values of θ_u for samples at the same salinity, are generally reproducible to within 2.5%. Measured θ_u data, for the soil at its natural salinity, were used to calculate values at other salinities, by accounting for the freezing point shift. The measured and calculated values generally agree to within 2-5% in θ_u. Finally, some field data are presented.

THE THERMAL REGIME OF THERMOKARST LAKES IN CENTRAL YAKUTIA	P-4

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Annual values of the components of the heat balance of the surfaces of thermokarst lakes and of land areas in the taiga zone of Eastern Siberia were obtained. The radiation balance and the effective radiation were higher in the case of the lake surface than from a meadow surface; the evaporation from the water surface, totalling 500 m, was twice as high as the precipitation and 1.8-2.4 times higher than from the soil surface in meadows. In contrast to the situation on land, turbulent heat exchange over the lakes was positive in winter and negative in summer. All components of the heat balance increased with lake depth. The mean annual temperature on the lake surface was 4-6°C higher than that on land. Freeze-up occurred at a water temperature of 1.5-4°C. In springtime under-ice warming of the water resulted in temperatures of 10°C and melting of the ice from below amounted to 35-45 percent of the total melting. In summertime the surface water warms up to 25-30°C. Mean annual temperatures of the lake bed are positive throughout the entire water area. The maximum warming effect on the bottom materials is produced by a water layer 1-1.5 m in depth. In the central areas of large lakes the annual heat absorption by the bottom is equal to the heat loss but exceeds it as one approaches the shore.

SONIC AND RESISTIVITY MEASUREMENTS ON BEREA SANDSTONE CONTAINING TETRAHYDROFURAN HYDRATES: A POSSIBLE ANALOGUE TO NATURAL GAS HYDRATE DEPOSITS

I

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Deposits of natural gas hydrates exist in arctic sedimentary basins and in marine sediments on continental slopes and rises. However, the physical properties of such sediments, which may represent a large potential energy resource, are largely unknown. In this paper, we report laboratory sonic and resistivity measurements on Berea sandstone cores saturated with a stoichiometric mixture of tetrahydrofuran (THF) and water. We used THF as the guest species rather than methane or propane gas because THF can be mixed with water to form a solution containing proportions of the proper stoichiometric THF and water. Because neither methane nor propane is soluble in water, mixing the guest species with water sufficiently to form solid hydrate is a difficult experimental problem, particularly in a core. Because THF solutions form hydrates readily at atmospheric pressure it is an excellent experimental analogue to natural gas hydrates. Hydrate formation increased the sonic P-wave velocities from a room temperature value of 2.5 km/s to 4.5 km/s at -5°C when the pores were nearly filled with hydrates. Lowering the temperature below -5°C did not appreciably change the velocity however. In contrast, the electrical resistivity increases nearly two orders of magnitude upon hydrate formation and continues to increase more slowly as the temperature is further decreased. In all cases the resistivities are nearly frequency independent to 30 kHz and the loss tangents are high, always greater than 5. The dielectric loss shows a linear decrease with frequency suggesting that ionic conduction through a brine phase dominates at all frequencies, even when the pores are nearly filled with hydrates. We find that the resistivities are strongly a function of the dissolved salt content of the pore water. Pore water salinity also influences the sonic velocity, but this effect is much smaller and only important near the hydrate formation temperature.

ADFREEZING STRESSES ON STEEL PIPE PILES THOMPSON, MANITOBA	C-3(1)

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Studies of uplift forces on steel pipe piles in frost-susceptible varved clays were carried out near Thompson, Manitoba, over three consecutive winters. The installation consisted of pipe piles that were 169, 323, and 458 mm in diameter and 3.3. m long. Each pile size was replicated three times on the same site, and all piles had separate reaction frames anchored to bedrock. For the first winter, when the thick gravel layer that was placed over the site was allowed to freeze to the piles, high uplift forces were measured. The pile was isolated from the gravel in the two subsequent winters, and the adfreeze values corresponded more closely to those determined previously.

LAWS GOVERNING INTERACTIONS BETWEEN RAILROAD ROADBEDS AND PERMAFROST	I

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In southern areas of permafrost occurrence interactions between railroad roadbeds and permafrost are characterized by changes through time both in the intensity of the thawing of permafrost and settlement of the grade as deformation of the foundation materials occurs. These interactions may be divided provisionally into three periods: those of intense deformation, moderate deformation and complete stabilization. The first period is characterized by an irregular regime of thawing and settlement of the foundation material. Initially thawing and settlement are very intense but towards the end of the period this intensity declines markedly. The beginning of the period coincides with that of construction and it ends 1-2 years after completion of the grade. These trends are dictated by the changes in the natural permafrost conditions provoked by construction of the roadbed. The second period is characterized by a relatively low intensity of thawing and settlement which tends to die away with time. The duration of this period is dictated by the degree of disturbance of the natural local conditions and the deformability of the thawing permafrost materials under the influence of the completed grade. The third period is characterized by complete stabilization of the roadbed which corresponds to the needs of normal operation of the line. Depths of thaw and amounts of settlement display no linear correlation. The thaw depth depends on the degree of disturbance of the natural thermal regime, and on hydrological, permafrost and other natural conditions, whereas total settlement depends on the composition and ice content of the thawing permafrost and also on the compressibility of the permafrost materials under a given operating load.

APPLICATIONS OF THE FAST FOURIER TRANSFORM TO COLD REGIONS ENGINEERING	I

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The utility of using the fast Fourier transform as a means of consolidating climatic data into a form useful for cold regions engineering design is presented and discussed in this paper. It is shown that a 20-year data set consisting of 175,320 hourly values of a climatic variable can be represented by only 118 Fourier coefficients with little loss of information content. Complete consolidated climatic data sets are presented for Barrow and Fairbanks, Alaska. In addition, some other applications of the Fourier transform to the field of cold regions engineering are discussed and specific examples are presented.

LONG-TERM CREEP DEFORMATION OF ROADWAY EMBANKMENT ON ICE-RICH PERMAFROST	I

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Six different combinations of insulation layers, toe berms, and air-ducting systems were installed at an embankment near Bonanza Creek to study thermal degradation at side slopes and toe sections. The performance of these design measures has been monitored since the completion of construction in 1974. Though some of these measures show encouraging results in minimizing long-term thaw settlements, creep settlements are recorded at some of the central sections of the embankment where soil conditions consist of generally frozen ice-rich organic soils to fine-grained soils. In this paper, the long-term creep deformations recorded for the roadway embankment near Bonanza Creek are evaluated. Based on all data recorded for the last 8 years, a long-term creep deformation behavior of the roadway embankment (about 7.6 m in height) in ice-rich permafrost is formulated. Based on theoretical analyses, the vertical creep movements (within the central portions of the embankment) are calculated, and they show reasonable qualitative

agreement with the measured data. Measured movements indicate that the primary creep movements occurred within the first 3 years after the construction. The analysis presented provides a rational basis for embankment design on ice-rich permafrost.

PREDICTION OF CONSTRUCTION CHARACTERISTICS OF SLUICED MATERIALS USED IN FOUNDATIONS UNDER PERMAFROST CONDITIONS AND IN SEVERE CLIMATES

C-3(2)

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During engineering preparation of an area for construction in permafrost areas by means of hydraulic action it is essential to predict the thermal interaction of the sluiced and natural materials and their structural properties. The investigation revealed that the use of sluiced and underlying materials as foundations can be handled in three different ways: the sluiced material forms the levelled building surface; a combination of sluiced materials and the underlying materials is used for the building foundation; no load is exerted directly on the underlying material and only the sluiced material forms the foundation. With these schemes in mind, requirements in terms of the construction properties of materials are examined and principles for using them as foundations are formulated.

SEASONAL FROST MOUND OCCURRENCE, NORTH FORK PASS, OGILVIE MOUNTAINS, NORTHERN YUKON, CANADA

P-4

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Between 1980 and 1982 a total of 65 seasonal frost mounds were observed at several localities in the North Fork Pass, interior northern Yukon. The majority were of the frost blister variety, although icing blisters and icing mounds also occurred. The largest was 3.5 m high. Several persisted for more than 1 year and a few experienced reactivation and further growth in a second winter. Stratigraphic investigations, together with ice fabric analyses, suggest the mounds result from the freezing of suprapermafrost groundwater during winter freezeback under conditions of high hydraulic potential. Piezometers, installed in areas of active mound formation, indicate pressures rangig from 40 to 80 kPa are associated with mounds 1-2 *m* high.

CRYOLITHOGENESIS AS A TYPE OF LITHOGENESIS	I

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The paper examines a special, climatically controlled type of lithogenesis, namely cryolithogenesis. This zonal type of lithogenesis is dictated by the processes of cryodiagenesis and cryohypergenesis, occurring specifically in the polar and subpolar zones. Typical cryolithogenic products of cryodiagenesis and cryohypergenesis are distinguished, along with the corresponding peculiarities of their geographical distribution. Some critical comments are presented with regard to certain alternate existing concepts of cryolithogenesis.

THE EFFECT OF HYDROLOGY ON GROUND FREEZING IN A WATERSHED WITH ORGANIC TERRAIN	H-l(2)

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This is an investigation into factors affecting seasonal frost penetration in organic and inorganic terrains including the effect of the water table on freezing. Five different terrain types were instrumented with frost gauges and snow stakes. Piezometers were used to record water table fluctuations , and soil thermistors were used to determine temperature gradient and heat flux. Frost penetration among sites, and variation of frost depth within sites was investigated. Where the water table was at the surface and considerable flow occurred through upper layers, circulation of water reduced the rate of freezing but caused cooling to occur more rapidly in deeper layers, but where little flow was observed, cooling of lower layers lagged considerably, resulting in more rapid frost penetration in upper layers. Freezing of positive and negative relief elements was different for bogs and fens. Here again, the elevation of the water table was largely responsible.

SEDIMENTATION AND FLUVIAL DISSECTION?{ IN PERMAFROST REGIONS WITH SPECIAL REFERENCE TO NW-CANADA	I

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The paper deals with the question, whether under periglacial conditions the destruction of pediments by fluvial dissection or the formation of pediments are prevailing processes. Studies on this problem were carried out mainly in the Mackenzie and in the central Richardson Mountains, which since the beginning of the Quarternary period are subject to periglacial but not to glacial conditions. Pediplains are common in the whole area. Most of them are thought to be periglacial pediplanation surfaces (cryopediments). The aim of the paper is to report observations about the main processes causing the formation of these pediments by backwearing (intense slope retreat of the adjacent steep slopes by mass wasting and rill-wash, solifluction and sheet wash activity, favoured by the surplus water from the steep relief and nivation on the upper parts of the pediplains, transport of the debris across the pediments into the main rivers). Fluvial action is different in areas not yet affected by the dissection caused by isostatic uplift and in the marginal areas, where this dissection is very intense. Outside the recently dissected parts there is no competition between cryoplanation and fluvial activity.

PALEOPERIGLACIAL CLIMATE AND HYDROCOMPACTION IN CALIFORNIA, U.S.A.	I

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Engineering impacts of paleoperiglacial climate in Californiafs San Joaquin Valley are significant. Severe, controversial, polygenetic features (contorted bedding, loam wedges, hummocks and rock polygons) seem to indicate severe periglacial paleoclimates which may explain the origin of rapid and hazardous subsidence - hydrocompaction (a property of some arid sediments to loose their dry strength after wetting, creating spontaneous collapses and cracks and damaging buildings, dams, pipelines and canals). Hydrocompaction locally exceeds 5 m and has spotty occurrences on the western flank of the valley in Pleistocene piedmont Coast Range mudflow-alluvium. About $6 million were spent on preconstruction wetting of alinements of San Luis Canal and distribution pipelines to prevent post-construction damages by hydrocompaction.

Excessive porosity of alluvium susceptible to hydrocompaction can be explained by the freeze-drying of water-saturated Pleistocene summer mudflows, expanded volumetrically by freezing during cold winter seasons and dried by westerly wind passing over the Coast Ranges. Such sublimation resulted in preservation of newly developed porosity which was maintained buring the Holocene semiarid climate. Variations in microclimate could be responsible for local occurrences of sediments susceptible to hydrocompaction. It is possible that hydrocompaction, widespread in loess deposits in the U.S.A. and elsewhere, has a similar origin.

ALPINE PERMAFROST IN TIAN SHAN, CHINA | P-3

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The distribution of permafrost in Tian Shari depends chiefly on vertical zonation. Because of local conditions, the lower limit of permafrost varies from place to place: the lowest limit is 2700 m on north-facing slopes and 3100 m on south-facing slopes, about 1000 m below the local snow line. In general, the lower limit descends 171 m with each 1° increase in latitude and 10.6 m with each degree of increase in longitude. Permafrost can be divided into three belts: unstable permafrost, transitional permafrost, and stable permafrost. The map of permafrost distribution in Tian Shari is based on temperature observations in bore holes, field observations of cryogenic phenomena, and interpretation of aerial photographs. The development of ground ice in coarse-grained sediments, both buried glacial ice and segregated ice, is a peculiarity of Tian Shari. Under the stone stripes, rock circles, and frost-heaved rocks , massive ground ice is found. An old moraine with a silt content of less than 15% has proved to be rich in ice.

PERMAFROST THAW ASSOCIATED WITH TUNDRA FIRES IN NORTHWEST ALASKA	E-2

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Thaw depths, soil temperatures, and vegetation cover were measured between 1978 and 1982 in tussock tundra on burns representing current, 1,2,3,4,5,7,8,9, and 10 year old fires in either the Seward Peninsula or the Noatak River areas of Alaska. Percentage increase of thaw in tussock tundra on flat terrain was 10-40% during the first 5 years following fire, with a possible peak at 2 years and a return nearly to prefire thaw depths by the tenth year. Thaw depths following fire were significantly deeper in tussock tundra on slopes (> 5%) than on flatter terrain. Tussock tundra soil temperatures were significantly higher in a 3-5 week-old burn than in an unburned control, but were similar to the control in a 10 year old burn. Increases in vascular plant cover following fire in tussock tundra averaged 10% per year during the 10 years following fire and could account for decreases in thawing and soil temperatures over this time. Other factors, such as seasonal time of burning, thickness of the soil organic horizons and tussock density, vary regionally and may affect postfire thawing. Prolonged deeper thawing found in burned white spruce taiga emphasizes the importance of vegetation recovery for ameliorating postfire thawing regimes.

DISTRIBUTION AND GEOLOGY OF GROUND ICE ALONG THE YUKON PORTION OF THE ALASKA HIGHWAY GAS PIPELINE NORTH OF KLUANE LAKE	P-5

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Ground ice occurs within specific geologic environments along the Alaska Highway Gas Pipeline in the Yukon Territory. At shallow depths, aggradational ice is commonly in the form of ice lenses and rarely in the form of ice wedges. Great thicknesses of aggradational ice are

present where thick fine-grained postglacial sediments have accumulated. Epigenetic ground ice has formed in fine-grained sediments under poorly drained ground adjacent to streams, lakes, swamps, ponds and drainageways. It has also formed in fine-grained sediments draped over truncated permeable strata, in fine-grained sediments complexly interbedded with coarse-grained sediments, and in fine-grained sediments adjacent to bedroc'k valley walls. Generally, epigenetic ground ice has formed in environments where ample groundwater has been supplied to aggrading permafrost tables, environments characterized by high groundwater gradients.

A MATHEMATICAL MODEL FOR PATTERNED GROUND: SORTED POLYGONS AND STRIPES, AND UNDERWATER POLYGONS

P-7

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This paper presents a model in which Rayleigh convection of the water in an active layer is responsible for the regularity, size, and shape of some types of sorted patterned ground. These convection cells result in uneven melting of the underlying ice front during thawing. The resulting undulatory ice front provides a pattern of which sorted stone polygons and stripes are the "fossil mirror." The model predicts the width to depth-of-sorting ratio for sorted patterned ground. Furthermore , the model predicts the existence and width to depth-of-sorting ratio of underwater sorted polygons. These predictions are corroborated with field study data from both "normal" and underwater sorted polygons.

GELIFLUCTION DEPOSITS AS SOURCES OF PALEOENVIRONMENTAL INFORMATION	P-5

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A gelifluction lobe above treeline at Walker Lake in the Brooks Range of Alaska was examined for pedological and palynological evidence of the expansion of the boreal forest during the Holocene. Soil pits excavated to the base of the active layer (1 m) revealed organic rich material consisting of ancient vegetation buried by the advancing lobe front. Laminations, platy soil structure, slickensided soil peels, and "plough marks" from pebbles in this organic-rich deposit indicate basal sliding is an important component of downslope movement. Radiocarbon dates obtained from buried organics indicate a relatively constant lobe advance rate of about 3.21 mm yr^{-1} throughout much of the Holocene. A paleosol buried beneath the advancing lobe shows that a degree of soil development comparable to that of modern soils of the area was achieved by about 3,200 years B.P. Pollen spectra from the buried organic layer differ markedly from the regional lake pollen record, but give evidence that the treeline has recently advanced to its modern position during the past 5,000 years, and has not been more expanded in the past. We conclude that gelifluction deposits contain valuable paleoenvironmental data for studies of vegetation history and soil development. Such deposits are particularly important in geomorphic situations where lakes and bogs are absent and site-specific information is required.

INVESTIGATION OF THE AIR CONVECTION PILE AS A PERMAFROST PROTECTION DEVICE	M-1

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Winter performance and summer characteristics were measured for the air convection pile permafrost protection device. Velocity and temperature profiles were measured in the tube and annulus of air convection piles having below ground lengths of 3 m (10 ft) and 6 m (20 ft) containing 0.25 m (10 in) diameter tubes concentric with a 0.46 m (18 in) diameter outer piles. It was found that there was turbulent flow in both the tube and annulus and that the thermal performance could be expressed in terms of Nusselt and Rayleigh numbers by the equation $Nu = 0.21\ Ra^{0.29}$ for temperature differences between

permafrost and ambient air temperature exceeding 14°C (25°F). In another 3 m (10 ft) pile, ice formation rates were measured under simulated summer conditions. It was found that a maximum ice thickness of 3.8 cm (1.5 in) is obtained and that the rate of formation is very slow for above-ground heights of about 2 m (7 ft) or more. Although the air is conceptually stagnant during summer, air movement was detected in the device for surface winds exceeding 2.0 m/s (4.5 mph) for the 3 m (10 ft) pile and 4.5 m/s (10 mph) for the 6 m (20 ft) pile.

SOME EXPERIMENTAL RESULTS ON SNOW COMPACTION	I

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This paper presents the results of snow field compaction at snow temperatures near 0°C and some stress-strain properties obtained from rigid plate load and unconfined compression tests. The data and results of some load tests performed at outer Antarctica are also presented.

POWER LINES IN THE ARCTIC AND SUBARCTIC: Experience IN ALASKA	I

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There is a substantial background of experience on the design, construction, and operation of power lines on and in the frozen earth of Alaska. This paper contains a digest of mostly successful examples of Alaska power line elements operating with the frozen earth. The paper considers footings, anchors, structures, conductor and electric grounding. Examples are taken from operating power systems which serve the small village (50 consumers); the large urban/rural community (50$000 consumers); and a number of federal, state and industry installations.

THE ROLE OF SPECIFIC SURFACE AREA AND RELATED INDEX PROPERTIES IN THE FROST HEAVE SUSCEPTIBILITY OF SOILS

M-5

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Soil properties important to the frost heave phenomenon must be identified to establish which index property tests can aid in evaluating frost heave susceptibility. Following a consideration of existing frost heave theories, the frost heave mechanism was identified as being fundamentally related to the specific surface ara of the soil. Specific surface area may be related to index property test results, specifically, the liquid limit and the clay mineralogy of the fine fraction. Laboratory frost heave tests were performed to develop relationships beteewn index properties and frost heave susceptibility. Tests were performed on soil mixtures consisting of uniform sand with 5%, 10%, and 20% fines of different mineralogic composition, representing a range of specific surface areas. Over 30 frost heave tests were conducted on 11 distinct soil mixtures. The frost heave test consisted of freezing a soil column and noting the intake of water into the specimen as well as the frost heave. Using the concept of segregation potential, the frost heave susceptibility of a soil was found to increase with increasing percentages of fines, decreasing activity of the fine fraction, and, for a specific fine fraction mineralogy, increasing liquid limit of the fine fraction.

DETERMINATION OF THE THERMAL PROPERTIES OF FROZEN SOILS

I

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This paper describes the development of a method for determining soil thermal properties (conductivity and diffusivity) at temperatures close to 0°C, based upon the transient heat flow from a cylindrical copper probe. A very snail heat input and a very sensitive temperature measurement system allow the maximum temperature change in the soil sample to be kept to less than 0.1°C. The soil sample is first cooled to about -10°C, to ensure ice nucleation, and then determinations are

done at closely spaced intervals on a warming curve. At each temperature, a least squares regression on the time-temperature data is used to determine the soil properties. The analytical solution is sensitive to both the soil conductivity and the apparent heat capacity; therefore the latter is also determined independently using the unfrozen water content curve obtained via time domain reflectometry. Results for two saturated silts are presented.

PERMAFROST STUDIES ALONG THE NORTHERN ALASKAN COAST USING GEOPHYSICAL TECHNIQUES	I

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The results of several field seasons of work are presented in the form of summary maps, tables and charts. These data were collected in the region of Prudhoe Bay, Alaska along 250 kilometers of coast and to distances of 20 kilometers off the coast. Seismic refraction methods, both on offshore islands and in adjacent waters, were used to map frozen and nonfrozen materials in the study area. One result is a map showing locations of shallow, less than 40 meters beneath the ocean surface, permafrost zones. Another map presents typical compression wave velocities measured in frozen and nonfrozen materials throughout the region. An extensive set of refraction measurements near Prudhoe Bay is used to obtain compressional wave velocities in bottom materials including sands, sandy gravels, and silty sands. Velocity data from 10 islands in the region, including both natural and man-made gravel islands are presented and used to interpret the amount of ice bonding in the island materials.

ANALOG METHODS FOR DETERMINING LONG-TERM DEFORMABILITY OF PERMAFROST MATERIALS	C-2(I)

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The paper demonstrates the possible use of temperature-and-stress-time analog methods for predicting long-term deformation of frozen earth materials. A solution was achieved which allows one to process the data from ground testing using a spherical punch by analog methods.

Comparison of the long-term deformation as computed by the analog methods with that determined by creep equation as suggested by S. S. Vyalov has shown that they coincide almost exactly.

THE STRUCTURE OF ROCK STREAMS	I

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The authors have investigated rock streams by analyzing the frozen materials of which they are composed. On the basis of abundant data it was shown that rock streams are not chaotic accumulations of coarse material as was earlier considered but orderly geodynamic systems evolving according to certain rules. Three hypsometric belts have been distinguished, merging one into the next in orderly fashion. Each of these belts consists of a strictly defined combination of facies and subfacies differing both in structure and in the range of factors affecting its movement. The range of sediments occurring in a rock stream depends on its genesis, stage of development, and geological and geomorphological peculiarities. The data obtained by the authors have enabled them to elaborate scientifically substantiated recommendations as to the building of engineering structures on rock streams or in their zones of impact and to approach environmental protection in a rational fashion.

FAIRBANKS WASTEWATER TREATMENT FACILITY: GEOTECHNICAL CONSIDERATIONS	C-5

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Subsurface investigation and geotechnical evaluation of the site of the Fairbanks wastewater treatment facility identified the soil profile, the extent of frozen ground , and other pertinent geotechnical parameters necessary for design and construction considerations. Primary geotechnical-related concerns included thaw settlement, extent of overexcavation, and minimizing groundwater infiltration into the excavation. The overlying ice-rich silt stratum was considered to be unsuitable for proposed site development because of its high thaw strain potential.. The underlying gravel-sand stratum was considered to be

suitable for foundation bearing, although the potential for limited thaw strain and seismically induced dynamic densification were of concern. From all indications, the structure has not exhibited any significant settlement during the period of operation. An example of differential movement attributed to a possible combination of soil thawing and heaving occurred when subsequent placement of the septic disposal building partially on silt outside the original excavation and backfill limits resulted in significant tilting of the structure.

ACTIVE LAYER ENERGY EXCHANGE IN WET ANI) DRY TUNDRA OF THE HUDSON BAY LOWLANDS	G-1

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Results of weekly calculations of ground heat flux for Churchill, Manitoba, made from September 1981 to December 1982 are presented. Measurement sites included a variety of well-drained upland, semiupland and wet lowland locations, a forested site, and an ice-cored palsa. Net radiation, Q^*, was measured at representative sites in summer and at one site in winter with the latter measurement being applied with corrections to all sites. The ground heat flux, Q_G, was divided into sensible and latent heat components and was determined from soil moisture and temperature measurements. Snow depths were shallow on open tundra sites and deep at the forest and a forest-influenced site. As a result, final snowmelt at the latter sites occurred 7 weeks later than at the former ones. Q^* was similar for all sites with a maximum variation of 14% from the all-site average. Active layer depths on upland sites were double those in the wet lowland. During the thaw season Q_G was almost the same for all sites and averaged 12% of Q^*. Q_G during freezeback fully compensated for the net radiational heat loss due to negative Q^* in winter. The similarity in Q_G fOr such a heterogeneous group of sites is explained in terms of thermal conductivities and vertical temperature gradients. The results are seen as having some general applicability and show that Q_G is an important component of the surface energy balance.

PORFREEZ: A GENERAL PURPOSE GROUND WATER FLOW, HEAT AND MASS TRANSPORT MODEL WITH FREEZING, THAWING ANI) SURFACE WATER INTERACTION	I

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This paper describes the mathematical basis and verification of a model for simulation of coupled fluid flow, heat and mass transport processes with freezing, thawing and interaction with surface water streams. The model solves the dynamically coupled governing equations with appropriate algorithms for changes in the phase of water substance and porous matrix properties. The model provides for two-dimensional Cartesian or three-dimensional axisymmetric coordinate systems. The host porous media may be arbitrarily inhomogeneous and anisotropic with time-dependent properties. The convective and density-disparity phenomena are dynamically coupled and the ground water body may interact with an overlying stream and the atmosphere. The boundary conditions may be of the Dirichlet, Neumann or mixed kind. The phase change algorithm is based upon the Clapeyron relations developed by Miller and co-workers and provides for both pressure and temperature dependence. The model has built-in options for alternate relations for changes in the porous matrix properties. It provides for interaction with an overlying stream through coupling of the ground water flow and heat trasnfer equations with those for a fully developed turbulent stream. The method of solution is Nodal-Point-Integration coupled with Alternating-Direction-Implicit procedure. The model provides for nonuniform meshes and is second order accurate both in time and space. The various components of the model, including the freezing/thawing mechanisms have been verified against analystic solutions, laboratory data and other numerical models. The paper presents verification for the problem of a propagating freezing front.

DESIGN CONSIDERATIONS FOR LARGE STORAGE TANKS IN PERMAFROST AREAS	c-5

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Large water and/or oil storage tanks (50,000 gal. or more) are usually necessary for camps, sites or communities in the Arctic. The design, construction, and operational problems for over 40 large water storage tanks in arctic and subarctic Alaska are reviewed and summarized. The majority of the difficulties encountered with the tanks fall into three areas: foundations, interior painting, and outside

insulation systems. Foundation settlement or heaving has proven to be the most widespread problem with large storage tanks. Unfrozen lenses, "warm" permafrost, and incorrect adfreeze strengths have all contributed to the several instances of settlement. Piling and gravel pads have both received widespread used, depending on local soil conditions and the availability of equipment and materials. Another very common problem is the failure of the interior painting sytems. These failures have occurred with both the vinyl and epoxy paint systems and tend to be caused by the lack of adequate curing temperatures, inadequate ventilation during curing, and the individual layers being applied too thick.

THAWING AND FREEZING IN TUNDRA SOILS	I

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At Stordalen, Abisko, Northern Sweden, a tundra mire has been subject to studies of the annual cycle of soil thawing and refreezing. The microrelief of the surface shows elevated and depressed elements [illegible] of mineral soil, mostly silt. Thawing of elevated elements, which are drier, reaches smaller depths than thawing of depressions. Thus the frost-table topography is more pronounced than that of the ground surface. These conditions are opposite to those observed at, for example, Barrow, Alaska. The differences are explained not only by slightly different soils at the two compared sites. The moisture content of the elements at Stordalen show also such a great difference that, in the moist depressions, a higher thermal conductivity dominates over that of the dry, and thermally insulating, organic top-soil of the elevated elements. A secondary thaw has been observed at the frost table at the time when refreezing begins at the surface in October. Thawing throughout the winter has also been observed at the frost table if an unfrozen layer remains below the seasonally refreezing layer. This secondary thaw has not been described previously in the English literature. Thaw depths show strong correlations with thawing index and precipitation during May and June, but decrease as the thaw proceeds.

CREEP OF FROZEN SOILS ON ROCK SLOPES	P-6

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This article presents the result of experimental investigations into the creep of frozen materials on rock slopes. Analysis of field data revealed that creep in frozen waste heaps in northern regions is a typical theological process. Laboratory investigations included two types of tests: simple shear tests and tests of shear-with-skewing. More than 400 samples of soil frozen to the rock were tested. The mechanics of shear were investigated and the formation of two zones was established: a zone of contact, and an overlying zone. By using the data from the experimental studies and from field observations it was possible to develop a method of calculating the rate of creep of frozen waste heaps on rock slopes and to predict the failure of these waste heaps.

ACCUMULATION OF PEAT CARBON IN THE ALASKA ARCTIC COASTAL PLAIN AND ITS ROLE IN BIOLOGICAL PRODUCTIVITY	E-3

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Terrestrial peat on the coastal plain of arctic Alaska is estimated to be accumulating at a rate equivalent to about 7-18 g C $\cdot m^{-2} \cdot yr^{-1}$, or 10-20% of the annual net carbon fixation. The accretion of root matter and surficial vegetation as peat is inversely proportional to mirobial activity and grazing pressure by herbivores, since the depth of the permafrost horizon responds to the insulative properties of the vegetative mat. Basal peats along the coastline in the vicinity of Prudhoe Bay range from 8,000-12,000 years B.P. and their stable carbon isotope ratios indicate that vascular plants and mosses contribute the bulk of the organic matter. The aquatic habitats of the tundra represent active sites for peat oxidation and conversion to faunal biomass. Inputs of peat occur via streambank erosion, thaw lake expansion and coalescence, and coastline inundation and erosion. Stable carbon isotope ratios and carbon dating of surface lake sediments indicate that peat, rather than algal production or recent terrestrial vegetation, constitutes the bulk of the organic matter.

SOLID WASTE DISPOSAL NATIONAL PETROLEUM RESERVE IN ALASKA	I

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The disposition of solid waste has always been a problem for twentieth century man and in the permafrost areas of the Arctic the problem is compounded. The most utilized option has been to backhaul the debris to urban areas for disposal or recycling. In the mid-1940's the Navy's exploration program brought tons of supplies to the north slope of Alaska. This logistics deluge continued through 1953 when the construction of the Air Forcefs Distant Early Warning (DEW) line began, and since, there have been many years of continued government activities and their concurrent supplies. Under the Navy and later the U.S. Department of the Interior (USGS) an attempt was made to clean up and consolidate this debris. In the winter of 1979-1980 a pilot project was undertaken to bury the debris at two sites. A Cat train would travel over approved trails to the designated burials during the winter months when such travel was environmentally safe. A D-8 Caterpillar tractor with blade and ripper tooth was used. The overburden was stripped to one side and then the hole was dug using tooth and blade. When the hole was deep enough to take the debris and still be covered by a minimum of 2 feet of fill, the debris was pushed in, compacted, and everything covered. Once covered, the overburden was spread again, the scar seeded and fertilized, and the seed and fertilizer walked in with the Cat tracks. A seed mixture high in tundra bluegrass seed and standard 10-20-10 fertilizer was employed. The high rate of survival of the original plants in the overburden was surprising and gratifying. Sume burials were difficult to locate from the air after only two growing seasons.

SOME NONTRADITIONAL METHODS FOR SEISMIC INVESTIGATIONS IN PERMAFROST	I

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Small taliks and ice masses, both occurring at shallow depth, as well as other features make refraction and reflection techniques rather ineffective for permafrost studies. Through the use of data on the physics of ultrasonic oscillations and on seismic wave velocities and dynamics observed in permafrost areas, some nontraditional seismic exploration methods are suggested. They are based on converted mono- or polytype Rayleigh waves generated at the permafrost-talik boundaries, reverberations over ice layers, and other parameters. These methods enable us to enlarge the scope of permafrost research. Furthermore, the utilization of high-amplitude Rayleigh waves ensures environmental protection.

ECOLOGICAL RELATIONSHIPS WITHIN THE DISCONTINUOUS PERMAFROST ZONE OF SOUTHERN YUKON TERRITORY — I

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Recognizing the immediate need for baseline resource information to cope with present and anticipated exploitation and development, an exploratory level integrated resource survey was undertaken in the Yukon Territory. This survey, which identified 22 broad scale ecosystems (Ecoregions), was succeeded by more detailed ecological land classification studies (Ecodistrict, Ecosection) in a number of locations throughout the southern part of the Territory. During these surveys, a number of ecosystems containing perennially frozen soils and/or that evolved as a result of permafrost degradation were examined and characterized. Several of these are described and relationships between the various ecosystem components discussed.

SEASONAL THAWING OF PALSAS IN FINNISH LAPLAND — P-4

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This study investigates the thickness of the active layer and its temporal and regional differences in palsas - permafrost cored peat mounds - in the bogs of northernmost Finland. Regional differences in the rate and amount of thawing are not found. The normal thawing depth per year is 55-70 cm. The minimum thickness of the insulating peat layer on palsas in Finland appears to be about 50 cm.

REVEGETATION OF ARCTIC DISTURBED SITES BY NATIVE TUNDRA PLANTS	E-2

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The aim of this research was to develop new methods by which the recovery of native vegetation might be promoted on development-related disturbances in northern Alaska. Current methods depend on an expensive and heavily supported introduction of nonnative grasses, often with detrimental effects on native plant recovery. The research included studies of both native plant population dynamics and the regulation of tundra nutrient cycles. The results showed that the single most important factor in native vegetation recovery is preservation or replacement of the upper organic layer of soil. The organic layer is important because (1) it contains a large, readily germinable native seed pool, (2) native seed germination rates are higher in organic than in mineral soils, (3) it reduces soil thaw and thermokarst erosion, and (4) it reduces nutrient losses and nutrient movement in the soil, resulting in more normal patterns of nutrient availability. Future management practices should include conservation of soil organic matter as a top priority, with heavy fertilization and seeding only where erosion potential is great or the organic mat is lost.

A CLASSIFICATION OF GROUND WATER IN THE CRYOLITHOZONE	H-2

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A subdivision is presented of the major types of groundwater in the cryolithozone, based on conditions of deposition and on the dynamics of development of the cryogenic aquicludes confining them. Among suprapermafrost waters (type 1) one may distinguish suprapermafrost vadose water (subtype la) and suprapermafrost groundwater (subtype lb). Intrapermafrost water (type 2) may also be subdivided into two subtypes. The first involves intrapermafrost water confined by horizontal cryogenic aquicludes (2a) and the second intrapermafrost water capable of vertical movements between frozen materials (2b).

Subpermafrost waters (type 3) are subdivided into those in contact with the bottom of the permafrost (subtype 3a) and those not in contact with it (3b). The groundwater subtypes thus identified nay be further subdivided into different categories and subcategories.

A BRIEF INTRODUCTION TO PERMAFROST RESEARCH IN CHINA	PRC

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The study of permafrost in China has progressed since the initial work in 1949, and is now at the state of all-out development. The distribution and characteristics of permafrost in China have been analyzed, and taliks and other periglacial phenomena have been classified. Several kinds of permafrost maps have been compiled, including a comprehensive map showing the distribution of glaciers and frozen ground in China. A repeated segregation theory has been suggested to explain the formation of a massive ice layer beneath the permafrost table. Fossil periglacial phenomena are used to reconstruct the distribution of ancient permafrost. A series of applied parameters, including the thermal, physical, and mechanical parameters of typical soils, have been provided. An engineering classification system for frozen soils has been suggested. Some theories on frost-heaving, thaw settlement, heat transport, moisture migration, and attenuation creep of frozen soils and on the similarity criteria in model tests are recommended. Studies in road engineering, water conservation engineering, industrial and civil construction, and artificial freezing techniques for mining have been conducted. More than 2000 km of railways have been built in permfrost regions, and an oil pipeline over 1000 km long has been built from Golmud, Qinghai, to Lhasa, Xizang (Tibet).

A COMPREHENSIVE MAP OF SNOW, ICE, AND FROZEN GROUND IN CHINA (1:4,000,000)	I

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On the basis of recent progress on the study of glaciers, frozen ground, and seasonal snow and ice, a preliminary and comprehensive map of snow, ice, and frozen ground in China has been compiled by the Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, to express the general distribution of these phenomena in our country. The map shows the following items: (1) mountain glaciers, including the continental and monsoon maritime types of glaciers as well as the current isopleth of the snow line and the hazardous places of glacial debris flows and flood from burst of glacial lakes, (2) seasonal snow, containing the stable and unstable snow cover regions, *(3)* seasonal ice, involving sea ice and river-lake ice, *(4)* permafrost, including continuous, discontinuous, and insular permafrost, (5) seasonally and instantaneously frozen ground, and (6) periglacial phenomena and Quaternary glaciation, such as the isopleth of the past snow line, blockfields, stone stripes, polygons, frost-heave hummocks, and involutions.

DESIGN AND CONSTRUCTION OF CUTTING AT SECTIONS OF THICK-LAYER GROUND ICE | 1

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Cutting at sections of thick layer ground ice upsets the original ground layer's natural state of thermal equilibrium. To keep a new system stable, its thermal state, within a certain scope, must be restored to the original state or adapted to the conditions caused by the change of thermal state. Using this as the starting point for determining protective measures, the authors summarize the practical experience and experimental and research findings accumulated in China since 1960, especially recent ones made at sections with thick layers of ground ice on the Qinghai-Xizang Plateau, and present two major proposals for protecting permafrost in situ--the refilling and heat preservation method, based on the principle of similarity of heat power, and the method of supporting (sustaining) a structure that is based on the principle of local thawing self-burial stability. The design essentials of these techniqus are described, and representative patterns of cross-sections are given. The influence of the harsh weather conditions on the Plateau on construction quality, technology, and machinery is discussed, and the main points of links in construction are emphasized.

AN EXPERIMENTAL STUDY OF CRYOGENIC FACTORS AFFECTING GEOLOGICAL PROCESSES	I

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It was determined that rocks subjected to stress for long periods at negative temperatures experience a reduction in stability. This accelerates the disintegration of the rocks in the hypergenesis zone due to pressure release unloading, weathering, and erosion. This effect should be taken into account in mining, construction and geological investigations. It was demonstrated that weathering of rocks in the cryolithozone is accompanied by the simultaneous formation of the unconsolidated materials of varying particle size. Cryogenesis results in intensive removal of ions of some elements in water and thus increases the mineral content of the ground water. Migration of matter in the cryolithozone is clearly demonstrated both in ice and in water. Elements differ greatly with regard to their mobility, something which distinguishes the cryolithozone from other climatic zones.

EXPLOSIVE EXCAVATION OF FROZEN SOILS	c-5

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Explosive cratering trials were carried out at four distinct sites in the vicinity of Inuvik, NWT. The primary aim was to correlate measured properties of the frozen soils with the cratering results. Two of the sites were underlain by coarse grained, sand soils, and two by fine grained silty soils. At each site ground temperatures and seismic properties were measured and core samples taken to allow laboratory measurement of moisture content, density, strength, and seismic properties. At each site seven craters were formed using 5 kg charges of ANFO explosive detonated at various depths. From crater measurements the optimum depths of charge burial and the maximum dimensions of the apparent and true craters were found. It was concluded that no single property is sufficient to characterize the soil with respect to its cratering behavior. Parameters derived from the seismic velocities appear to offer the best hope for possible characterization.

DEEP ELECTROMAGNETIC SOUNDING OVER THE PERMAFROST TERRAIN IN THE MACKENZIE DELTA, N. W. T., CANADA | G-2

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A number of deep electromagnetic (EM) soundings using a multifrequency and a transient system were carried out over several locations near Tuktoyaktuk, N.W.T., during the spring of 1982. The locations were near drill holes that had already been surveyed with various geophysical logs. The multifrequency EM system used a vertical magnetic dipole as the transmitter with 128 frequencies from 1 Hz to 60 kHz for the detection of conductive horizons to a depth of 700 m from the surface. The transmitter for the transient soundings was a large Turam-type loop that can transmit square wave pulses with two base frequencies of 3 and 30 Hz. The motivation for the experiments was to test a relatively inexpensive and environmentally acceptable geophysical technique for detecting horizontal layers at large depths, especially the contact between ice-bonded permafrost and the underlying unfrozen sediments, which varies in depth from 250 m to 650 m in the Mackenzie Delta area. The multifrequency EM sounding interpretations generally agreed well with well-log information at most sites. The time-domain results, on the other hand, detected major interfaces but could not resolve minor discontinuities. This could be attributed to the fact that the resolving capability of the time-d'omain system was somewhat less than that for the multifrequency system. The experiments demonstrated the viability and usefulness of conducting routine electromagnetic soundings for detecting and delineating horizons within areas of thick continuous permafrost.

SUMMER STREAMFLOW AND SEDIMENT YIELD FROM DISCONTINUOUS-PERMAFROST HEADWATERS CATCHMENTS | H-1(1)

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The presence of permafrost in a catchment system affects the" hydrology and water quality of streamflow. Summer streamflow, and suspended sediment in streamflow from first-order catchments in the discontinuous-permafrost taiga of central Alaska (latitude 65"10'N) have been analyzed. In terms of resultant streamflow, permafrost-

underlain terrain is much more responsive to precipitation inputs than is permafrost-free terrain and proportion of permafrost, with concomitant cold, thick organic layers overlying mineral soil, is a primary determinant of differing streamflow characteristics in headwaters catchments. A permafrost-free first-order stream consistently has higher (summer) baseflow than does an adjacent permafrost-dominated first-order stream. A small permafrost-dominated catchment has consistently lower suspended sediment concentrations than does a similar-size virtually permafrost-free catchment. During storm-free periods suspended and dissolved loads are consistently less than 5 $mg\ell^{-1}$ in both basins. Concentrations are commonly an order of magnitude higher during storm events. Sediments and stream–flow relationships are highly variable in this stream system.

SNOW AND ICE IN CARIBOU-POKER CREEKS RESEARCH WATERSHED, CENTRAL ALASKA

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Seasonal snow and ice study has been conducted in the 104 km^2 Caribou-Poker Creeks Research Watershed (latitude 64°30'N) since 1969. Snow accumulation was measured annually on 1000-m “transected” at four locations on north- and south-facing slopes from 1970-1975. Three standard snow courses and one snow pillow installed in 1969 are operated by the Institute of Northern Forestry, USDA Forest Service (in cooperation with Soil Conservation Service). A special study of snowpack drifting at Caribou Peak (773 m elevation) was conducted in 1975-76. The research basin provides good examples of both "taiga" snow (extensive depth hoar development, density 0.20 g cm^{-3}) and of “tundra” snow (extensive drifting, reworking, and wind-packing, density up to 0.45 g cm^{-3}). Extensive seasonal ice (aufeis) forms in the valleys of this research basin during most winters. Aufeis can impound up to 10% of total winter streamflow as solid-state storage, with local accumulations up to 3+ m thick and occupying an entire valley floodplain. This aufeis is hydrologically significant: water is stored as ice, for release by melt following the major snowmelt season; aufeis obstructs streamflow, often redirecting flow out of normal channels; aufeis causes severe problems for streamflow measurement programs; aufeis markedly modifies local microclimate and aquatic habitats. The Caribou-Poker Creeks Research Watershed, which has been designated as one component of a national network of Experimental Ecological Reserves, provides an “outer laboratory” suitable for long-term observation and research on seasonal snow and ice in the subarctic.

PERMAFROST SENSITIVITY TO CLIMATIC CHANGE | G-1

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Possible large-scale climatic warming, due to the so-called greenhouse effect, has obvious implications for the stability of permafrost conditions. This paper presents a preliminary examination of the possible effects of climate change on the ground thermal regime in the zone of discontinuous permafrost. Caution must be exercised in extrapolating a warming trend in the atmosphere to the ground. The significance of atmospheric warming for permafrost depends on the accompanying increase in the ground surface temperature, and on the proximity of ground temperatures to 0°C. The characteristics of natural surfaces determine the interaction between climate, microclimate, and ground thermal conditions. A numerical microclimatic model, based on the surface energy balance, has been used to investigate the range of ground temperature response under a uniform climate, due to variation in site conditions. Site factors included slope, albedo, wetness, roughness, snow cover, and soil thermal properties. Site wetness and snow cover were the most sensitive factors. The potential for permafrost degradation during 25 years of climatic warming was then simulated for various sites using climatic data for Whitehorse, Yukon Territory. In one part of the analysis, three different patterns of warming were analysed at a single site. The distribution of warming during the year had relatively little effect on long term permafrost degradation. Much greater differences in degradation resulted from variation in site conditions, for the case of uniform warming.

RESISTIVITY LOGGING OF FROZEN ROCKS | I

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The article examines the present state of some aspects of resistivity logging as a means of studying the cryolithozone, and the results of investigations in the past few years. The efficacy of resistivity logging is determined by the differentiation of the electrical properties of frozen ground, by the accuracy of measurement and by the technical conditions of drilling. The potential of the major methods is being fully realized in holes drilled without using fluid solutions as long as the values for electrical resistivity of the frozen rocks do not exceed 800-1000 ohm-meters. An increase in the

range of measurements turned out to be possible only by using measuring equipment with a high input resistance and of new technical elements that substantially improve the accuracy and operational characteristics of resistivity logging equipment where parameters of constant and low frequency electric fields were being measured in dry holes. The investigations carried out and the observational error achieved allow one to apply resistivity logging studies of low-gradient processes occurring within the permafrost zone, to improve the methods and technology of studying geoelectrical cross sections, and to study variability in the physical and chemical properties of permafrost in relation to the effects produced by external physical factors.

σD AND σ^{18}O COMPOSITION OF SUCCESSIVELY-FORMED ICE LAYERS : IMPLICATIONS IN PERMAFROST STUDIES	I

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Points representing, on a σD - σ^{18}O diagram, the isotopic composition of successively-formed ice layers during freezing are aligned on a straight line with a slope different from the well-known precipitation slope (S ≃ 8). The value of the slope can be determined from the initial isotopic composition. In a system where water is not renewed during the process of freezing the successively-formed ice layers show more and more negative values in σD and σ^{18}O. Two studies confirm the validity of these theoretical results. Firstly, experiments on progressive unidirectional freezing were conducted in the laboratory. Results indicate that the samples are aligned on the predicted straight line in their predicted relative positions. Secondly, ice layers formed by refreezing of meltwater in the upper permafrost zone beneath a Canadian Arctic glacier were sampled. Results indicate that these samples are aligned on a slope (S ≃ 5) different from that of glacier ice samples taken nearby (S ≃ 8). This slope is in close agreement with that calculated from the model. This study sheds some light on the problem of the origin of ground ice masses and indicates that care must be taken before attempting to interpret a difference in σ^{18}O of ground ice in terms of paleoclimate.

ENGINEERING DESIGNS FOR LAYING PIPELINES IN PERMAFROST AREAS AND BOGGY TERRAIN IN THE NORTH	C-1

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On the basis of extensive research and prototype construction, the USSR has accumulated considerable experience in the area of northern pipeline construction; engineering designs have been developed and standard documents produced to solve the problems of building large-diameter pipelines in northern regions. Systems for laying pipelines which are new in principle have been developed for various conditions. These include an above-ground slightly curved section; an above-ground system with partial compensation for longitudinal strains with patented devices for anchoring the pipeline on heaving or water logged sections; an underground system on supports for floodplain sections with permafrost conditions; a system where the exposed pipeline is laid on the surface with compensating sections; and finally various modifications of all of these. Methods of analyzing the various systems and recommendations as to engineering design have been developed.

GLOSSARY OF PERMAFROST TERMS	I

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A revision of the Glossary of Arctic and Subarctic Terms (Arctic, Desert, Tropic Information Center Publication A-105, 1955) is underway in order to make it more useful to polar researchers in light of advances in technology and changes in terminology that have evolved over the years. One of the objectives in this revision is to convert the 1955 glossary into a Glossary of Polar Terms by incorporating the large body of terms that have become common place in the multi-disciplinary and international research programs in Antarctica. A first attempt in English may provide the basis for a multilingual glossary if the terminology is generally accepted internationally. Among the expansions of terms that have resulted from the revision of the 1955 ADTIC glossary is in the field of permafrost. Draft copies of terms and definitions are being readied for distribution to specialists in the various disciplines. Their critiques of term lists will be used to improve the drafts and compile a revised glossary. All terms included in the master file of the glossary are stored on word processor discs, facilitating editing and sorting of particular subject areas, such as permafrost, for printouts of selected terms. A preliminary version of the glossary will be presented at this Conference, and completion of the revised glossary is expected in 1984.

INVESTIGATIONS AND IMPLICATIONS OF SUBSURFACE CONDITIONS BENEATH THE TRANS-ALASKA PIPELINE IN ATIGUN PASS	C-1

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In June 1979, a leak was detected in the trans-Alaska pipeline in Atigun Pass, located in the east-central Brooks Range. A major investigation was performed for the purpose of providing detailed subsurface information as input to the design of remedial measures to repair the leak and to detect any other problem areas. Another area of pipe settlement was found on the south side of the pass in an insulated section of the pipeline. Subsurface exploration revealed thawing of the foundation materials, apparently as a result of subsurface water flow. Large-diameter diamond coring with refrigerated fluids was found to be the only exploration method capable of providing samples of adequate quality for thaw strain testing. Thaw strain test data, in conjunction with information on subsurface conditions obtained by refrigerated coring, allowed estimation of the settlement that might occur if the pipeline foundation materials were to continue to thaw. Data from test holes and other investigations during 1980 and 1981 have allowed determination of the need for additional repair work and a rational prediction of future pipeline performance.

MOISTURE AND TEMPERATURE CHANGES IN THE ACTIVE LAYER OF ARCTIC ALASKA	I

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Occasional deep percolation of meteoric water in the foothills of the Brooks Range is critical to the genesis and physical behavior of well-drained Spodosols. In situ measurements of soil water tension and temperature were made during three consecutive summers at two sites in northern Alaska, one in the boreal forest and one in the arctic tundra. Soil climate responses to changes in weather conditions are explained with additional data on soil physical properties measured in the laboratory. Important factors controlling depth of wetting front penetration include precipitation, vegetation cover, soil texture, and antecedent soil moisture content. Coarse-textured soils in the arctic tundra show leaching of the profile with only 5-7 mm of precipitation.

Medium-textured soils in the boreal forest require in excess of 25 mm of rain to overcome high evapotranspirative demands. Stable soil temperature profiles develop by July, exhibiting a sharp decrease in temperature with depth. These conditions are abruptly altered by a significant pulse of heat transmitted through the active layer during summer storms. This study shows that deep percolation is an important mechanism of transport for soil water, solutes, and heat at well-drained sites in permafrost-affected regions.

PLEISTOCENE DIAPIRIC UPTURNINGS OF LIGNITES AND CLAYEY SEDIMENTS AS PERIGLACIAL PHENOMENA IN CENTRAL EUROPE	I

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Diapir-like intrusions of lignite into the gritty or sandy topsoil, several meters thick, are widespread in central European lignite fields and wherever clayey sedimentation are lying near the surface. These structures occur outside the Scandinavian ice sheet. This eliminates the assumption that this formation was primarily caused by the weight of the ice. Rather, the upturning were caused by density inversions during the degradation of the permafrost. The light lignite, water-saturated by the freezing process, rose up--much the same as saline domes--into the overlying layers having a greater specific weight. Previously frozen lignite has an agglomerate structure, resembling coffee grounds. Disturbed layers thus provide information about the minimum depth of permafrost penetration. If it did not penetrate as far as the lignite, then the latter did not become upturned. The boundary between agglomerate and undisturbed lignite appears to mark the limit of maximum frost penetration and thus the lower limit of the permafrost. The maximum thickness of the Pleistocene permafrost in central Europe decreases rapidly from several dozen meters in the northeast to less than 10 m in the west and southwest.

LARGE-SCALE DIRECT SHEAR TEST SYSTEM FOR TESTING PARTIALLY FROZEN SOILS	I

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The design and construction of offshore earth-fill structures in the arctic environment requires the determination of mechanical properties of the construction material under appropriate thermal conditions.

Salt-water saturated materials exhibit a zone of partially frozen soil at the frozen/unfrozen soil interface. To define the critical failure surface and governing shear strength in this zone, the effects of partial freezing on the mechanical behavior as a freezing front advances must be well understood. A large-scale direct shear apparatus was developed in order to test the shear strength of a soil sample through an undisturbed partially frozen interracial zone. The apparatus has the capability of shearing a 30 cm square frozen specimen using a wide range of shear displacement rates. The specimen is instrumented with thermistors to provide the capability to monitor the thermal regime as the partially frozen zone progresses toward a predetermined shear plane in a 30 cm deep sample. The shear box is constructed from transparent plexiglas material which minimized thermal disturbance and permits visual inspection of the sample during shearing. A sample preparation system was designed to provide a specimen having a reproducible thermal condition while thermal and mechanical disturbance during handling is minimized. The paper presents details of the design of the large-scale direct shear apparatus and testing procedures. Typical results from tests conducted on saline gravels using the system are shown which demonstrates the usefulness of system and procedures for determining the strength of partially frozen soils.

A COLLOCATION ANALYSIS FOR SOLVING PERIODIC THAWING AND FREEZING PROCESSES IN ACTIVE LAYERS OF PERMAFROST	M-2

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The periodic variation of the ground surface temperature causes alternative thawing and freezing processes in the active layer of the permafrost. The ground surface is an important location of the present problem, which is selected as the collocation point of the analysis. Analytical results are compared with those obtained from the zeroth-order and the first-order quasi-steady approximations, and the first-order perturbation method. The accuracy of the collocation analysis is not less than that obtained from the first–order perturbation approximation.

DEFORMABILITY OF CANALS DUE TO FREEZING AND THAWING — C-5

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The destruction of canals by frost heave and thaw settlement is a serious problem in the northern regions of China. To lay down effective measures for preventing frost damage, the author has investigated the deformation characteristics of canals during freezing and thawing periods in-situ. The results show that frost heave differs along the cross-section of a canal: it is greatest at the bottom, smaller on the slope, and least on the top. The length of the slope is shortened during freezing and extended during thawing, and depends mainly on the amount of frost heave at the foot of the slope. Freezing and thawing will cause the collapse of canals and destroy the lined pavement, due to the distortion of concrete slabs, soil erosion, and thawing collapse. Based on the data, the author has worked out formulas for estimating both the amount of slope shortening and the displacement of concrete slabs, and proposes measures to protect canals from frost damage.

VENTIFACTS AS PALEOWIND INDICATORS IN A FORMER PERIGLACIAL AREA OF SOUTHERN SCANDINAVIA — P-2

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Studies of ancient wind activity have been performed in a coastal area of southern Sweden, situated below the highest shoreline of Late Weichselian time. The area is composed of fluvioglacial and eolian deposits. Cultivated fields show very distinct patterns (crop marks) of cast ice-wedge polygons. Pavements of intensely blasted stones are found below an eolian sand cover. Many ventifacts are sculptured with two facets. Larger, well-anchored ventifacts have been studied in detail (fluting and grooving) to determine the active wind direction. The main directions of wind-blasting are from the ENE-ESE and W-SW sectors. The east-facing facets are the most numerous and generally also represent the greatest re-shaping of stones. According to shoreline chronology, the area was deglaciated about 13,000 B.P. and constituted a periglacial environment. During this period the area was constantly influenced by steady, easterly winds from the nearby ice cap, shaping the east-facing facets. The west-facing facets are considered to have been formed during the Allerød period (11,800 to 10,900 B.P.).

HEAT AND SALT TRANSPORT PROCESSES IN THAWING SUBSEA PERMAFROST AT PRUDHOE BAY, ALASKA	G-3

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The thickness of the subsea thawed layer near the West Dock, Prudhoe Bay, Alaska, and its temperature, pore water salinity and pore water pressure are described. The pressure data are the first of their kind and provide good evidence for non-hydrostatic behavior that is probably due to pore water motion. Present knowledge of heat and mass transport mechanisms controlling the thawed layer development is summarized. Heat transport is conductive, but salt transport (necessary because temperatures are negative) is by pore water motion, probably on the order of a few tenths of a meter per *year.* What drives the motion is still uncertain. Driving by the release of relatively fresh, buoyant water by thawing must occur, but it may not provide enough energy to explain the observations, Driving by surface wave action seems unimportant, at least at West Dock.

WINTER CONSTRUCTED GRAVEL ISLANDS	C-4

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This paper addresses a theoretical assessment of the performance of winter constructed gravel islands with respect to settlement. The basis of the material presented is our work during the recent winters in which we have inspected several gravel islands as they were constructed in the Alaskan Beaufort Sea as well as other winter constructed gravel pads. Construction procedures used to build the islands are summarized, and the effect of technique and construction materials on the subsequent performance of the fill is addressed. Our observations indicate that total island settlement potential is primarily dependent on the inplace dry density of fill. The actual settlement and the rate of settlement were found to depend on the thermal environment. We also found that in at least one case the island fill was stratified into three distinct layers shortly after construction. This paper presents opinions developed regarding the formation of these strata and how the performance of the island relates to the layers formed. The methods used to make these observations and the methods used to estimate thaw strain are also covered.

THAW PROCESSES IN COARSE SEDIMENT BEACHES, SOMERSET AND BYLOT ISLANDS, N. W. T., CANADA	I

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Beneath the emergent shingle beaches of northern Somerset Island, N.W.T., maximum seasonal thaw rarely exceeds 80 cm. Two distinct zones of thaw exist. Beneath the backshore, above the reach of waves, fluctuations in thaw are dominated by climatic factors. Rates of thaw are 1 to 5 cm/d and the thaw depth which parallels the beach surface corresponds to the frost table (0° isotherm). In contrast, beneath the foreshore zone, the thaw depth profile lies 20 cm beneath the frost table and large fluctuations in thaw are caused by the presence of brine, buried brash ice and changes in beach morphology. Maximum rates of thaw of 16 cm/d occur immediately following the melting of shorefast ice. Beneath the low, transgressive barrier beach of northern Bylot Island, seasonal thaw depths extend to just over 100 cm. There is less distinction in thaw characteristics across the barrier beach because of the frequency of wave overwash. During storm wave and high river discharge events ice-bonded sediment is frequently exposed and differential rates of thaw along and between the sediment bedding planes reach 30 to 70 cm/d for very short periods.

THERMOKARST FEATURES ASSOCIATED WITH BURIED SECTIONS OF THE TWINS-ALASKA PIPELINE	C-1

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Following startup in 1977, thermokarst ground surface features started to appear along buried segments of the Trans-Alaska Pipeline. Features observed included longitudinal cracks and various depressions. Proper interpretation of these features became an important element of pipe settlement investigations which were initiated in 1979. Most of the features were relatively shallow and were not related to pipe thaw settlement. However, a few features provided an advance indication of developing critical pipe settlement conditions. These advance indications enabled the planning and undertaking of timely remedial actions.

THE ECOLOGY OF PERMAFROST AREAS IN CENTRAL ICELAND AND THE EFFECTS OF IMPOUNDMENT	E-1

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In the central highland of Iceland , extensive hydroelectric developments are now planned. Small areas were flooded in 1981, but there are concerns over the ecological effects of a much larger reservoir, planned at a later stage. This would involve inundation of parts of the Thjorsarver Reserve, comprising the most extensive and richest tundra vegetation in Iceland. In 1981, a long term study of the ecology of the Thjorsarver tundra was initiated, with emphasis on the vegetation and soils and the potential effects of impoundment. Permanent transects were set up in disturbed and undisturbed areas for detailed recording of vegetation and soil parameters. This paper reports the preliminary results on the distribution and thickness of permafrost, active layer development, ground water and soil characteristics, but only brief descriptions of the vegetation.

STRATIGRAPHIC EVIDENCE FOR VARIABLE PAST PERMAFROST CONDITIONS AT CANYON VILLAGE BLUFF, NORTHEAST ALASKA	P-1

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The Canyon Village Bluff, a 30 m high gravelly exposure located along the Porcupine River (northeast Alaska), contains stratigraphic evidence of four fossil ice-wedge-cast horizons within alluvial sediments. Radiocarbon dating and geomorphic features in the area indicate that all ice-wedge-cast horizons are more than 35,000 years old and may be late Quaternary in age. Each ice-wedge horizon is interpreted to represent one cold-warm oscillation of soil temperature which could have been caused by any number of factors. These features indicate that the bluff locality has been very sensitive to conditions causing soil-temperature changes for a prolonged period of time.

LOESSLIKE YEDOM-COMPLEX DEPOSITS IN NORTHEASTERN STAGES AND INTERRUPTIONS IN THEIR ACCUMULATION; AND THEIR CRYOTEXTURES	P-1

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Loess layers of a yedom complex with a special cryotexture accumulated during the glacial periods in the cryoarid landscapes of northeastern USSR, while during the interglacial buried soil profiles and thermokarst facies were formed in cryohumid landscapes. This pattern corresponds in principle to that of the classic loess deposits of the periglacial regions of Europe.

WATER REDISTRIBUTION MEASUREMENTS IN PARTIALLY FROZEN SOIL BY X-RAY TECHNIQUE	M-3

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This paper reports the results of water redistribution measurements in partially frozen soils under overburden pressure. The authors developed an experimental apparatus using X-ray technique to measure the water flow both in the unfrozen and frozen part of a freezing saturated soil under overburden pressure. The experimental method consists of taking X-ray photographs of the sample in which small lead shots are embedded, determining the location of small circular images of lead shots on the film and measuring the dilatations or the consolidations in each part of the sample by comparing them with those of subsequent films. During the experiment the temperatures of end plates were held constant. After the experiment was started, a large ice lens was formed around the center of the sample. Ice segregation was also observed in the region that was colder than the center of the sample. Tine amount of dilatations due to ice segregation was measured quantitatively with displacements of lead shots. The consolidation of the unfrozen part was observed. And the water flow both in the unfrozen and in the frozen part was calculated.

FROZEN GROUND IN THE ALTAI MOUNTAINS OF CHINA | I

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Frozen ground in the Altai Mountains of China can be divided into three zones: seasonally frozen ground, sporadic permafrost, and widespread permafrost. In seasonally frozen ground, the depth of the thawed layer is 0.8-1.0 m in the peat layer, 0.9-1.6 m in the loam layer, and over 1.9 m in sandy gravel sediments; the mean annual ground temperature is no lower than -1.0°C. The sporadic permafrost zone is situated between 2200 and 2800 m a.s.l. In general, permafrost islands are distributed in peat layers in marshy depressions and in caves on northfacing slopes. Some palsas with 1- to 2-m ice layers were found. The widespread permafrost zone is situated in the high mountain zone above 2800 m a.s.l. The permafrost thickness is estimated to be less than 400 m, and the mean annual ground temperature *is* higher than -5°C. The lower limits of permafrost in the last glacial period and Neoglaciation were 750-900 m and 400-600 m, respectively, lower than at present. permafrost in the sporadic zone was formed during the Neoglaciation, while the lower part of the permafrost layer in the widespread permafrost zone was probably formed during the last glacial period.

RESEARCH ON THE FROST-HEAVING FORCE OF SOILS | I

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To investigate the normal frost-heaving forces that act upon foundations, frost-heave tests were conducted under various conditions in both field and laboratory. Test results showed that the frost-heaving force substantially depends upon the frost susceptibility and water content of the soil, temperature, frost penetration depth, and the area of the bearing plates. A number of empirical equations are presented to evaluate the influence of these factors on frost-heaving forces. Based on model tests, the authors propose that the normal frost-heaving force be considered to be composed of two parts--the normal frost-heaving force produced by the restrained ground body beneath the bearing plates and that produced by the unrestrained ground body surrounding the restrained soil column. Therefore, the authors conclude that the value of the normal frost-heaving forces is not very great, but approaches a certin "stable" limit.

IN-SITU DIRECT SHEAR TESTS AT THE FREEZE/THAW INTERFACE AND IN THAWED SOILS	I

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To build railroads in permafrost regions requires an understanding of the shear strength of soils at the freeze/thaw interface while evaluating the stability of embankment slopes, foundations, and cut slopes. Considering the relatively high water content in the freeze-thaw transition zone in soil, many researchers have suspected that the freeze/thaw interface could be the weaker surface of shearing. To clarify this, the authors conducted indoor and outdoor direct shear tests at the interface and in thawed soils. Results both in-situ and in the laboratory showed that the shearing strength at the freeze/thaw interface is greater than in thawed soils, as are both the interfrictional angle and the cohesion force. The weaker surface of shearing was not at the freeze/thaw interface, but in thawed soil with high water content. Therefore, to evaluate the stability of roadbeds in permafrost regions, shear-strength values should be taken from thawed soils with high water content.

A CLASSIFICATION OF ROCK STREAMS	P-6

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The paper presents a genetic classification of rock streams. Rock stream formation may be observed under certain combinations of climatic, lithological and geomorphological conditions. Numerous processes are involved in the formation and migration of the coarse materials of rock streams, e.g. weathering of bedrock, heaving of fragments from an unconsolidated substrate, eluviation of fines, and needle ice formation. Each rock stream is composed of a certain combination of facies units, although all of them are predetermined by its evolution. Hence, the proposed classification of rock streams is based on focussing on the principal mechanisms controlling the formation of the coarse mantle overlying the rock stream. One of the shove-listed rock-stream-forming factors is commonly dominant. As a result, four types of rock streams are distinguished: the "weathering of bedrock"' type, the "heaving of coarse material'" type, the "eluviation of fines" type and the "gravity" type. Where two of the processes are dominant the following types of rock streams are formed: the "weathering of bedrock and heaving of coarse material" type and the "bedrock weathering and eluviation of

fines'" type. According to the nature of the contact between the rock stream and its source area 14 subtypes are identified. supply of material may occur uniformly *over* a wide area, via networks of cracks and locally, or from escarpments and bedrock remnants.

STRESS-STRAIN CONDITION AND THE ASSESSMENT OF SLOPE STABILITY IN AREAS OF COMPLEX GEOLOGICAL STRUCTURE UNDER VARIOUS TEMPERATURE REGIMES

c-2(1)

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Calculations of the stress-strain condition and the stability of rock masses in northern regions are complicated by the effects of temperature and by associated physical and mechanical processes. In terms of thermodynamics these processes are controlled by the stress tensor, temperature, concentrations of individual components and phases, crack density tensor, and by irreversible internal parameters. Equations of the condition of the rock, including the above-mentioned variables complete the system of equations of equilibrium expressing geometric relationships and heat-mass exchange. It is possible to *simplify* the proposed scheme to the level of engineering possibilities by taking into account adequate representation of results. In this case a set of engineering investigations essential for assessing the stability of the sides of reservoirs under different regimes would include the following: 1) On the basis of data derived from engineering exploration the real structure is represented in the form of engineering and geological models and reflecting the peculiarities of its composition, structure and condition; 2) the laws governing the behavior of rocks under loads in frozen, thawed, and thawing conditions are determined under both field and laboratory conditions. On this basis the physical and mechanical properties'of the rocks of separate zones and the elements of the actual slope are determined. Geomechanical models of the rock mass are then built on the basis of the data obtained; 3) items 1) and 2) allow one to compile calculations of the stress-strain condition of the slope under varying conditions; 4) on the basis of the data derived from calculations of the stress-strain condition minimum stability safety factors may be determined in each element of the layout network, potential slip planes may be identified and integral safety factors of slope stability may be calculated.

ICE-WEDGE CASTS AND INVOLUTIONS AS PERMAFROST INDICATORS AND THEIR STRATIGRAPHIC POSITION IN THE WEICHSELIAN	P-2

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Ice-wedge casts and large size involutions are typical periglacial features in the Weichselian deposits of northwestern Europe. The ice-wedge casts consist of a central part with vertical lamination and a faulted marginal part. The casts are often arranged in a subparallel pattern, which represents an initial stage in the development of a true polygonal network. They are always closely associated with overlying intense involutions with amplitude of ca. 1.5 m. These involutions are often flat-bottomed and developed in a symmetrical way. They are explained as "periglacial load structures". Degradation of the ice-rich permafrost top caused a state of over-saturation in poorly drained areas. Consequently all cohesion was lost and a reversed density gradient originated. Other types of smaller sized deformations do not require the presence of a permafrost. In the Weichselian sediment series two levels of ice-wedge casts connected with intense involutions are recorded. They point to permafrost conditions at the start of the Middle Weichselian and at about 20-25,000 years BP. In between these two periods climates were relatively milder.

GROUND MOVEMENTS AND DENDROGEOMORPHOLOGY IN A SMALL ICING AREA ON THE ALASKA HIGHWAY, YUKON, CANADA	H-2

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Perennial groundwater discharge in a tributary of Donjek River causes severe icing problems at km 1817.5 (mile post 1130) on the Alaska Highway. Surveys of a section across the icing area revealed vertical ground movements of up to 0.92 m between winter and summer. Subsurface ice bodies up to 0.75 m thick appear to form in some winters, degrading in the following summer(s). The ground movements and the ice bodies are indicative of the formation and degradation of frost mounds. Airphotos of the study area indicate that icing activity was either induced or enhanced by construction of the highway. The distribution of reaction wood in white spruce growing on the valley bottom indicates several episodes of tilting, in various directions. The reaction-wood

chronology shows that ground movements occurred in this area long before construction of the highway. Construction of the highway may, however, have affected the rate of groundwater discharge and the magnitude of icing and frost-mound activity.

SOIL-LANDSCAPE RELATIONSHIPS IN THE SEWARD PENINSULA	I

Van Patten, D.J.

Properties of soils of upland areas in the discontinuous permafrost zone of the Seward Peninsula, Alaska, are determined in large part by their position in the landscape, their parent material, the vegetation they support, and the effects of cryoturbation. The toposequences of soils were studied. One, in calcareous parent material, consisted of Pergelic Cryorthents, Pergelic Cryochrepts, and Pergelic Cryoborolls. The other, in acidic parent materials, was made up dominantly of Pergelic Cryumbrepts, Pergelic Cryochrepts, and Pergelic Cryorthods. Under alpine vegetation accumulation rates of organic carbon were much higher in the acidic than in the calcareous parent materials; under spruce forest, the difference in accumulation rates was less apparent. Irregular distribution of organic matter, together with the distortion of genetic horizons in some profiles indicates that cryoturbation is a pedogenetically destructive process. Physical and chemical properties of a gelifluction lobe were compared with more stable surfaces. Radiocarbon dating was used to record movement.

CRYOHYDROCHEMICAL PECULIARITIES OF ICE-WEDGE POLYGON COMPLEXES IN THE NORTH OF WESTERN SIBERIA	P-1

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General conclusions are drawn from new data derived from 280 samples of wedge ice and 210 samples from the deposits bounding the wedges which were analyzed from the chemical composition of their dissolved salts. Slightly mineralized and strongly mineralized ice of Pleistocene and Holocene ages was identified. It is emphasized that saline sea water is involved in the formation of highly mineralized syngenetic wedge ice in the northern areas of Western Siberia.

LONG-TERM USE OF FROST TUBES TO MONITOR THE ANNUAL FREEZE-THAW CYCLE IN THE ACTIVE LAYER

E-3

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In *1968* frost tubes were installed into the permafrost in a white spruce-black spruce/Ledum groenlandicum/Hylocomium stand near Fairbanks, Alaska and the annual cycle of freezing and thawing was monitored through 1982. The annual freeze-back of the active layer began in mid-October. The data the active layer was completely frozen varied with the winter's snow depth and air temperature: complete freezing was as early as December 13 and as late as January 28. Snow cover *was* **usually** permanent by October 8 and the last snow was usually melted by May 6. Thawing from the surface downward in the spring was directly related to the thaw index. Thawing began as early as April 20 and as late as May 7. Maximum thaw ranged from 54 to 61 cm with an average of 58 cm. Footsteps of the observers compacted some vegetation along their route, resulting in a slight depression in the lower surface of the active layer under their trail, but there was no significant difference in the thaw depths adjacent to the frost tubes after 14 years. Use of frost tubes is a reliable way to determine the annual freezing and thawing cycles in the active layer for periods of at least 14 years.

DYNAMIC PROPERTIES OF NATURALLY FROZEN SILT

C-2(2)

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Resonant frequency and cyclic triaxial tests were conducted on naturally frozen silt samples. Dynamic elastic properties (expressed in terms of dynamic Young's and shear moduli) and energy absorbing properties (expressed as damping ratio) were determined. The influence of various dynamic loading parameters (confining pressure, temperature, frequency, and strain amplitude), water content, and anisotropy on dynamic properties was evaluated. Confining pressure and water content were generally found to have little effect on either dynamic moduli or damping ratio. The test results indicate dynamic moduli decrease with increasing strain amplitude and increase with increasing frequency and ascending temperature. The damping ratio generally increases with

increasing axial strain amplitude and decreases with increasing frequency and descending temperature. The soil/ice structure (i.e., lens thickness, orientation, and spacing) does not appear to influence the dynamic properties of naturally frozen silt.

THAW PLUG STABILITY AND THAW SETTLEMENT EVALUATION FOR ARCTIC TRANSPORTATION ROUTES: A PROBABILISTIC APPROACH	I

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A unified, probabilistic approach to the evaluation of thaw plug stability and thaw settlement is outlined for practical application to arctic or subarctic transportation routes. The approach can explicitly account for uncertainties, geotechnical variability, and limitations in available geotechnical data/information. Using Bayesian probability concepts, landform identification, and statistical characterization of landform soil property parameters, it can provide site-specific estimates of thaw plug stability and thaw settlement. The ❑ethodology is suited to situations where regional or local landform soil property parameters can be statistically well known, but site-specific data may generally be either unavailable or sparse. Estimates can be based only on landform information or systematically updated and improved with site-specific data to the extent they are available. Estimates include the mean and the variance of both thaw plug stability limit equilibrium factor of safety (FS) and average thaw settlement magnitudes (TS); using these, estimates can be made of the probability of instability (Pf) and of reliability/probability levels on the settlement estimates, including the probability of any given estimate being above or below a given critical value. Differential settlement is not treated.

STONE POLYGONS: OBSERVATIONS OF SURFICIAL ACTIVITY	P-7

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Small stone polygons, approximately one meter between centers, have developed in a 675 m^2 depression at 3,865min the Blanca Massif of the Sangre de Cristo Mountains in southern Colorado, U.S.A. (37°35'N., 105"30'W.). The absence of vegetation and human disturbance permitted observations to determine the rate of horizontal displacement of stones in the centers of the polygons. Photographs taken of the

centers in August 1975, 1978, 1979, 1980, and 1982 provide the evidence from which the displacement can be measured. Gaps in the photographic record occurred because the site was underwater in August of 1976, 1977, and 1981. A sample of 173 identifiable stones, greater than 1.3 cmin length, moved an average of 4.75 cm during a 7 year period; one stone moved 18.3 cm during these observations. The average rate of movement per stone was 0.68 cm per year from 1975 to 1982. In general the stones moved toward the gutters. Clast motion can be attributed to heaving and thrusting by frost action, needle ice, and perhaps lacustrine ice.

A NEW TECHNIQUE FOR DETERMINING THE STATIC FATIGUE LIMIT OF FROZEN GROUND	I

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Existing techniques for determining the static fatigue limit (R_{cs}) of the frozen ground are tine-consuming and labor-intensive (Vyalov et al., 1966, 1978; Tsytovich, 1973). The proposed new method can achieve an accelerated determination of the static fatigue limit by means of brief tests by gradually increasing loading on sublimated samples of frozen ground. The physical bases of the method, which has been verified experimentally are as follws. They are: 1) the static fatigue limit of frozen clay materials depends upon the structural bonding of the mineral framework rather than on bonding by ice-cementing; 2) the structure and texture of the mineral framework do not vary considerably during sublimation of the icecrete until the ground moisture equals the content of unfrozen water under the same thermodynamic conditions; and 3) the static fatigue limit of sublimated ground approximates in magnitude its theoretical instantaneous strength R_o. To determine R_{cs} by the proposed method within limits of accuracy which are acceptable for practical purposes, it is recommended that one select for analysis samples of frozen clay material with a massive or micro-veined cryogenic texture within the temperature range of -3 to 20°C.

A HIERARCHICAL TUNDRA VEGETATION CLASSIFICATION ESPECIALLY DESIGNED FOR MAPPING IN NORTHERN ALASKA	E-3

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This paper presents a tundra vegetation classification scheme that is designed for describing vegetation at four levels: (1) very-small-scale maps, (2) LANDSAT-derived maps, (3) photo-interpreted maps, and (4) plant community descriptions. 4 system of nomenclature is described that links the four levels.

THE INFLUENCE OF SUBSEA PERMAFROST ON OFFSHORE PIPELINE DESIGN	M-1

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' The way in which permafrost affects the design of land-based pipelines carrying hot fluids is well documented and has been the subject of a considerable amount of engineering analysis in the last decade. This paper considers the related problem of designing offshore pipelines in areas where subsea permafrost is encountered. A thermal analysis using a finite element model is described, and results based on measured soil data are presented for the cases where a pipeline is supported in a causeway and -where it is trenched into the seabed. This is followed by a discussion of settlement analysis, considering such questions as the determination of thaw strain and the influence of arching in the soil. The selection of a criterion to determine '*allowable" pipeline curvatures and the question of treating the statistical variability of soil and permafrost conditions along the pipeline route are also covered.

USE OF D.C. RESISTIVITY MEASUREMENTS FOR DETERMINING THE THICKNESS OF THIN PERMAFROST	I

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Direct current resistivity measurements have been made at four sites in the Fairbanks area. The sites are in discontinuous permafrost where the permafrost thickness is normally less than 100 m. The sites represent a variety of soil types including silt, peat and gravel, silt and clay, and a site where 8 to 9 m of thawed silt overlies about 30 m of permafrost. Schlumberger arrays were used with electrode spacings sufficient to probe about 200 m. Borehole temperature data exists at all sites for determining permafrost temperature and thicknesses. The D.C. resistivity data are analyzed using manual curve matching to obtain estimates of the number of layers, thicknesses and resistivities. These estimates are used in a computer program which produces a layered model. The layered model is then used to generate data points to compare with the original data. Favorable correlations were obtained on all but one site. The models were then compared to permafrost thicknesses determined from boreholes. Borehole temperature data at one site gives a permafrost thickness of 39 meters which corresponds favorably to the model thickness of 43.6 meters. The resistivity of permafrost in saturated silt is 300 to 500 Ωm which corresponds well to the model resistivity of 399.5 Ωm. The problems of using the D.C. resistivity method and its usefulness for determining permafrost thickness will be discussed.

EROSION IN A PERMAFROST-DOMINATED DELTA	G-3

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Field trips to the Colville River delta have provided the opportunity to repeatedly examine and monitor the types and rates of erosion occuring at a number of locations. Field measurements have been made in several distinct environmental situations, including high banks composed of Gubik materials, peat banks in locations of lake tapping, a pingo and adjacent lake fill, and the head of a mid-channel bar. In all cases permafrost is involved, and in some, ice wedges are important. Rates of retreat are variable. During the past 30 years a number of banks have been eroding at average rates of between 1 and 3 m per year;

rates that have a high annual variability. At times of block collapse, retreats of up to 12 m may be almost instantaneous. However, in areas of block collapse the average annual rates of erosion are usually similar to those elsewhere because collapsed blocks serve as buffers to further retreat for 1 to 4 years.

SORTED PATTERNED GROUND II? PONDS AND LAKES OF THE HIGH VALLEY/TANGLE LAKES REGION, CENTRAL ALASKA, U.S.A.	P-6

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Well-developed sorted patterned ground is widespread on gently sloping shores and bottoms of shallow lakes and temporary ponds in the High Valley/Tangle Lakes region of the Amphitheater Mountains, on the south side of the central Alaska Range. This area is within the zone of discontinuous permafrost and has a mean annual air temperature of -4*C. The numerous lakes and ponds occupy depressions in middle to late Quaternary silty tills which blanket the valleys. Sorted patterned ground forms include stone circles, stone polygons, stone pits, and stone stripes, with circles and polygons being most common. All patterned ground sites, whether presently underwater or subaerially exposed, occur in situations of fluctuating water levels. It is suggested that the features formed by frost sorting, frost heaving, and mass displacement when lake shores and pond bottoms were subaerially exposed during drier periods. Although the patterned ground appears to have developed at some time in the past, many sites show evidence of being at least semi-active today.

PERIGLACIAL ACTIVITY ON THE SUBANTARCTIC ISLAND OF SOUTH GEORGIA	P-4

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Very little information is available on periglacial features and activity on the subantarctic islands. From measurements on South Georgia geliflaction is observable to a depth of 12 cm at very active sites but most sites show movement only to 8 cm. For small scale stripes sorting is generally 5-6 cm deep with the majority of sorting activity in autumn. Altitude appears to affect sorting through the incidence of freeze-thaw cycles, with east facing sites showing most activity. Stripe orientation is not related to wind direction. The rate of clast movement downslope was linearly relatd to clast length and site slope.

PROPERTIES OF FROZEN AND THAWED SOIL AND EARTH DAM CONSTRUCTION IN WINTER	C-4

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To solve problems of winter construction of earth dams, we conducted an experimental study on paving sloping clay core, making frozen clay blanket, and laying sloping weathered sand core for cofferdam in winter, and made an extensive investigation on the construction of medium and small-sized earth dams. We found that the pace of winter construction can be speeded up while still maintaining quality on the basis of the following characteristics of frozen and thawed soil: (1) The compatibility of filled soil under negative temperature can be as good as that under positive temperature when soil is in the supercooled state. (2) The permeability of thawed soil is higher than that of unfrozen soil, the consolidation process is faster, and there are no significant differences between the quick shear strengths 'of the two soils. Therefore, the mechanical properties of the clay soil with water content close to the plastic limit shows no significant change after compacting and freezing. (3) When it is submerged in water, frozen clayey soil thaws and crumbles quickly on its surface, filling in voids between frozen masses and increasing its density. It can be used for construction. (4) Roughening has no notable influence on the compressibility and permeability of the binding layers and on their shearing strength; it can be omitted for binding layers.

PALEOCLIMATIC INFERENCES FROM FOSSIL CRYOGENIC FEATURES IN ALPINE REGIONS	I

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Features indicative of intensive frost action and of permafrost observed in the Ruby, Schell Creek, and Snake ranges of Nevada and the Cordon del Plata of the Mendozan Andes , which include lobate and small linguoid (ice-cemented) rock glaciers, sorted circles and stripes,

garlands, and stone-banked lobes, permit a reconstruction of some of the paleoclimatic conditions adjacent to the ice in alpine areas that were glaciated during the Pleistocene. The distribution of paleocryogenic forms on surfaces where snow cover is minimal suggests that the mean annual air temperature above and adjacent to the valley glaciers in these desert mountain ranges in both hemispheres during the last Pleistocene glaciation would have been 5″ - 6°C lower than the present ones at the same altitudes. During the Holocene neoglaciations, the lowering of temperature probably was 1.5° - 2°C.

UNDERGROUND CAVITIES IN ICE-RICH FROZEN GROUND	C-5

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An analytical study of closure behavior and stress changes surrounding unlined and lined circular openings in warm, ice-rich permafrost has been undertaken. The creep law of polycrystalline ice has been used to describe the constitutive behavior of fine-grained, ice-rich permafrost soils. The results show that shallow openings in warm permafrost experience very large strains above the crown of opening. Placement of a tunnel liner will reduce the tunnel closure to an insignificant level. A new analysis of the in situ deformation behavior of the Fox Tunnel near Fairbanks, Alaska, has shown that the flow law for polycrystalline ice does not yield an upper-bound solution to the observed room closure measurements. However, it is argued that the in situ deformations resulted from creep and plastic yielding.

DIURNAL FREEZE-THAW FREQUENCIES IN THE HIGH LATITUDES: A CLIMATOLOGICAL GUIDE	I

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This study provides relatively simple climatological models for determining the incidence of frost days (minimum daily temperature ≤ 0″C), ice days (maximum daily temperature ≤ 0″C), and freeze-thaw days (minimum daily temperature ≤ 0°C, maximum daily temperature > 0°C) throughout Iceland, Greenland, Alaska, and Siberia. Both areas and station models yield estimates of the frequency of diurnal freeze-thaw cycles per month or year. The various models demonstrate the

relationships between daily freezing conditions and the different temperature regimes. The results should improve understanding of periglacial activity and provide a means of predicting possible climatic effects on the construction of buildings, roads and airport runways.

ROCK GLACIERS - PERMAFROST FEATURES OR GLACIAL RELICS? | I

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The two main models of rock glacier composition, ice-rock mixture and glacier ice cores, are briefly examined. It is argued that there seems to be no evidence which suggsts that talus can normally become a rock glacier just by the addition of ice. Talus exists at high slope angles but shows no signs of glacier-like movement. All that appears necessary for a rock glacier to form is relict glacier ice and sufficient debris cover to preserve the core for long periods. As they are such thin bodies of ice, they can flow only slowly; this is sufficient to explain their behavior and distribution. Although permafrost can be present in an area of rock glaciers and may prolong the existence of the ice core, it is not necessary for their formation.

COLD-MIX ASPHALT STABILIZATION IN COLD REGIONS | I

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Problems arising with unbound aggregate runways in the northern environment are identified and arctic paving experience briefly reviewed. Following consideration of a range of possible stabilizing agents, cutback bitumen was identified as being the most promising for conditions in the high arctic. A modified Marshall method of mix design for cold-mix stabilization of northern aggregates near to 0°C is described. Laboratory and field test results are presented and the effects, on ground temperature, of unbound, stabilized and white painted stabilized pavements are reported. It is concluded that cold-mix stabilization, at temperatures little above freezing, is feasible using the method described.

BASIN WATER BALANCE IN A CONTINUOUS PERMAFROST ENVIRONMENT	H-1(1)

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The hydrology of a basin in the continous permafrost region of Canada was studied for 6 years to establish seasonal and annual water balances. Emphases were placed upon the spatial and temporal variations of snowmelt, rainfall, vaporation, streamflow and active layer storage capacity. Spring melt released considerable meltwater which could not be accommodated by a thinly thawed active layer. High runoff resulted. Evaporation was active concurrently but from the snow-free portion of the basin. Summer rainfall was often of low intensity. Storage capacity increased as the frost table receded and much of the rain could be held in the active layer to maintain evaporation and baseflow. Over the years, snowfall constituted **about three-quarters of annual precipitation, about 80%** of which was consistently removed by runoff. Annual evaporation was small and net change in storage for the 6-year period was negligible.

STRESSES AND MOISTURE MOVEMENTS INDUCED BY THERMAL GRADIENTS IN FROZEN SOILS	I

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Stress changes and moisture movements induced by thermal gradients in saturated frozen soils, have been investigated with a specially designed cell. Results from tests indicate that the strength of the soil may play a significant role in the formation of segregation ice. As the "warm" side temperature was established, a large influx of water occurred at the warm end of the sample accompanied by a fall in stress towards atmospheric pressure. This is the result of volume decrease due to thawing within the sample. Once a linear temperature profile was attained, water was expelled from both ends of the sample, the flux being greater at the warm end. Stress on the warm side of the sample remained at or near atmospheric pressure for the remainder of the experiment, while the stress on the "cold" side varied cyclically. It is suggested that the ice pressure on the cold side rises until it exceeds the strength of the soil, at which point the soil yields, segregation ice begins to form, and the in situ stress then falls.

In the final stage, the flux ceases when the total outflow from the sample equalled the initially greater inflow. The measured stresses were then atmospheric.

RELATIONSHIPS BETWEEN RUNOFF GENEFUTION AND ACTIVE LAYER DEVELOPMENT NEAR SCHEFFERVILLE, QUEBEC	H-l(1)

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The generation of runoff in areas underlain by permafrost is similar to that of temperate regions, but is distinguished by the seasonal changes in the extent, shape, and thickness of the areas generating runoff as well as the storage and transfer of small amounts of water by frost-related mechanisms. Studies conducted near Schefferville, Quebec have shown that these mechanisms can significantly alter the development of the active layer. The development of the active layer partially controls the distribution of saturated surfaces in a given catchment, and thus its hydrologic response to runoff-generating events. This phenomenon is similar to the variable-source area runoff generating mechanism of temperate regions, except that the ratio of stormflow to baseflow is also partially controlled by the depth and extent of the active layer. A detailed study of a small catchment at Schefferville has demonstrated that consideration of these effects can increase the precision of models of runoff-generation from such catchments.

A STUDY OF THERMAL CRACKS IN FROZEN GROUND	I

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The formation of thermal cracks damages roads and hydraulic construction and causes seepage and other problems. Thermal cracks usually occur in early winter, when the snow cover is still thin and the surface temperature falls rapidly to -20°C or lower, and they may reach 1.5 m in depth and 10 to 16 m in width. The particle composition, water content, temperature gradient, freezing depth, and freezing penetration rate of soil as well as the snow cover and vegetation all affect crack formation. Thermal cracks occur when the maximum contractional stress σ_{max} reaches the ultimate tensile strength σ_0^{ℓ} of the soil. The distance between cracks is directly proportional to σ_0^{ℓ} and inversely proportional to the temperature gradient and linear contractional coefficient of frozen soil. The width of the crack is proportional to the freezing depth, and is related to the minimum temperature and the temperature when the crack occurs. The main stresses can be determined and used to predict crack formation.

FROST-HEAVING CHARACTERISTICS OF CLAY SUBSOIL	I

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Frost-heaving tests on Wanjia silty clay were conducted at different preconsolidation states both in the laboratory and the field. Test results show that the frost-heaving characteristic of the clay is closely related to its preconsolidation state. When it is overconsolidated, the amount of frost heave as a function of freezing depth can be described by an exponential equation, while at normal consolidation, it can be described by a linear one. If the clay is in an underconsolidated state, it undergoes consolidation during the initial stage of freezing; when it reaches normal consolidation, the relationship between the amount of frost heave and the freezing depth is linear. Based on the analysis of the frost-heave characteristics of the clay in different consolidation states, the author concludes that under normal consolidation, neither pore water pressure nor suction occurs during freezing, and the frost-heaving force cannot exceed the bearing capacity of the subsoil.

DEVELOPMENT OF PERIGLACIAL LANDFORMS IN THE NORTHERN MARGINAL REGION OF THE QINGHAI-XIZANG PLATEAU SINCE THE LATE PLEISTOCENE	I

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Based on field investigations and C^{14} dating, there have been three cold periods since the Late Pleistocene: (1) the main Wurm Glaciation, when the air temperature was about 7° to 8°C lower than at present, and the lower limit of the periglacial belt was at 2200-2300 m a.s.l.; (2) the second stage of the Middle Holocene, when the air

temperature was about 2.5°C lower than at present, and the lower limit of the periglacial belt was at about 3300 m a.s.l.; and (3) the Neoglaciation at the end of the Middle Holocene, when the air temperature was about 2.7°C lower than at present, and the lower limit of the periglacial belt was at about 3200 m a.s.l. Between these three cold periods, there were warm stages with air temperatures 1°-2°C higher than at present, and the periglacial lower limits were at about 3500 to 3900 m. During the cold periods, many periglacial phenomena were formed, namely frost-heave mounds, sand wedges, involutions, blockfields, spline cyroplanation terraces, and sorted and nonsorted polygons. The modern periglacial belt can be divided vertically into three zones: the zone of frozen weathering and of freeze-thaw denudation in the upper part, the zone of freeze-thaw creep and frost heaving in the middle, and the zone of frost heaving and heat thawing in the lower part.

A PRELIMINARY STUDY OF THE DISTRIBUTION OF FROZEN GROUND IN CHINA	G-1

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Based on field data and statistical calculations, a distribution map of frozen ground in China has been compiled. It was found that the different types of frozen ground are located in different climatic zones. Permafrost is located mainly in the northern temperate zone, seasonally frozen ground in the middle and southern temperate zones, and intermittently frozen ground in subtropic areas. The values of mean annual air temperature at the lower or southern limit of permafrost depend on the differences between the annual mean ground temperature and the air temperature; these differences vary with districts because of the variation in solar radiation. The altitude of the lower limit of permafrost depends on four factors: latitude, the change rates of annual mean air temperature to latitude and altitude, and the difference between the annual mean ground temperature and the air temperature at that point. Differences of altitude between the snow line and the lower limit of permafrost vary with climatic districts: 1000-1500 m for arid districts, 500-1300 m for semi-arid districts, 250-1000 m for subhumid districts, and 0-400 m for humid districts.

DETERMINATION OF ARTIFICIAL UPPER LIMIT OF CULVERT FOUNDATION IN PERMAFROST AREAS OF THE QINGHAI-XIZANG PLATEAU	I

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In permafrost regions, the bearing capacity of foundation soil changes with periodic thawing and freezing. Many shallowly buried culvert foundations have been destroyed by uneven subsidence from thawing and frost heaving. The authors present a method for calculating the safe burial depth of culvert foundations and the approximate maximum thaw depth in accordance with specific features of the permafrost areas of the Qinghai-Xizang Plateau. This paper presents the calculation of maximum thawing depth, provided thawing of culvert foundation is permitted, and the design principle for keeping the ground beneath a culvert foundation in the unfrozen state. To simplify design, empirical formulas are recommended as reference as well. Comparing the calculated results with data from an experimental culvert in the Fenghou Mountains, the authors give the relation curve of the water-passing surface temperature of an experimental culvert vs. the ground surface and atmospheric temperatures of the local weather station.

THE FORMATION OF CRYOGENIC STRUCTURE AND TEXTURE IN UNCONSOLIDATED ROCKS	P-5

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The paper presents the results of investigations into the mechanics and laws governing the formation of cryogenic structure and texture in unconsolidated rocks during freezing or thawing. A number of thermophysical, physico-chemical and physico-mechanical processes were studied theoretically and experimentally using a range of modern techniques. In the light of the results obtained, conditions for the formation and development of segregated ice layers and for the creation of various cryogenic textures were examined. A system of classifying cryogenic textures is proposed, unique in its potential to explain the

formation of various types and kinds of cryogenic textures within a standard framework on the basis of the major classification parameters and of the conditions of segregated ice formation. The paper considers peculiarities in the formation of cryogenic structure as revealed both in laboratory experiments and in the field. A close relationship is demonstrated between the structural parameters and their degree of variability and the intensity of the processes accompanying the freezing and thawing of unconsolidated rocks. The peculiar microstructure of naturally frozen unconsolidated rocks of various origins is described and a classification system of cryogenic structures is proposed which takes into account the type of ice cement, the pattern of bonds between the structural elements of rocks and the nature of the areas of contact.

CONDITIONS OF PERMAFROST FORMATION IN THE ZONE OF THE BAIKAL-AMUR RAILWAY	P-3

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On the basis of statistical analysis of data derived from many years of observations conducted at 170 weather stations in the region, quantitative relations between the basic environmental parameters were obtained. They enable us to explain the formation of taliks in the western and eastern fringes of the zone and also the extreme low temperatures (down to -7 -12°C) and the extreme thickness (700-1300 m) of the permafrost in the alpine areas of the Udokan and Kodar ranges. It was established that continuous permafrost occurs in the regions where the mean annual air temperature is lower than -7°C. In those parts of the zone where the mean annual temperature falls between -3 and -7°C, either seasonally frozen ground or permafrost occurs. As a rule, no permafrost forms in regions where the mean annual air temperature is above -3°C.

A MATHEMATICAL MODEL FOR THE VISCOPLASTIC DEFORMATION OF FROZEN SOILS	I

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A theological model for frozen soil and ice, based on a theory of viscoplastic hardening, is suggested. The critical equations take the form of non-holonomic incremental relationships and describe the behavior of frozen ground and ice with time both in pre-limiting and

limiting states. The model is formulated in such a way that no special experimental work is required to derive its parameters. Design parameters may be determined from triaxial compression tests. The results of numerical calculations of the behavior of frozen soils under triaxial compression are presented for various loading trajectories and for cases involving both decaying and progressive creep. The predicted soil behavior agrees well with experimental data. Results of applying the proposed model for solving the boundary problem using the finite elements method are also presented.

AIR DUCT SYSTEMS FOR ROADWAY STABILIZATION OVER PERMAFROST AREAS	M-4

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This paper presents the results of both an experimental and analytical research program undertaken to develop design *criteria* for air duct systems. These systems have been used in Alaska as a method of preventing degradation of permafrost beneath highway embankments. An experimental duct was assembled and instrumented to determine the relationship between air flow rates and temperature difference, heat transfer rates, air duct length, stack heights, etc. A finite element computer model has also been used to investigate the placement of the air duct under the roadway. Optimum placement of the air ducts would allow sufficient winter cooling of the ground so that degradation of the underlying permafrost would not occcur during the summer thawing season. Thermal profiles resulting from the finite element simulations showing the effects of air duct placement are presented. From the data presented in this paper, the design engineer should find it easier to design air duct systems for roadway stabilization in permafrost areas.

PRELIMINARY EXPERIMENTAL STUDY OF WATER MIGRATION AT THE ICE/SOIL INTERFACE | I

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On the basis of the theory of adsorption and Darcy's law, and by using the contact method, samples of Qinghai-Xizang red clay and Lanzhou yellow silt were tested to determine their individual amounts of unfrozen water and the hydraulic conductivity and diffusivity in unsaturated soil (without ice in soil at negative temperature). The results show the following regularities: The amount of unfrozen water increases with time and approaches a certain constant value; different soils have different adsorption rates and different processing curves. At high temperatures, the adsorption rate is high, and the unfrozen water content is also large, while the rate of curvature approaching the final value is smoother. At low temperatures, the final value of unfrozen water is also smaller. During the entire process, diffusivity is not constant, but is a function of water content. The accuracy of the results depends on the interval of measurement used in the experiment.

LONG-TERM RESISTANCE OF ANCHORS IN PERMAFROST | I

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Pull-out tests on reinforced concrete anchors with a nominal diameter of 10 cm were conducted at field research stations on the Qinghai-Xizang Plateau to investigate the long-term resistance of anchors in permafrost. Based on analysis of the load-displacement behavior of the anchors tested, the authors present the concept of gradually advancing failure of the adfreezing strength between the anchors and their surrounding soils. The authors consider that there exists an "effective length" for anchors in permafrost, which may be of great significance in the study of piles and anchors in permafrost. Test results show that the ultimate resistance of permafrost anchors depends primarily upon the length and diameter of the anchors; soil temperature, composition, and moisture; and the loading rate. From tests it was found that the displacement rate of an anchor in permafrost can be expressed by $\dot{\gamma} = K(\tau - \tau_{\infty})^n$, where τ_{∞} is the long-term resistance of anchors in permafrost.

A STUDY OF THE CALCULATION OF FROST HEAVING	M-4

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In recent years, numerous irrigation canals lined with concrete and masonry slabs have been built in regions of seasonally frozen ground in Gansu, China. Many of them, however, have been damaged by the heaving action of frozen soil. So it is of great importance to find a practical way to determine frozen depth and frost heave under various conditions. Frost heaving is known to be a comprehensive process of heat conduction and moisture migration. The authors describe the moisture migration process by the theory of unsaturated soil water movement, developed since the 1950's, and an improvement over the taxonomic method prevalent in the past study of soil water. A stepwise calculation method for one-dimensional frost penetration and heaving is derived by simplifying the boundary conditions of heat and moisture transport and temperature distribution. This method provides not only the maximum frozen depth and frost heave, but also describes the freezing process and the heaving ratio along the frozen depth. Analytical formulas for deeply and shallowly seated ground water levels are presented with illustrating examples.

THE PERIGLACIAL ENVIRONMENT OF THE LATE PLEISTOCENE ALONG THE QINGHAI-XIZANG HIGHWAY	I

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There are several kinds of periglacial phenomena on the Qinghai-Xizang Plateau. Polygon and wedge-shaped casts 1 to 50 m in diameter were formed during the last glacial period , and the involutions buried at depths of 3 to 11 m may have been formed during the Neoglaciation. Based on C^{14} dating, pollen analysis, and periglacial phenomena, the paleogeographic environment during the Late Pleistocene can be reconstructed. About 35,000 years ago, the Qinghui He Basin and other high plains in southern Qinghai were an interperiglacial environment, and carbonate nodules were formed in lake deposits; the upper parts of the Kunlun and Tanggula Shari were periglacial environments. From 26,000 to 14,000 years ago, the mean annual air temperature was about -7° to

-8°C. No carbonate nodules developed in the lake basins, but large polygons and sand wedges were formed on terraces along some rivers, and glaciers continued to grow in the high mountains. The lower limit of the periglacial belt in the northern part of the Qinghai-Xizang Plateau descended to 3200-3400 m a.s.l. From 14,000 to 12,000 years ago, the climate was still rather cold, as indicated by undecayed buried plants.

CALCULATION OF THAWED DEPTH BENEATH HEATED BUILDING IN PERMAFROST REGION

14-2

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Determining the maximum thawed depth beneath heated building foundations is one of the important subjects in engineering cryopedology. It is related directly with the materials, the depth and the type of foundation. Almost all the equations calculating the thawed depth include transcendental functions. Thus, it is difficult to consider the effect of the thermal resistance of floor and the heat flow under ground, and to solve the equation. The authors of this article have worked out a new formula for the maximum thawed depth beneath a structure. In this formula, the effect of the heat flow under ground and the ratio of the length and width of building are considered. The advantages of this formula are as follows: the physical conception is well defined; it is clear and simple; a convenient nomograph can be plotted; the difference between the calculated and observed values is less than 8%.

PERMAFROST BENEATH THE ARCTIC SEAS

G-3

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Frozen seabed materials are widespread beneath the arctic seas, thus forming a submarine cryolithozone. The major part of this submarine cryolithozone consists of mineralized materials containing water supercooled below 0°C. Perennially frozen rocks occur as a continuous belt along both continental and island coasts, and also as isolated masses on the open shelf within the limits of the Zyryan-Kargin lacustro-alluvial plain. The conditions of formation and survival of the frozen sediments beneath the seabed in the arctic seas are discussed.

SOME FEATURES OF PERMAFROST IN CHINA	PRC

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The permafrost that underlies 2,150,000 km^2 of China can be divided into two broad categories: high-latitude permafrost and high-altitude (alpine) permafrost. High-latitude permafrost is found in the northeast, and its distribution and characteristics depend chiefly upon latitudinal zonation. The mean annual ground temperature increases by 0.5°-1°C/1°N, and permafrost varies in thickness from 5-20 m in the south to 50-100 m at the northernmost limit. High-altitude (alpine) permafrost occurs in the high mountains and plateaus of western China and is vertically zoned. The mean annual ground temperature varies from -0.1° *to* -2.5°C at the lower limit to -4° or -5°C at the higher limit. Correspondingly, the permafrost increases in thickness with elevation. Alpine permafrost also shows latitudinal variation, however. As the latitude increases, the lower limit of the alpine permafrost descends with a variable of about 150-200 m/1°N. The latitudinal and vertical zonation of permafrost distribution may be modified by a zonal factor. On the Qinghai-Xizang Plateau, some taliks are the result of geothermal anomalies and surface and ground water; and in northeast China, temperature inversions in winter, together with the swampy process, make for well-developed permafrost in the valleys rather than on the higher crests. Horizontal ground-ice layers are widely developed on north-facing slopes and in well-vegetated intermontane swampy depressions, especially in fine-grained soils. In coarse-grained sediments, there is cemented and cemented-segregated ground ice. In perennially frozen bedrock, there is some vein-shaped ground ice in cracks.

STABILIZATION OF HIGHWAY SUBGRADE IN PLATEAU PERMAFROST REGION OF CHINA	I

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This paper deals with stability of highway subgrade under asphalt pavements which were located at plateau permafrost *areas* in China. According to the requirements for permafrost protection, roads are generally divided into sections in construction. The sections were classified into four categories depending upon the water content and settlement coefficient of the frozen soils. The N-factors of the gravel and asphalt pavements were developed by using the data obtained from the in site observations and meteorological stations. It was found that they are much greater than that in the high latitude areas. The design surface thawing index of asphalt pavement of this region can be determined by the long term data of air temperature. The minimum depths of the embankment for the stability of highway subgrade were recommended. The redistribution of water of subgrade soils was discussed and measures for prevention against frost action were also suggested.

CREEP BEHAVIOR OF FROZEN SILT UNDER CONSTANT UNIAXIAL STRESS	C-2(2)

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A series of unconfined compression creep tests was conducted on remolded, saturated frozen Fairbanks silt at constant-stress(u) and constant-temperature conditions. It was found that a sudden change occurred in the slope of log ε vs. $1/\sigma$ curves at almost the same minimum strain rate (about $10^{-6}s^{-1}$) for various test temperatures. Therefore, the authors suggest that the creep of frozen soil be classified into two types: short-term creep and long-term creep. Different constitutive and strength-loss equations are presented for each type of creep. The criterion of creep failure of frozen soil is considered to have the general form of $\varepsilon_m \times t_m^n = \varepsilon_f$, where n is a material constant dependent only upon water content, ε_f is the failure strain, and t_m is the time to failure in minutes. On the basis of Assur's creep model (1980) and this criterion, a creep equation was derived that can describe the entire process of creep of frozen soil.

UNDERGROUND UTILIDORS AT BARROW, ALASKA: A TWO-YEAR HISTORY

M-1

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Barrow, Alaska, located on the Arctic Coastal Plain, is the northernmost community in the United States, with a population of approximately 3,800. The town is a modern arctic Eskimo community serving as the governmental center for the large North Slope Borough (Figure 1). Whaling and game hunting still constitute a major portion of the subsistence of the town's inhabitants. Permafrost underlies the entire Arctic Coastal Plain. The bottom of the permafrost zone in the Barrow area lies 300-400 m below the surface. Polygonal or patterned ground is common in the area. The permafrost consists of ice-rich silt and contains numerous ice wedges and other ice inclusions (Black 1964). The area is characterized by typical arctic tundra growth of moss and sedges. The active layer of seasonal freezing and thawing is approximately 0.5 m in the undisturbed areas and varies in the disturbed areas in a manner proportional to any gravel fill that has been placed over the tundra. The City of Barrow has not had areawide piped water or sewerage facilities in the past. Water is pumped from the upper portion of the Isatkoak Lagoon to treatment facilities in Barrow. The treated water is then hauled to residences via private carriers, and many residents haul ice from clean water sources south of the town for potable water uses. Sewage wastes are collected at residences in holding tanks or plastic bags then transferred to a "'honey bucket"' truck for deposition at the landfill at the South Salt Lagoon. The North Slope Borough is improving these conditions by installing piped sewerage and water facilities in an underground utilidor system. Due to the unprecedented nature of this project, in terms of constructability and the compatibility of a heated utilidor buried in ice-rich permafrost, an instrumented test section was constructed and operated in ice-rich soil in order to verify thermal modeling used in the design and to investigate the interaction between a heated utilidor and the surrounding permafrost (Cerutti et al, 1982). This paper presents and evaluates the data obtained from the test section during the last two years.

INDEX OF AUTHORS

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NOTE SUPPLEMENTAL LIST OF NAMES ON PAGE 277.

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