Canadian National Committee for the
International Permafrost Association

7th INTERNATIONAL CONFERENCE ON PERMAFROST

Yellowknife, N.W.T. Canada, 23 – 27 June 1998

PROGRAM, ABSTRACTS and IPA REPORTS

PERMAFROST

Seventh International Conference

June 23-27, 1998

Program,

Abstracts,

Reports of the International Permafrost Association

Yellowknife, Canada

Editors: Antoni G. Lewkowicz
Michel Allard

Acknowledgments

We are grateful to Shawne Clarke and Steve Kokelj, University of Ottawa and Laurent Desrochers and Caroline Lavoie, Université Laval, for their hard work through the various stages of the production of this volume.

Preface

This volume comprises the Conference Program, short abstracts, extended abstracts and reports of the International Permafrost Association.

The technical portion of the Conference Program includes two Plenary sessions, two extensive Poster sessions and 22 Oral sessions. To fit all of these activities into the time available, three concurrent sessions were necessary for much of the conference.

The short abstracts are from the 188 refereed papers that appear in full within the main Proceedings Volume.

The 59 extended abstracts were submitted by graduate students and other authors who wished to present posters at the Conference and publish a summary of their research endeavours. These extended abstracts were edited but not reviewed. Both the short and extended abstracts are organized alphabetically in this volume by senior author.

The reports of the Secretary General and the Working Groups of the International Permafrost Association, found in the last part of this volume, cover the period since the Sixth International Permafrost Conference in Beijing. The latter were prepared by various members of the Working Groups and describe meetings organized, publications produced, international collaboration and plans for the future. Some of these Working Groups will be renewed in Yellowknife while others have completed the tasks for which they were created. All Working Groups will report orally at the second plenary session. Overall, the IPA reports indicate an impressive amount of activity during the five years between conferences.

It is our hope that this volume will prove useful to the delegates attending the Seventh International Conference on Permafrost, as well as the international community of permafrost engineers and scientists at large.

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TECHNICAL PROGRAM

MONDAY JUNE 22

1400-1700 **IPA EXECUTIVE COMMITTEE**
(Open Meeting)
Melville Rooms A and B

1930 **ICE-BREAKER RECEPTION**
Katimavik Room C

TUESDAY JUNE 23

0900 **OPENING CEREMONY**
Katimavik Rooms B and C

1010 BREAK

PLENARY SESSION: ADVANCES IN PERMAFROST SCIENCE AND ENGINEERING
Katimavik Rooms B and C
Co-Chairs: Vladimir Melnikov, Russia and Troy Péwé, USA

1030	C.R. Burn	Field investigations of permafrost and climate change in northwest North America
1120	J.F. Nixon	Recent applications of geothermal analysis in northern engineering

1210 LUNCH
Yellowknife Inn

1330 **POSTER SESSION 1**
Yellowknife Inn
(See list of posters at end of program)

1510 BREAK

MOUNTAIN PERMAFROST
Katimavik Room B
Chair: Wilfried Haeberli, Switzerland

1530	W. Dobinski	Permafrost occurrence in the alpine zone of the Tatra Mountains, Poland
1550	G.K. Lieb	High-mountain permafrost in the Austrian Alps (Europe)
1610	C. Kneisel	Occurrence of surface ice and ground ice/permafrost in recently deglaciated glacier forefields, St. Moritz area, eastern Swiss Alps

FOUNDATIONS IN PERMAFROST
Katimavik Room C
Chair: Ed Hoeve, Canada

1530	A. Phukan	Driven piles in warm permafrost
1550	B. Nidowicz Y. Shur	Russian and North American approaches to pile design in relation to frost action
1610	A.B. Christopherson T.S. Nottingham J.W. Pickering K.W. Braun	West Dock causeway bridge foundations

QUATERNARY EVOLUTION OF PERMAFROST AREAS
Melville Rooms A and B
Chair: Jan Boelhouwers, South Africa

1530	J.B. Murton H.M. French M. Lamothe	The dating of thermokarst terrain, Pleistocene Mackenzie Delta, Canada
1550	W.R. Eisner K.M. Peterson	Pollen, fungi and algae as age indicators of drained lake basins near Barrow, Alaska
1610	P.O. Oksanen P. Kuhry R.N. Alekseeva V.V. Kanev	Permafrost dynamics at the Rogovaya River peat plateau, subarctic Russia

1630	L. King A. Kalisch	Permafrost distribution and implications for construction work in the Zermatt area, Swiss Alps	P. Thalparpan M. Phillips W. Amman	Snow supporting structures in steep permafrost terrain in the Swiss Alps	I.B. Campbell G.G.C. Claridge D.I. Campbell M.R. Balks	Permafrost properties in the McMurdo Sound-Dry Valley region of Antarctica
1650	D. Vonder Mühll T. Stucki W. Haeberli	Borehole temperatures in Alpine permafrost: a ten year series	A.N. Tseyeva G.M. Ignatova G.E. Egorov L.T. Roman V.L. Poleshchuk	Construction experience on hydraulic fill in a permafrost area	DISCUSSION	

1715-1900 **IPA COUNCIL MEETING 1**
Melville Rooms A and B

2000 **PUBLIC LECTURE**
Northern Arts and Cultural Centre

S.A. Wolfe — Living with frozen ground: impact of permafrost on Yellowknife

WEDNESDAY JUNE 24

	ROCK GLACIERS *Katimavik Room B* Chair: Francesco Dramis, Italy		PIPELINES AND GEOTECHNIQUE *Katimavik Room C* Chair: Rupert Tart, USA		PERMAFROST LANDSCAPES AND SOILS *Melville Rooms A and B* Chair: Michel Allard, Canada	
0830	W. Haeberli M. Hoelzle A. Kääb F. Keller D. Vonder Mühll S. Wagner	Ten years after the drilling through the permafrost of the active rock glacier Murtèl, eastern Swiss Alps: answered questions and new perspectives	J.M. Oswell A.J. Hanna R.M. Doblanko	Update of performance of slopes on the Norman Wells pipeline project	M.T. Jorgenson Y. Shur H.J. Walker	Evolution of a permafrost-dominated landscape on the Colville River Delta, northern Alaska
0850	M. Hoelzle S. Wagner A. Kääb D. Vonder Mühll	Surface movement and internal deformation of ice-rock mixtures within rock glaciers at Pontresina-Schafberg, Upper Engadin, Switzerland	A.J. Hanna D. McNeill A. Tchekhovski T. Fridel C. Babkirk	The effects of the 1994 and 1995 forest fires on the slopes of the Norman Wells Pipeline	J.C. Walters C.H. Racine M.T. Jorgenson	Characteristics of permafrost in the Tanana Flats, interior Alaska
0910	J.A. Strelin T. Sone	Rock glaciers on James Ross Island, Antarctica	M.M. Burgess J.F. Nixon D.E. Lawrence	Seasonal pipe movement in permafrost terrain, KP2 study site, Norman Wells Pipeline	G. Broll G. Mueller C. Tarnocai	Permafrost-affected soils in the Pangnirtung Pass area, Baffin Island, Canada
0930	M. Guglielmin C. Smiraglia	The rock glacier inventory of the Italian Alps	J. Greenslade J.F. Nixon	Design aspects of a buried oil pipeline on the Alaskan North Slope	C. Wüthrich I. Möller D. Thannheiser	Soil carbon losses due to increased cloudiness in a high Arctic tundra watershed (western Spitsbergen)
0950	P. Urdea	Rock glaciers and permafrost reconstruction in the southern Carpathian Mountains, Romania	J.F. Nixon	Pipe uplift resistance testing in frozen soil	D.G. Zamolodchikov D.V. Karelin A.I. Ivaschenko	Postfire alterations of carbon balance in tundra ecosystems: possible contribution to climate change
1010	BREAK		BREAK		BREAK	

	DESIGN AND CONSTRUCTION OF ROADS, AIRPORTS AND WASTE DISPOSAL FACILITIES ON PERMAFROST *Katimavik Room B* Chair: Peter Vician, Canada		PERIGLACIAL PROCESSES 1: ICE WEDGES AND PATTERNED GROUND FORMATION *Katimavik Room C* Chair: Antoni Lewkowicz, Canada		INFORMATION SCIENCE AND PERMAFROST *Melville Rooms A and B* Chair: Roger Barry, USA	
1030	K. Johnson G. Craig S. Spry	Design and construction of a sewage lagoon in Grise Fiord, NWT	M. Allard J.N. Kasper	Temperature conditions for ice-wedge cracking and growth: some results from a field experiment	M.J. Clark R.G. Barry	Permafrost data and information: advances since the Fifth International Conference on Permafrost
1050	T. Mølmann B. Bergheim M. Valeriote	Svalbard airport geotechnical study: engineering methodology and results	L.J. Plug B.T. Werner	A numerical model for the organization of ice wedge networks	C. Haggerty C. Hanson	GGD-Browse: bridging the gap between data descriptions and data
1110	D.J. Goering	Experimental investigation of air convection embankments for permafrost-resistant roadway design	R. Peterson W.B. Krantz	A linear stability analysis for the inception of differential frost heave	H.J. Walker L. Hadden	Placing Colville River delta research on the Internet in a digital library format
1130	A. Instanes R.J. Fannin K. Haldorsen	Mechanical and thermal stabilisation of fill materials for road embankment construction on discontinuous permafrost in North-west Russia	S.A. Harris	Nonsorted circles on Plateau Mountain, S.W. Alberta, Canada	I.D. Streletskaya M.O. Leibman L.A. Gerhart C.D. Haggerty A. Brennan	Russian permafrost map bibliography and index
1150	Wu Ziwang Zhu Linnan Guo Xinmin Wang Xiaoyang Fang Jianhong	Critical and design heights of fill material in permafrost regions on National Road 214, eastern Qinghai-Xizang Plateau, China	B. Hallet	Measurement of soil motion in sorted circles, western Spitsbergen	DISCUSSION	

1210 LUNCH
Explorer Hotel

1330-1930 **LOCAL FIELD EXCURSION**

1730 **CALM PROTOCOL MEETING**
Melville Rooms A and B

1930 **BARBECUE**

THURSDAY JUNE 25

Time	MODELING HEAT TRANSFER IN PERMAFROST *Katimavik Room B* Chair: Al Taylor, Canada		PERIGLACIAL PROCESSES 2: FROST WEATHERING AND MASS MOVEMENTS *Katimavik Room C* Chair: Jef Vandenberghe, Netherlands		PERMAFROST ENGINEERING: FIELD AND LABORATORY STUDIES *Melville Rooms A and B* Chair: Branko Ladanyi, Canada	
0830	J.A. Hyatt	Ground thermal regimes at a large earthwork reservoir on Baffin Island, Nunavut, Canada	A. Prick	Frost weathering in a mountain permafrost area (Plateau Mountain, Alberta, Canada)	M. Wegmann H.-R. Keusen	Recent geophysical investigations at a high Alpine permafrost construction site in Switzerland
0850	A.-M. Cames-Pintaux K. Hadj-Rabia M. Allard	Analysis of thermal measurements acquired in Nunavik: comparison of field data with numerical models	V.N. Konishchev	Relationship between the lithology of active-layer materials and mean annual ground temperature in the Former USSR	Chen Yaming Sun Yanfu Liu Hongxu Yin Yanhua Wang Jiacheng Zhang Jiayi	An investigation of the microstructure of frozen soil at fatigue failure under dynamic cycling load with confining pressure
0910	D.W. Riseborough M.W. Smith	Exploring the limits of permafrost	N. Matsuoka K. Hirakawa T. Watanabe W. Haeberli F. Keller	The role of diurnal, annual and millennial freeze-thaw cycles in controlling Alpine slope instability	Zhu Yuanlin Ping He Zhang Jiayi Zhang Jianming	Effect of temperature and strain rate on the constitutive relation of frozen saturated silt
0930	L.N. Khroustalev	Use of computers in geocryological engineering	J. Branson	Preferential incorporation of coarse sediment during needle ice growth: a preliminary analysis	Zhang Jianming Zhu Yuanlin Zhang Jiayi	Adfreeze strength of model piles in frozen soil under dynamic loads
0950	I.D. Streletskaya	Cryopeg responses to periodic climate fluctuations	A.G. Lewkowicz S.A. Clarke	Late-summer solifluction and active layer depths, Fosheim Peninsula, Ellesmere Island, Canada	He Ping Zhu Yuanlin Shi Qinsheng Zhang Zhao	Statistical analyses of frozen soil creep properties

1010 BREAK

1030 **POSTER SESSION 2**
Yellowknife Inn
(See list of posters at end of program)

1210 LUNCH
Yellowknife Inn

Time	COASTAL AND OFFSHORE PERMAFROST *Katimavik Room B* Chair: Hans Hubberten, Germany		HYDROLOGY OF PERMAFROST REGIONS *Katimavik Room C* Chair: Robert van Everdingen, Canada		FROST HEAVE *Melville Rooms A and B* Chair: Cheng Guodong, China	
1330	S.A. Wolfe S.R. Dallimore S.M. Solomon	Coastal permafrost investigations along a rapidly eroding shoreline, Tuktoyaktuk, N.W.T.	M.-K. Woo K.L. Young	Characteristics of patchy wetlands in a polar desert environment, Arctic Canada	B. Ladanyi A. Foriero	Evolution of frost heaving stresses acting on a pile
1350	R.B. Nairn S.M. Solomon N. Kobayashi J.C. Virdrine	Development and testing of a thermal-mechanical numerical model for predicting arctic shore erosion processes	S. Kokelj A.G. Lewkowicz	Long-term influence of active-layer detachment sliding on permafrost slope hydrology, Hot Weather Creek, Ellesmere Island, Canada	J.-M. Konrad M. Shen R. Ladet	Prediction of frost heave induced deformation of dyke KA-7 in northern Québec
1410	F.E. Are	The contribution of shore thermoabrasion to the Laptev Sea sediment balance	W.L. Quinton P. Marsh	Meltwater fluxes, hillslope runoff and streamflow in an Arctic permafrost basin	Y. Ito T.S. Vinson J.F. Nixon J.F. Stewart	An improved step freezing test to determine segregation potential

1430	N.N. Romanovskii A.V. Gavrilov A.L. Kholodov G.P. Pustovoit H.W. Hubberten F. Niessen H. Kassens	Map of predicted offshore permafrost distribution on the Laptev Sea Shelf	D.L. Kane D.J. Soden L.D. Hinzman R.E. Gieck	Rainfall runoff of a nested watershed in the Alaskan arctic	G. Doré J.-M. Konrad M.-A. Bérubé	The effect of consolidation on frost susceptibility of silty soils
1450	K. Hinz G. Delisle M. Block	Seismic evidence for the depth extent of permafrost in shelf sediments of the Laptev Sea, Russian Arctic?	W.H. Pollard C. Omelon D. Anderson C. McKay	Geomorphic and hydrologic characteristics of perennial springs on Axel Heiberg Island, Canadian High Arctic	C. Harris M.C.R. Davies	Pressures recorded during laboratory freezing and thawing of a natural silt-rich soil
1510	BREAK		BREAK		BREAK	

	USE OF GEOPHYSICAL TECHNIQUES IN PERMAFROST AREAS *Katimavik Room B* Chair: Lorenz King, Germany	**ACTIVE LAYER THICKNESS AND TEMPERATURE** *Katimavik Room C* Chair: Hanne Christiansen, Denmark	**GAS HYDRATES** *Melville Rooms A and B* Chair: Nikolai Romanovskii, Russia

1530	T.A. Brent J.C. Harrison	Characterization and mapping of the permafrost zone on land based seismic reflection data, Canadian Arctic Islands	S.I. Outcalt K.M. Hinkel F.E. Nelson L.L. Miller	Estimating the magnitude of coupled-flow effects in the active layer and upper permafrost, Barrow, Alaska, U.S.A.	S.R. Dallimore T.S. Collett	Gas hydrates associated with deep permafrost in the Mackenzie Delta, N.W.T., Canada: regional overview
1550	C.L. Horvath	An evaluation of ground penetrating radar for investigation of palsa evolution, MacMillan Pass, NWT, Canada	S. Carey M.-K. Woo	A case study of active layer thaw and its controlling factors	T.S. Collett S.R. Dallimore	Quantitative assessment of gas hydrates in the Mallik L-38 well, Mackenzie Delta, N.W.T.
1610	S.A. Arcone E.F. Chacho A.J. Delaney	Seasonal structure of taliks beneath arctic streams determined with ground-penetrating radar	G. Mueller G. Broll C. Tarnocai	Soil temperature regimes and microtopographic contrasts, Baffin Island, N.W.T., Canada	J.F. Wright E.M. Chuvilin S.R. Dallimore V.S. Yakushev F.M. Nixon	Methane hydrate formation and dissociation in fine sands at temperatures near 0°C
1630	N. Yu Bobrov S.S. Krylov I.V. Soroka	Statistical investigations of shallow permafrost by electromagnetic profiling	A.V. Pavlov	Active layer monitoring in northern West Siberia	V.A. Skorobogatov V.S. Yakushev E.M. Chuvilin	Sources of natural gas within permafrost, North-west Siberia
1650	V. Yu. Zadorozhnaya	Transient EM sounding in the study of permafrost	S.I. Zabolotnik	Latitudinal and altitudinal trends of seasonal soil thaw in Yakutia	DISCUSSION	

1730 **WORKING GROUP MEETINGS**
(Sign up list at Registration)

1900 **COCKTAILS**
Katimavik Rooms B and C

2000 **BANQUET**
Katimavik Rooms B and C

FRIDAY JUNE 26

0830-1010 **PLENARY 2: WORKING GROUP REPORTS, DISCUSSION AND FUTURE DIRECTIONS**
Katimavik Rooms B and C
Chair: Jerry Brown, USA

1010 BREAK

Time	GROUND ICE *Katimavik Room B* Chair: Charles Harris, UK		INFLUENCE OF CLIMATE CHANGE AND CLIMATE ON PERMAFROST *Katimavik Room C* Chair: Margo Burgess, Canada	
1030	S.A. Wolfe	Massive ice associated with glaciolacustrine delta sediments, Slave Geological Province, N.W.T., Canada	D.A. Gilichinsky R.G. Barry S.S. Bykhovets V.A. Sorokovikov T. Zhang S.L. Zudin D.G. Fedorov-Davydov	A century of temperature observations of soil climate: methods of analysis and long term trends
1050	R. Gragnani M. Guglielmin A. Longinelli B. Stenni C. Smiraglia L. Cimino	Origins of the ground ice in the ice-free lands of the Northern Foothills (Northern Victoria Land, Antarctica)	C.A.S. Smith C.R. Burn C. Tarnocai B. Sproule	Air and soil temperature relations along an ecological transect through the permafrost zones of northwestern Canada
1110	S.D. Robinson W.H. Pollard	Massive ground ice within Eureka Sound bedrock, Ellesmere Island, Canada	A.E. Taylor F.M. Nixon J. Eley M. Burgess P. Egginton	Effect of atmospheric temperature inversions on ground surface temperatures and discontinuous permafrost, Norman Wells, Mackenzie Valley, Canada
1130	B.J. Moorman F.A. Michel A. Wilson	The development of tabular massive ground ice at Peninsula Point, N.W.T., Canada	K. Takata M. Kimoto	Impact of soil freezing on the continental-scale seasonal cycle simulated by a general circulation model
1150	J.A. Hyatt	The origin of lake-bed ground ice at Water Supply Lake, Pond Inlet, Nunavut, Canada	S.S. Vyalov A.S. Gerasimov S.M. Fotiev	Influence of global warming on the state and geotechnical properties of permafrost
1210	LUNCH *Explorer Hotel*		LUNCH *Explorer Hotel*	

Time	PHYSICS AND CHEMISTRY OF FROZEN GROUND *Katimavik Room B* Chair: Angélique Prick, Belgium		USE OF REMOTE SENSING AND GIS IN PERMAFROST REGIONS *Katimavik Room C* Chair: Truls Mølmann, Norway		IPA COUNCIL MEETING 2 *Melville Rooms A and B*
1330	K.W. Biggar M. Nahir S. Haidar	Migration of petroleum contaminants into permafrost	A. Kääb G.H. Gudmundsson M. Hoelzle	Surface deformation of creeping mountain permafrost. Photogrammetric investigations on rock glacier Mùrtel, Swiss Alps	IPA COUNCIL MEETING 2

1350	C.R. Burn V.R. Parameswaran L. Kutny L. Boyle	Electrical potentials measured during growth of lake ice, Mackenzie Delta area, N.W.T.	F. Keller R. Frauenfelder J.-M. Gardaz M. Hoelzle C. Kneisel R. Lugon M. Phillips E. Reynard L. Wenker	Permafrost map of Switzerland	IPA COUNCIL MEETING 2
1410	S.E. Grechishchev A.V. Pavlov V.V. Ponomarev	Phase equilibrium and kinetics of saline soil water freezing	B. Etzelmüller I. Berthling J.L. Sollid	The distribution of permafrost in southern Norway - a GIS approach	IPA COUNCIL MEETING 2
1430	Zhang Lixin Xu Xiaozu Deng Yousheng Zhang Zhaoxiang	Study of the relationship between the unfrozen water content of frozen soil and pressure	Li Xin Cheng Guodong Chen Xianzhang	Response of permafrost to global change on the Qinghai-Xizang Plateau - a GIS aided model	IPA COUNCIL MEETING 2
1450	DISCUSSION		H.B. Granberg P.W. Vachon	Delineation of discontinuous permafrost at Schefferville using Radarsat in interferometric mode	IPA COUNCIL MEETING 2
1510	BREAK				
1530	**CLOSING CEREMONY** *Katimavik Rooms B and C*				
1710-1900					**IPA COUNCIL MEETING 2** (CONTINUED) *Melville Rooms A and B*

POSTER SESSION 1 - TUESDAY JUNE 23

V.I. Aksenov G.I. Klinova I.V. Scheikin	Material composition and strength characteristics of saline frozen soils
V.T. Balobayev A.S. Tetelbaum S.D. Mordovskoy	Numerical model of layer pressure dynamics below permafrost
L. Bernhard F. Sutter W. Haeberli F. Keller	Processes of snow/permafrost-interactions at a high-mountain site, Murtel/Corvatsch, eastern Swiss Alps
B.L. Berry	Long-term predictions from three million tears of climatic, glacial and periglacial history
J.G. Bockheim C. Tarnocai	Nature, occurrence and origin of dry permafrost
N.P. Bosikov	Wetness variability and dynamics of thermokarst processes in central Yakutia
N. Cannone A. Pirola	Vegetation analysis and mountain permafrost mapping in the Italian central Alps
V.G. Cheverev	Physical and chemical characteristics of a polymeric coating for the soil surface to protect against erosion by wind and water
A.B. Chizhov A.Yu. Dereviagin	Tritium in Siberian permafrost
E.M. Chuvilin E.D. Ershov O.G. Smirnova	Ionic migration in frozen soils and ice
E.M. Chuvilin E.D. Ershov N.S. Naletova	Mass transfer and structure formation in freezing saline soils
S.A. Clarke A.G. Lewkowicz	Influence of climate fluctuations on solifluction: an experimental study
F. Costard J. Aguirre-Puente N. Makhloufi	Fluvial-thermal erosion: laboratory simulation
C. Crampton	Studies of some rivers and associated permafrost in northern British Columbia and Yukon
I.D. Danilov	Global climatic changes, permafrost and glaciation of the Arctic region
Deng Yousheng Zhu Lingnan Wu Ziwang Zang Anmu Li Yongfu Ma Zhongying	Problems of frozen rock engineering in the Dabanshan Tunnel in Qinghai Province
M.M. Dubina V.V. Konovalov Yu. A. Chernyakov	Mathematical modeling of thermomechanical behaviour of building-ground system in cryolithozone
V.I. Fedoseeva	Experimental investigations of gold migration in the frozen massifs
B. Forbes	Cumulative impacts of vehicle traffic on high arctic tundra: soil temperature, plant biomass, species richness, and mineral nutrition
S.M. Fotiev M.O. Leibman	The role of neotectonics in permafrost origin and features of the Baikal-Amur mainline region, Russia
R. Frauenfelder B. Allgöwer W. Haeberli M. Hoelzle	Permafrost investigations with GIS - a case study in the Fletschorn area, Wallis, Swiss Alps
A.D. Frolov Y.D. Zykov V. Snegirev	Principal problems, progress, and directions of permafrost geophysical investigations
J.-M. Gardaz	Aspects of Rock Glacier and Mountain Permafrost Hydrology: Cases Studies in the Valais Alps, Switzerland
V.I. Grebenets A.G.-O. Kerimov S.N. Titkov	Dangerous movement of an anthropogenic "rock glacier", Norilsk region, northern Siberia
N.N. Grib A.V. Samokhin U.N. Skomoroshko	Predicting the strength of frozen coal-bearing rock in the South Yakutian coal field by borehole logging
I.E. Guryanov	Problems of interaction between structures and permafrost: the example of headframe foundations
K. Hall	Some observations and thoughts regarding Antarctic cryogenic weathering
V.U. Izaxon	Bench stability control in a deep diamond open pit mine using thermal insulation
E.G. Karpov E.L. Baranovsky	Genesis and paleogeographical conditions of massive ground ice formation, Tab-Salya Section, northern Yenisey, Russia
M. Kessler B. Murray B. Hallet	A model for sorted circle formation and evolution
A. Klene J. Nevins J. Harris F. Nelson	Permafrost science and secondary education: direct involvement of teachers and students in field research
V.G. Kondratiev	Deformation of roadbeds on permafrost and its prevention
A.A. Konovalov I.D. Danilov	Multi-level permafrost of the arctic coastal accumulative plains - sequence of sea level oscillations
A.G. Kostyaev	Boundaries of the cryolithozone in Northern Eurasia as a debatable problem of Pleistocene paleocryology
E. Kotler C.R. Burn	The cryostratigraphy of unconsolidated material overlying auriferous creek gravels, Klondike area, Yukon Territory, Canada

G.P. Kuzmin	Experimental studies of the processes of ice formation and evaporation in air thermosyphons
E.K. Lilly D.L. Kane L.D. Hinzman R.E. Gieck	Annual water balance for three nested watersheds on the North Slope of Alaska
R. Lomborinchen	Frost heaving near Ulaanbaatar, Mongolia
V.J. Lunardini	Effect of convective heat transfer on thawing of frozen soil
L.L. Miller K.M. Hinkel F.E. Nelson R. Paetzold S.I. Outcalt	Spatial and temporal patterns of soil moisture and thaw depth at Barrow, Alaska, U.S.A.
K.F. Mobley M. Fitzpatrick J.E. Ferrell	Thermal assessment of passive cooled foundation soils beneath the Trans-Alaska pipeline at Atigun Pass
N.G. Moskalenko	Impact of vegetation removal and its recovery after disturbance on permafrost
F.E. Nelson S.I. Outcalt J. Brown N.I. Shiklomanov K.M. Hinkel	Spatial and temporal attributes of a long-term record of active-layer thickness, Barrow, Alaska, U.S.A.
Niu Yonghong Miao Tiande Zhang Changqing Zhang Jiangming	Damage model of frozen soil under multi-axial state stress
F.M. Nixon A.E. Taylor	Regional active layer monitoring across the sporadic, discontinuous and continuous permafrost zones, Mackenzie Valley, Northwestern Canada
V. Ostroumov C. Siegert A. Alekseev V. Demidov T. Alekseeva	Permafrost as a frozen geochemical barrier
W.H. Pollard T. Bell	Massive ice formation in the Eureka Sound lowlands: a landscape model
C.H. Racine M.T. Jorgenson J.C. Walters J.E. Roth	Thermokarst-derived vegetation and landscapes in the Tanana Flats, interior Alaska, U.S.A.
F.M. Rivkin	Regional characteristics of subfluvial talik formation and structure, Yamal Peninsula, Russia
N.N. Romanovskii G. Tipenko	Regularities of permafrost interaction with gas and gas hydrate deposits
G.E. Rozenbaum N.A. Shpolyanskaya	A model of Quaternary permafrost evolution in the Arctic
P.I. Salnikov	Properties of frozen ground affecting foundations in Southern Zabaikalie
A.E. Sheshukov A.G. Egorov	Numerical modeling of coupled moisture, solute and heat transport in frozen soils
Y. Shur M.T. Jorgenson	Cryostructure development on the floodplain of Colville River Delta, northern Alaska
V. Sloan L.D. Dyke	A comparison of decadal and millennial velocities of rock glaciers in the Selwyn Mountains, Canada
F.M. Thomson D.J. Petley	Thaw-consolidation behaviour of some British soils
A.C. Vasil'chuk Y.K. Vasil'chuk	The application of pollen and spores to determine the origin and formation conditions of ground ice in western Siberia
I.S. Vassiliev	Response of the thermal regime of soils to recent climatic changes in Yakutia
K. Wollny K. Belitz	Applications of geophysical investigations including seismics and ground penetrating radar for monitoring active layer development in alpine permafrost
V.S. Yakupov A.A. Akhmetshin M.V. Yakupov	Hydrocarbon deposits and attendant anomalies of permafrost upper and lower boundaries
A. Yavelov V. Movchan S. Obridco D. Sergeev I. Utkina T. Shchadrina	Map of potential environmental damage due to oil spills in the permafrost region of Russia
Yu Zhankui Zhu Yuanlin He Ping Zhang Jiayi	Experimental study of Poisson's ratio for frozen soil
Zhang Jianming Zhang Changqing Li Yafeng Miao Tiande	Analyses of microstructure damage from the creep process in frozen soil using a scanning electron microscope
T. Zhang K. Stamnes	Influence of climatic factors on the thermal regime of the active layer and permafrost at Barrow, Alaska
Z.X. Zhang R.L. Kushwaha	Simulation of freezing and frozen soil behaviour using a radial function neural network

POSTER SESSION 2 - THURSDAY JUNE 25

V.V. An V.N. Devyatkin	The influence of climatic, geodynamic and anthropogenic factors on permafrost conditions in Western Siberia
V.A. Basisty A.A. Buiskikh	Evolution of the cryolithic zone in sedimentation and denudation environments
K. Belitz K. Wollny	Application of multitemporal aerophotogrammetrical monoplotting for mapping past, and monitoring present, rock glacier deformation
J. Boike J.-W. Huberten	Climatological and hydrological influences on stable hydrogen and oxygen isotopes of active layer waters, Levinson-Lessing Lake area, Taymyr Peninsula
V.N. Borisov S.V. Alexeev	Interaction between brines and permafrost
O.P. Chervinskaya A.D. Frolov Y.D. Zykov	On the correlation of elastic and strength properties for saline frozen soils
V.G. Cheverev E.D. Ershov M.A. Magomedgadzhieva I.P. Vidyapin	Results of physical simulation of frost heave in soils
N. Choibalsan	Characteristics of permafrost and foundation design in Mongolia
N.J. Couture W.H. Pollard	An assessment of ground ice volume near Eureka, Northwest Territories
G. Da Re J.T. Germaine C.C. Ladd	The mechanical behaviour of frozen Manchester fine sand at small strains under high-pressure triaxial test conditions
I.D. Danilov I.A. Komarov A. Yu. Vlasenko	Pleistocene-Holocene permafrost of the east Siberian Eurasian arctic shelf
G. Delisle	Numerical simulation of permafrost development in the Laptev Sea, Siberia
Ding Yongjian	Recent degradation of permafrost in China and the response to climatic warming
E.D. Ershov I.A. Komarov R.G. Motenko	Phase composition and thermal properties of frozen saline soils over a wide range of negative temperatures
A.N. Fedorov P.Ya. Konstantinov I.S. Vassiliev N.P. Bosikov Ya.I. Torgovkin V.V. Samsonova	Observations of permafrost-landscape dynamics related to anthropogenic disturbances, Yukechi study site, central Yakutia
R. Fortier M. Allard	Induced polarization and resistivity logging in permafrost
H.M. French I. Egorov	20th Century variations in the southern limit of permafrost near Thompson, northern Manitoba, Canada
M.K. Gavrilova	Global climate warming and future temperatures in North America
J.B. Gorelik V.S. Kolunin A.K. Reshetnikov	Rigid-ice model and stationary growth of ice
W.A. Gould C. Bay L.C. Bliss F. Daniëls C.J. Markon S.S. Talbot D.A. Walker S. Zoltai	Circumpolar Arctic vegetation map: an overview and prototype maps for the North American Arctic
S.V. Gubin	Cryosol properties on permafrost: structure and dynamics
M. Guglielmin F. Dramis	Permafrost thermal monitoring at Terra Nova Bay area, Antarctica
S.A. Guly G.Z. Perlshtein	Ice food depot cooled with a heat pump: a pre-feasibility study
K. Hall	Nivation or cryoplanation: is there any difference
K. Harada K. Yoshikawa	Permafrost age and thickness at Moskuslagoon, Spitsbergen
L.D. Hinzman D.W. Robinson D.L. Kane	A biogeochemical survey of an Arctic coastal wetland
H. Ishidaira T. Koike M. Lu N. Hirose	Development of a distributed hydrological model for permafrost regions considering 1-D heat and water transfer and river flow processes
J.A. Jernsletten	Ground ice and slope failure in the canyon walls on Mars
Jin Huijun T. Nakano Cheng Guodong Sun Guangyou	Preliminary study on methane fluxes from an alpine wetland on the Qinghai-Tibet Plateau
E.G. Karpov E.L. Baranovsky	Changes in permafrost conditions along linear engineering structures in the north-taiga subzone of the arctic Yenisey area, Russia
V. Kaufmann	Deformation analysis of the Doesen rock glacier (Austria)
O.A. Kazansky	Calculation of paleoclimate temperatures from basic physical theory of segregation ice lens formation
U. Kienel S. Siegert J. Hahne	Late Quaternary paleoenvironmental reconstruction from a permafrost sequence (North Siberian Lowland, SE Taymyr Peninsula) - a multidisciplinary case study
I.P. Konstantinov	Oil and gas complex creation in Yakutia: environmental issues
E. Kotler F.A. Michel D.A. Hodgson	Gravimetric investigation of mounded till deposits, central Victoria Island, Northwest Territories, Canada

S.S. Krylov N.Yu. Bobrov	Anomalous electrical properties of saline permafrost on the Yamal Peninsula, North-Western Siberia, from field electromagnetic survey
M.O. Leibman	Thaw depth measurements in marine saline sandy and clayey deposits of Yamal Peninsula, Russia: procedure and interpretation of results
F.N. Leshchikov	Occurrence of cryogenic phenomena in seismic structures of the Baikal Rift Zone
Li Dongqing Wu Ziwang Fang Jianhong Wang Xiaoyang	Modeling and predicting permafrost degradation due to climate warming in the Huashixia Valley, Eastern Qinghai-Tibet Plateau
Li Shuxun Chen Ruijie	Simulation of the thermal regime of permafrost in northeast China under climate warming
Ling Feng Wu Ziwang Zhu Yuanlin He Chunxiong	Fractal simulation of the stress-strain curve of frozen soil
O.M. Lisitsyna N.N. Romanovskii	Dynamics of permafrost in northern Eurasia during the last 20,000 years
E. Little V.P. Nechaev K. Dlussky A.A. Velichko N.W. Rutter	Permafrost history during the Middle and Upper Pleistocene, Moscow-Oka region of the Russian Plain
V.M. Litvin	Permafrost of the Baikal-Patom plateau
A.S. Lyubomirov	Dynamics of the coastal zone of the Gulf of Anadyr, Bering Sea, due to tidal activity
Ma Wei Wu Ziwang Pu Yipin Chang Xiaoxiao	Monitoring the change of structures in frozen soil during the triaxial creep process by computer tomography
J.A. Majorowicz	A constraint to the methane gas hydrate stability from the analysis of thermal data in the northern Canadian sedimentary basins - Arctic Archipelago case
E.S. Melnikov	Uniting basis for creation of ecological maps for Russian cryolithozone
E. Ménard M. Allard Y. Michaud	Monitoring of ground surface temperatures in various biophysical micro-environments near Umiujaq, eastern Hudson Bay, Canada
Y. Mutou K. Watanabe T. Ishizaki M. Mizoguchi	Microscopic observation of ice lensing and frost heave in glass beads
J. Putkonen	Suitability of central Alaska for early detection of climate warming
L.T. Roman	Kinetic nature of soft-frozen soil strength
F.A. Romanenko	Underground ice and relief evolution of islands and coasts of the Russian Arctic
V.E. Romanovsky T.E. Osterkamp	Role of unfrozen water in the active layer and permafrost
D. Sarrazin M. Allard	The analysis of some permafrost features through cryostratigraphy and ground penetrating radar (G.P.R.) investigations on an emerging coast, Nastapoca River, Subarctic Québec
N. Sharkhuu	Trends of permafrost development in the Selenge River Basin, Mongolia
N.I. Shender A.S. Tetelbaum Yu.B. Skatchkov	Response of the cryolithozone of Yakutia to climate change
P.N. Skryabin Yu.B. Skatchov S.P. Varlamov	Climate warming and monitoring of thermal state of soils in central Yakutia
T. Sone J.A. Strelin	Stone-banked terraces in Riscos Rink, James Ross Island, Antarctic Peninsula Region
S. Springman L. Arenson	Some geotechnical influences on thawing Alpine permafrost
D. Trombotto E. Buk J. Corvalen J. Hernández	Present state of measurements of cryogenic processes in the Lagunita del Plata, Mendoza, Argentina, Report Nr. II
D. Tumurbaatar	Seasonally and perennially frozen ground around Ulaanbaatar, Mongolia
B. van Vliet-Lanoe P. Worsley S. Gurney B. Hallégouët	Cainozoic permafrost record
Y.K. Vasil'chuk A.C. Vasil'chuk	Oxygen-isotope and enzymatic activity variations in the syngenetic ice-wedge complex Seyaha of the Yamal Peninsula
S.S. Volokhov	The role of the zone of contact of frozen soils with foundation materials in the formation of adfreezing strength
Wang Jiacheng Wang Yujie	A study of the microstructure of frozen soil
Wu Qingbai Mi Haizeng Li Xing Li Wenjun	A model to evaluate the engineering geology on frozen ground from Xidatan to Wudaoliang along the Qinghai-Xizang Highway using GIS
V.S. Yakupov M.V. Yakupov	On the difference between ground ice resistivities in central Yakutia and the subarctic lowlands
K. Yoshikawa	The groundwater hydraulics of open system pingos
V.N. Zaitzev E.D. Ershov K.A. Kondratieva	Geocryological map of the USSR at a scale of 1:2,500,000

Short Abstracts

(from the Proceedings)

MATERIAL COMPOSITION AND STRENGTH CHARACTERISTICS OF SALINE FROZEN SOILS

V.I.Aksenov, G.I.Klinova, I.V.Scheikin

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The physical and mechanical properties of frozen ground depend mostly on its phase components (unfrozen water vs. ice content) which vary with temperature, salinity, salt composition and moisture.

Equations to calculate the temperature at the start of freezing and the phase components are presented in this paper. The former depend on the salinity, moisture and average molecular weight of dissolved particles. The phase components are calculated for different soil moistures and phase change temperatures. The unfrozen water content of clay is plotted versus temperature and salinity. Approaches to the determination of a boundary between plastic-frozen and hard-frozen states of saline soils are analyzed. The relationship between the mechanical properties of saline frozen ground and phase components is considered.

TEMPERATURE CONDITIONS FOR ICE-WEDGE CRACKING: FIELD MEASUREMENTS FROM SALLUIT, NORTHERN QUÉBEC

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The temperatures at which thermal cracking occurred along ice-wedges around a tundra polygon were measured over two years near Salluit, northern Québec. Electrical cables were buried in the active layer across furrows or cracks in the soil at various places around the polygon. The time of breaking of the electrical cables, and the air, soil surface and ground temperatures down to 2.5 m were monitored with a datalogger. In the course of the two winters, several cables broke with the opening of thermal cracks. Over the two years, the first cracks opened in late December-early January when the temperature at the permafrost table was about -15°C, and after a drop of air temperature from about -20°C to below -32°C. Mean cracking temperature at wedge top was -20°C in the first year and -19.7°C in the second year. The data also allow estimates of the minimum temperature changes and cooling rates required to induce ice-wedge cracking. The cracks closed (or narrowed) and re-opened (or widened) in response to winter temperature fluctuations at the soil surface. The measured thermal conditions for cracking substantiate the previous theoretical work on this basic process at the origin of tundra polygons.

THE INFLUENCE OF CLIMATIC, GEODYNAMIC AND ANTHROPOGENIC FACTORS ON PERMAFROST CONDITIONS IN WESTERN SIBERIA

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The problem of global change cannot be clearly addressed for all permafrost regions as inaccurate data are used for certain geocryological problems. Permafrost state is determined by temperature measurements mainly in prospecting wells and the observed temperature in oil-gas fields is a result of pressure decrease and temperature decline under the expansion of the gas after the wells have been drilled. The so-called deep permafrost determined on the basis of temperature measurements, in the zone between Arctic Circle and the Ob River is the result of anthropogenic change and the permafrost thickness is here slightly increased. To receive a clear indication about cryogenic processes in an oil-gas province, it is necessary to have long-term observations in the deep special wells and to monitor gas migration.

SEASONAL STRUCTURE OF TALIKS BENEATH ARCTIC STREAMS DETERMINED WITH GROUND-PENETRATING RADAR

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We interpret the structure and development of taliks beneath stream channels from 375-MHz ground-penetrating radar profiles obtained in January and April within the Sagavanirktok River floodplain in Alaska. The upper surfaces appear smooth, often show an ice layer, and vary in depth with channel bathymetry. Partial freezing within taliks appears to cause weak reflections from the talik surface, internal reflections, and a distorted talik radar image. The taliks shrink as they propagate downward through the winter. Some taliks completely freeze by mid-April. Others may exist at 3.7 m beneath a typical, 1.8-m-deep frozen channel, and deeper beneath channels that do not freeze completely. The persistent though diminishing flow from drill holes demonstrates their permeability.

THE CONTRIBUTION OF SHORE THERMOABRASION TO THE LAPTEV SEA SEDIMENT BALANCE

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A schematic map of Laptev Sea shore dynamics is compiled for the first time, using available published data. It shows the distribution of thermoabrasion shores, mean long-term shore retreat rates, and areas of seabed erosion and accretion. The amount of sediment released to the sea from the 85 km Anabar-Olenyok section of the coast is calculated, as an example, at 3.4 Mt/year. These results are compared with published data on sediment transport of rivers running into the Laptev Sea. Estimates of the Lena River discharge range from 12 to 21 Mt/year, of which only 2.1 to 3.5 Mt may reach the sea. The analysis shows that the input of thermoabrasion at mean shoreline retreat rates of 0.7 to 0.9 m/year is at least of the same order as the river input and may greatly exceed it.

EVOLUTION OF THE CRYOLITHIC ZONE IN SEDIMENTATION AND DENUDATION ENVIRONMENTS

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This paper contains the computer-modelled results of permafrost development with different sedimentary and denudation rates. The permafrost conditions typical of intermontane depressions of the Yana-Chukchi Highlands have been used as the source data in this paper. Movements of tectonic blocks, which occurred through the Late Pleistocene and Holocene time periods, caused both the supply and re-distribution of non-consolidated rocks in this area. As the vertical movements of tectonic blocks were rather fast and significant, the processes of compensatory sedimentation or denudation of many blocks took place there. As the surface temperature changes from 1°C below zero to 3°C below zero, the thickness of frozen rocks changes from 82 m to 214 m, respectively. Neotectonic movements and the processes of compensatory sedimentation having rates 0.3-0.5 cm/year increased the corresponding thicknesses of frozen rocks to 130 m and 190 m, at the surface temperature of 1°C below zero; the surface temperature being 3°C below zero, these values became as high as 298 m and 350 m, respectively. According to the calculated results for 1 cm/year compensatory sedimentation rate, the lower boundary of permafrost is not yet stable even at 400 m depth. Neotectonic movements associated with the simultaneous denudation processes having 0.3-2.0 cm/year rates caused the changes in the permafrost thickness from 16 m to 184 m. The obtained modelling results support the possibility of formation of both an anomalously significant permafrost, as, for example, in the Ola Depression, where it has 350 m thickness, and on the left side of the Seimchan-Buyunda Depression, where it is up to 550 m, and an anomalously thin permafrost in some areas, as, for example on the western side of the Seimchan-Buyunda Depression, where it is from 30 m to 80 m only.

PROCESSES OF SNOW/PERMAFROST-INTERACTIONS AT A HIGH-MOUNTAIN SITE, MURTÈL/CORVATSCH, EASTERN SWISS ALPS

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In a study on the surface of the active rock glacier Murtèl/Corvatsch, a system of vertical funnels (holes) was examined within the snow cover in early winter. Such funnels distributed along topographic depressions and following cold-air drainage patterns efficiently couple the active layer with the cold winter atmosphere, thereby reducing the thermal insulation effect of snow. For late-winter, spring and early summer conditions, repeated snow-depth point measurements were interpolated on the basis of topographic parameters and used in a model to simulate the melting of snow during the spring and early summer period over the entire rock glacier. The effects of late melting and of thick snow, causing delayed surface warming during spring and early summer, combine with the effects of enhanced mid-winter cooling in furrows, to cause colder ground temperatures and a shorter thaw season. This explains the pronounced decrease of active-layer thickness in deep furrows as documented by earlier seismic refraction soundings.

MIGRATION OF PETROLEUM CONTAMINANTS INTO PERMAFROST

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It has been generally assumed by the engineering community that permafrost will act as an impermeable barrier to the migration of non-aqueous phase liquids (NAPLs). The results from recent site investigations in the Arctic have shown, however, that NAPLs can penetrate the permafrost to significant depths. The mechanisms responsible for the transport of the free phase product are believed to be gravity drainage and capillary suction into cracks and fissures in the frozen soil induced by thermal contraction. Diffusion of contaminants through the unfrozen water in soils is a possible mechanism, but due to the low solubilities of the NAPL components and the small amounts of unfrozen water, this is likely insignificant. The paper reviews the subject background, discusses diffusion of NAPL contaminants in frozen soil, and reviews the results of field site investigations showing the magnitude of vertical contaminant migration in various soils in the High Arctic.

STATISTICAL INVESTIGATIONS OF SHALLOW PERMAFROST BY ELECTROMAGNETIC PROFILING

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Electromagnetic (EM) profiling using a portable system operating at frequencies 40, 80 and 320 kHz was carried out at two sites in the Bovanenkovo gas field, Yamal Peninsula, northwest Siberia. Profile curves of apparent resistivity were examined by spectral analysis, and the fractal dimensions *(D)* of the curves were evaluated from the power density spectra. The profile curves obtained at the first site yielded *D* close to 1.5, the dimension of fractal Brownian noise. Such a character of apparent resistivity profiles suggests that the distribution of ice inhomogeneities in shallow permafrost at this site is fractal. The profile curve from the second site is not fractal. This indicates an absence of perceptible large-scale ice inhomogeneities in the geological section. The use of EM profiling for the investigation of the spatial distribution of ice and ice content in shallow permafrost is discussed.

NATURE, OCCURRENCE AND ORIGIN OF DRY PERMAFROST

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Dry permafrost may be defined as a material that remains below 0°C for two or more years in succession but that has insufficient interstitial ice to become cemented. Dry permafrost has a very low moisture (ice) content (≤5% volumetric basis) and occurs in areas receiving <100 mm annual precipitation and where sublimation and evaporation exceed the water-equivalent precipitation. Likely restricted to ice-free area of Antarctica (e.g., the "dry valleys"), dry permafrost may be confused with a deep active layer in coarse-textured sediments, especially in the High Arctic, central Yakutia, and in cold-arid alpine environments. The thickness of dry permafrost ranges from a few decimeters to at least 5 m. Although the origin of dry permafrost is unknown, it likely originates from sublimation of moisture from ice-cemented permafrost in cold-dry environments over periods of excess of 18,000 yr.

CLIMATOLOGICAL AND HYDROLOGICAL INFLUENCES ON STABLE HYDROGEN AND OXYGEN ISOTOPES OF ACTIVE LAYER WATERS, LEVINSON-LESSING LAKE AREA, TAYMYR PENINSULA

Julia Boike[1], Hans-Wolfgang Hubberten[2]

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Stable isotope data ($\delta^{18}O$, δD) of precipitation and active layer waters were collected in the Levinson-Lessing Lake catchment, Taymyr, Siberia during 1994 and 1995. They are used here in conjunction with hydrological and microclimate data to provide information on water-forming processes in the active layer. Summer precipitation defines a local meteoric water line different from the global meteoric water line, suggesting that the source of summer precipitation has been exposed to evaporative isotopic enrichment. The stable isotope composition of active layer waters indicate that they are mostly fed by summer rain. Small isotopic variabilities between sites in the catchment indicate differences in microclimatic and hydrologic characteristics. Furthermore, the isotope ratios have been successfully applied to differentiate between sources of active layer waters (snow and ground ice melt, rain water). Further studies are required to develop universally applicable models that describe isotopic behaviour in the active layer in these areas.

WETNESS VARIABILITY AND DYNAMICS OF THERMOKARST PROCESSES IN CENTRAL YAKUTIA

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This report reviews the relationship between the development of thermokarst processes and general wetness of an area. Alas lakes are mainly fed by precipitation. Ground ice feeds thermokarst lakes only during the intial stage of their formation. Therefore, lakes of closed alas depressions can indicate the degree of general wetness during different periods of time.

A plot of a tentative wetness coefficient (total annual precipitation divided by mean summer temperature) shows several cycles (1891-1995) that largely coincide with the available information on fluctuations of lake levels. This means that fluctuations in the alas lake level or the rate of development of a thermokarst process can be deduced from a tentative wetness coefficient of an area.

Development of thermokarst process has a cyclic character. There is a multi-secular cycle, due to variability of general wetness in a region, with secular and intrasecular fluctuations within it.

PREFERENTIAL INCORPORATION OF COARSE SEDIMENT DURING NEEDLE-ICE GROWTH: A PRELIMINARY ANALYSIS

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Soils affected by permafrost and periglacial activity commonly exhibit distinctive sorting patterns, either at a macroscopic or microscopic scale, in which coarse material is preferentially lifted towards, or across, the soil surface. Earlier laboratory investigations have indicated no difference between the grain-size distribution of the bulk soil sample and the sediment included within needle-ice crystals. The present study, however, based on laboratory and field data, shows that the included material is significantly coarser than the host material. The results suggest that, during the migration of a freezing front, fine particles are "pushed" ahead of it while "coarse" particles are incorporated within the ice.

CHARACTERIZATION AND MAPPING OF THE PERMAFROST ZONE ON LAND BASED SEISMIC REFLECTION DATA, CANADIAN ARCTIC ISLANDS

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Industry seismic profiles have been utilized to locate the base of ice-bonded permafrost (BIBP) throughout the Canadian Arctic Islands in porous Devonian through Tertiary bedrock to 1008 m below surface. Seismically-defined BIBP features, located at 160 to 480 milliseconds (ms), have been correlated with conventional BIBP as picked on petrophysical logs, and thermal profiles of studied exploration wells. Identifying seismic features include: 1) a continuous reflector from the base of permafrost ice that transects inclined stratal reflections; 2) amplitude decay of stratal reflectors at the BIBP; 3) bending of stratal reflectors that pass through the BIBP; 4) amplitude anomalies associated with a lithology and porosity dependent transitional BIBP and; 5) step-down of sub-permafrost reflectors that extend beyond the shoreline limit of permafrost. These data can provide an improved understanding of regional heat flow and porosity variation in bedrock, and insight into the growth and decay of the permafrost layer.

PERMAFROST-AFFECTED SOILS IN THE PANGNIRTUNG PASS AREA, BAFFIN ISLAND, CANADA

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Soils were studied along Pangnirtung Pass on Cumberland Peninsula in the southeastern part of Baffin Island, N.W.T. The soils studied are dominantly Cryosols. They have developed on till, eolian, fluvial and colluvial materials, and have active layer depths between 60 and 150 cm. Turbic Cryosols have developed primarily on till. These soils (Orthic Dystric Turbic Cryosols and Regosolic Turbic Cryosols) are acidic and have a loamy sand texture. Static Cryosols (Orthic Dystric Static Cryosols, Regosolic Static Cryosols, Brunisolic Dystric Static Cryosols and Gleysolic Static Cryosols), which are found on different parent materials, are also acidic, and in most cases they have a sandy or coarse sandy texture. The deepest solum development is found in Brunisolic Dystric Static Cryosols developed on well-drained eolian materials. Gleysolic Static Cryosols have developed on poorly drained locations. In addition, small areas of Organic Cryosols occur in the northern part of Pangnirtung Pass.

SEASONAL PIPE MOVEMENT IN PERMAFROST TERRAIN, KP2 STUDY SITE, NORMAN WELLS PIPELINE

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The Norman Wells pipeline is the first completely buried oil pipeline in Canada in permafrost terrain. From start-up in 1985 until late 1993, the oil was chilled year-round for entry into the line at -2°C. A seasonal freeze-thaw chilling cycle has since been in effect. A 100 m long site was established in 1994 to observe the interaction between the alternating cold and warm pipe and permafrost soils. Successive pipe elevation surveys have shown that the pipe undergoes seasonal heave and settlement of up to 22 cm. Net movement of up to 17 cm has occurred over three years, with the north end heaving, while the central and southern end settle. Pipe elevation surveys compare well to elevation data derived from Geopig runs and provide independent support to the internal geometry monitoring tool. Incremental pipe bending strains are low, less than 0.05%, and well within design limits.

ELECTRICAL POTENTIALS MEASURED DURING GROWTH OF LAKE ICE, MACKENZIE DELTA AREA, N.W.T., CANADA

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Electrical potentials generated during freezing were measured weekly between November 1996 and March 1997 in two lakes near Inuvik, N.W.T. One is in an upland setting, and receives only local water. The other, in the Mackenzie Delta, is connected to the Mackenzie River's discharge throughout the year. The potentials were measured in the uppermost metre of each lake on electrodes mounted on a PVC pipe and spaced at 10 cm intervals. The potentials were measured with reference to a basal electrode, which remained in water below the ice throughout the winter. The temperature at each electrode was measured by thermistors, to determine the development of the ice cover. Potential differences of up to 500 mV were recorded between the lower water pool and the ice throughout the winter at both lakes. The ice was of negative polarity in each case.

FIELD INVESTIGATIONS OF PERMAFROST AND CLIMATIC CHANGE IN NORTHWEST NORTH AMERICA

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Yukon Territory, adjacent portions of Northwest Territories, and Alaska contain a continental range of permafrost conditions. The response of permafrost to climatic change is recorded in the cryostratigraphy of late Pleistocene and Holocene sediments, with an early Holocene thaw unconformity being a widespread and prominent feature. More recently, temperature profiles from deep boreholes show an inflection associated with near-surface warming of 2° to 4°C since the Little Ice Age. Simultaneously, the southern limit of permafrost has moved northwards. In order to understand the present climate:ground temperature system, an analytical solution has been verified to relate the annual mean ground surface temperature to the annual mean permafrost surface temperature under equilibrium conditions. Ground surface temperatures have been obtained from air temperatures using n-factors. The solution assumes that heat transfer in the active layer is only by conduction. The relations show that the impact on permafrost temperatures of changes in snow cover and soil moisture conditions may surpass the effect of changes in air temperature *per se*. Observations from the sporadic permafrost zone indicate the persistence of permafrost despite recent warming. This is due to minimal snow cover on residual peat landforms, and to latent heat in ice-rich ground. The persistence further complicates interpretation of the response of permafrost to climate change.

PERMAFROST PROPERTIES IN THE MCMURDO SOUND–DRY VALLEY REGION OF ANTARCTICA

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The properties of permafrost at 230 sites in the coastal McMurdo Sound and Dry Valley regions of Antarctica were investigated. The permafrost properties are related to the climate, with the thickness of the active layer and the water content of the permafrost varying according to regional climatic differences. Inland, at colder, drier, locations, ground ice is sporadic and the permafrost at many sites is dry frozen. Study of surfaces disturbed by earth moving construction, and other geomorphic evidence, indicates that ground ice formation in Antarctica is extremely slow. On young surfaces, the salinity of the ground ice is frequently greater than in the active layer and extensive precipitation of salts on the surface may result from soil disturbances. Measurements of climatic parameters and soil thermal properties showed that ground surface albedo and soil salinity strongly influence the soil thermal regime, which in turn determines active layer depth and permafrost properties.

A CASE STUDY OF ACTIVE LAYER THAW AND ITS CONTROLLING FACTORS

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The roles of energy input and thermal properties of the soil on active layer thaw have been considered by modelling or studied piecemeal in the field. This paper reports a case study, undertaken near Resolute, Northwest Territories, Canada, that makes direct comparisons of the relative importance of ground heat flux, thermal properties and ice content effects on ground thaw. Results from the sites did not indicate a simple relationship between ground heat flux and active layer thaw. Soil thermal properties are related to thaw depth except for sites where there is abundant ground ice. Energy balance considerations revealed that large ice contents lead to a prolonged zero-curtain effect and facilitate downward heat conduction to the permafrost. The consequence is shallow thaws for the active layers with ice rich soils.

AN INVESTIGATION OF THE MICROSTRUCTURE OF FROZEN SOIL AT FATIGUE FAILURE UNDER DYNAMIC CYCLING LOAD WITH CONFINING PRESSURE

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The micro-mechanism of frozen soil fatigue failure has been discovered based on the analysis of microstructure observations of frozen soil fatigue failure under dynamic cycling load with confining pressure using an electron scanning microscope. It includes aggregate particle fragmentation and alignment and the development of micro-cracks. With the variation of load cycling frequency, confining pressure, and vertical cycling load, the frozen soil has a gradual changing pattern of microstructures, and the frozen soil fatigue failure changes from fragile failure to plastic failure, and again to fragile failure.

ON THE CORRELATION OF ELASTIC AND STRENGTH PROPERTIES FOR SALINE FROZEN SOILS

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The elastic and strength properties of frozen soils are controlled by their spatial cryogenic crystalline-coagulant structure (SCCS). The main features of saline sandy-clayey soils SCCS which begin to take shape at certain critical initial concentration (C_{cr}) of saturating pore solution are considered in this paper. Experimental data on dynamic elastic and strength characteristics of frozen saline soils with a wide range of pore solution concentration and composition are presented and discussed. Correlations are established between elastic and strength parameters and show that the strength can be estimated using acoustical studies of saline frozen soils. The results obtained are in a good agreement with the measured values C_{cr} for soils with a variety of plasticity indices.

RESULTS OF PHYSICAL SIMULATION OF FROST HEAVING IN SOILS

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A procedure and a device have been developed for determining the chemical potential of moisture and some other parameters of moisture transfer in freezing soils. Based on experimental research, new principles of the development of moisture potentials, moisture flow and coefficients of hydraulic conductivity have been established for the frozen and unfrozen parts of freezing soils. The wave-like dynamics of ice redistribution under a temperature gradient were established in frozen soils. It is shown that the relationship between moisture flow and gradient of moisture potential in freezing soils is nonlinear (Darcy's law does not apply). The results obtained allow mathematical models of the process to be improved.

TRITIUM IN SIBERIAN PERMAFROST

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More than 250 samples of various types of ground ice from the active layer and permafrost in Siberia were analyzed for tritium content. The samples were collected from drill cores, prospecting shafts and exposures from depths of about 0.2 to 13 m. Investigations were carried out at 9 sites located in regions of sporadic permafrost islands, discontinuons and continuons permafrost, between 54°N and 73°N. Maximum tritium concentration in the permafrost reached 230-323 TU (tritium units), and 300-352 TU in the active layer. Tritium analyses point to intensive moisture exchange between the earth surface, the active layer and the permafrost. The value of tritium concentration in frozen soil and ground ice is mainly determined by geographical location of the site, tritium decay, age and origin of ice and mechanism of ice formation.

CHARACTERISTICS OF PERMAFROST AND FOUNDATION DESIGN IN MONGOLIA

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Mongolian permafrost varies between -0.3°C and -4.0°C, and underlies substantial areas of the country. About 80 settlements are located in permafrost regions. This paper describes Mongolian permafrost and experiences in the design and construction of buildings on perennially frozen ground in Mongolia.

WEST DOCK CAUSEWAY BRIDGE FOUNDATIONS

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Constructed in 1994-5, the 262-m West Dock Causeway Bridge is located along the West Dock gravel causeway in the Beaufort Sea on Alaska's North Slope. The bridge, designed by Peratrovich, Nottingham & Drage, Inc., was constructed in response to concerns of coastal shoreline fish movement and water circulation. The bridge is founded on three in-water ice breaking steel piers and six pile bents protected by two sheetpile structures. The in-water piers are designed for a horizontal ice load of 5.3 MN and a design scour of 12.2 m below the existing seabed. Post design ultimate load analyses indicate that the piers are capable of withstanding 13.3-MN ice forces. The paper contains discussions of the foundation design, design considerations for piles founded in saline permafrost, a summary of the finite element analyses, a review of the full scale pile load and driving tests, and observations for offshore design.

IONIC MIGRATION IN FROZEN SOILS AND ICE

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An experimental study of the migration of ions of chemical elements in frozen soils and ice is described. The factors and conditions determining the intensity of migration of ions at negative temperatures are revealed. The acquired experimental data is evidence of the relatively high migration ability of ions in frozen soils and ice. The values of the effective diffusion coefficient (Def.) are in the order of 10^{-7} - 10^{-6} cm^2/s. The larger values Def. are characteristic of ice. In this paper we look into the trends of the ionic permeability of frozen soils and ice changes in relation to their temperature, structure and composition.

MASS TRANSFER AND STRUCTURE FORMATION IN FREEZING SALINE SOILS

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The correlation between salt and moisture transfer in freezing saline soils was examined experimentally. Salt transfer in saturated soils is primarily due to the transfer of salt ions within migrating water. Depending on various factors (for example, dispersion, mineral composition and external pressure) salt transfer can result in a change in the direction of frozen zone motion, formation of an unfrozen zone or this transfer can be entirely absent. The influence of mass transfer processes on the formation of cryogenic textures in freezing soils was also investigated. The ratio of ice content in mineral layers (pore ice) to segregated ice lenses in saline soils is substantially different from that of ordinary soils. The mechanism of ice layer formation in fine-grained soils changes from migration-segregation to orthotropic-compressive.

PERMAFROST DATA AND INFORMATION: ADVANCES SINCE THE FIFTH INTERNATIONAL CONFERENCE ON PERMAFROST

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In the decade since 1988, the International Permafrost Association Working Group on Data and Information has overseen a remarkable transformation of permafrost data strategy, and a substantial acquisition of permafrost data, metadata and information. The international commitment to the principles of data preservation and rescue is now strong in the scientific community, but funding remains problematic and individual transfer of data is often slow. The technical problems of data model and structure, data management and data dissemination are now well on the way to solution, but the "political" hurdles of data commodification and personal reluctance to share data remain significant. The value-adding capabilities of temporal and spatial comparison, identification of the drivers of variation, hypothesis testing and support for global typology definition offer powerful incentives to continue the data preservation and access objectives of the IPA Global Geocryological Database (GGD).

QUANTITATIVE ASSESSMENT OF GAS HYDRATES IN THEMALLIK L-38 WELL, MACKENZIE DELTA, N.W.T., CANADA

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The occurrence of gas hydrates in the Mackenzie Delta-Beaufort Sea region raises a number of concerns for resource and hazard assessments and for global change studies in permafrost regions. In preparation for a major gas hydrate research exploration well planned for February 1998, a detailed evaluation of terrestrial gas hydrate occurrences has been undertaken in the Mackenzie Delta-Beaufort Sea region. Newly developed gas hydrate well log evaluation techniques have been used to calculate sediment porosities and gas hydrate saturations in the gas-hydrate-bearing interval of the Mallik L-38 well. The gas hydrate accumulation delineated by the Mallik L-38 well has been determined to contain about 4,284,000,000 cubic meters of gas in the one square kilometer area surrounding the drill site.

AN ASSESSMENT OF GROUND ICE VOLUME NEAR EUREKA, NORTHWEST TERRITORIES

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In the area surrounding Eureka, Northwest Territories, ground ice accounts for a significant fraction of surficial material, comprising 30.8% of the upper 5.9 m of permafrost. Volume depends on the type of ice examined, ranging from 1.8 to 69.0% in different regions of the study area. Excess ice accounts for 1.3% of frozen materials. In areas underlain by massive ice, 16.2% of the permafrost is considered to be excess ice. Data is drawn from ground measurements and a number of secondary sources, including air photographs, maps, and previous studies which examined specific occurrences of ground ice in the Eureka area. The importance of quantifying the volume of ground ice in this area is discussed, especially in light of how a warming climate and anthropogenic activities in the area can alter the landscape.

GAS HYDRATES ASSOCIATED WITH DEEP PERMAFROST IN THE MACKENZIE DELTA, N.W.T., CANADA: REGIONAL OVERVIEW

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The occurrence of gas hydrates in the Mackenzie Delta-Beaufort Sea region raises a number of concerns for resource and hazard assessments and for global change studies in permafrost regions. In preparation for a major gas hydrate research well planned for February 1998, a detailed evaluation of terrestrial gas hydrate occurrences has been undertaken in the Mackenzie Delta-Beaufort Sea region. This evaluation included the review of the gas hydrate geologic setting, sediment associations, pressure and temperature conditions. After an exhaustive review of all the inferred gas hydrate occurrences in the Mackenzie Delta-Beaufort sea region, it was determined that the Mallik L-38 drill site offered the highest probability of encountering thick gas hydrate occurrences. Open hole well logs reveal that the Mallik L-38 well drilled about 111 m of gas-hydrate-bearing strata within the depth interval from 810.1 to 1,102.3 m, which is within the zone of predicted methane hydrate stability and below the base of ice-bearing permafrost.

PLEISTOCENE-HOLOCENE PERMAFROST OF THE EAST SIBERIAN EURASIAN ARCTIC SHELF

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Cryolithosphere dynamics in the East Siberian Eurasian Arctic shelf during the last 50,000 years were reconstructed on the basis of paleogeographic events including transgressions and regressions of the Arctic Ocean, and changes of paleoclimatic environmental conditions within subaerially exposed shelf areas after their flooding by sea water. Mathematical models and calculations were developed in accordance with these events. Three transgressive and three regressive stages in the evolution of the Arctic shelf were established for the last 50,000 years. Air and permafrost temperatures and their spatial and temporal variations were reconstructed for regressive epochs, while sea bottom temperatures, salinity and "overburden pressure" were reconstructed for transgressive periods. The possible thickness of permafrost in coastal areas is 345-455 m. The possible thickness of ice-bonded permafrost and non ice-bonded saline permafrost ranges from 240-350 and 20-25 m respectively in the central shelf, to 140-175 and 10 m in the outer shelf.

NUMERICAL SIMULATION OF OFFSHORE PERMAFROST DEVELOPMENT IN THE LAPTEV SEA, SIBERIA

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Seismic reflection surveys by BGR during cruises in 1993, 1994 and 1997 to study the tectonic structure of the Laptev Sea, Siberia, have detected a strong reflective unit extending to depths of typically 300 m to 850 m, which is tentatively interpreted to image the vertical extent of permafrost. This shelf area with water depths of in general less than 60 m must have existed under subaerial conditions during the lower sea level stages of the last cold stages, thus permitting permafrost growth. Assuming for this region a plausible scenario for the sea level change and climatic change during the last 160,000 years, the time-dependent development of permafrost growth is calculated. The numerical analysis suggests the development of several hundreds of meters of permafrost during the last cold stages, whereby rivers across the formerly dry Laptev shelf region may have caused permafrost-free channels.

PROBLEMS OF FROZEN ROCK ENGINEERING IN THE DABANSHAN TUNNEL IN QINGHAI PROVINCE

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The Dabanshan tunnel is located in the cold region of Qinghai province at an elevation of 3800 m above sea level. The mean annual air temperature is -3.1°C. The maximum thickness of material overlying the tunnel reaches more than 200 m and permafrost exists at the inlet and exit of the tunnel. The temperature field, the stress field and the paths of groundwater flow will be changed by the excavation and operation of the tunnel. The seasonally frozen rocks surrounding the tunnel will be changed into permafrost. The main patterns of frost damage in the tunnel are the swelling, cracking and peeling off of the tunnel lining; seepage of groundwater through the cracks; and frost ad icings in the tunnel, including ice suspended from overhead. To prevent frost damage, the following measures are being taken: sprinkling Pu-insulation material on the lining, over-excavating at broken and weakened zones, providing water-proof plates on the inside of the lining and installing smaller parallel drainage tunnels under the main tunnel.

RECENT DEGRADATION OF PERMAFROST IN CHINA AND THE RESPONSE TO CLIMATIC WARMING

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With climatic warming, significant changes are occurring in the permafrost regions in China. On the Qinghai-Xizang Plateau, the southern limit of permafrost has been degrading at a rate of hundreds of meters per year in recent decades. The thickness of the active layer is increasing by about 2-10 cm/a and the average annual temperature of the frozen ground is increasing by about 0.07-0.21°C/10a. The changes are approximately the same order of magnitude in the alpine permafrost zone in the Tianshan Mountains. In northeastern China, the changes of permafrost are more evident. The southern limit of permafrost is moving northward at a rate of 1500-3000 m/a, the permafrost table is descending at a rate of 9-11cm/a, and the average annual temperature of the frozen ground is increasing by 0.13-1.6°C/10a. These changes in permafrost correspond to climatic change in China. During the past decades, a marked rise of air temperatures in the northwestern, and especially in the northeastern region of China correlates with the degradation of the permafrost.

PERMAFROST OCCURRENCE IN THE ALPINE ZONE OF THE TATRA MOUNTAINS, POLAND

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At an altitude of 1990 m a.s.l., the mean annual air temperature in the Tatra Mountains of southern Poland is -1°C. The values of the freezing and thawing indices suggest that, at such an altitude, the depth of ground thaw ought to be smaller than that of ground freezing. Geophysical methods were used to try to confirm that permafrost is present. The most common result for electroresistivity soundings is about 300 kOhm-m. Seismic soundings indicate velocities from 2260 to 2670 m/s at the depths of 9 m or so. Several hundred BTS measurements have also been made in the study area and temperatures from 0 to -4.8°C have been recorded. The results strongly suggest the presence of discontinuous permafrost in the Tatra Mountains and it appears that it underlies an area of the order of 100 km^2 .

THE EFFECT OF CONSOLIDATION ON FROST SUSCEPTIBILITY OF SILTY SOILS

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The frost susceptibility of silty soils tends to increase with level of consolidation. This has been explained by the fact that the intergranular structure of an overconsolidated soil might lead to higher unfrozen water contents thus increasing the effective hydraulic conductivity of the soil in the frozen fringe.

This study was undertaken to demonstrate the validity of this theory using direct observation, with a Scanning Electron Microscope (SEM), of the intergranular structure of a clayey silt and specific measurement of the pore characteristics. It was found that the intergranular structure is strongly influenced by the level of consolidation. A simple model was developed to estimate the unfrozen water content in the frozen fringe. According to a series of measurements on pores observed using the SEM, it was found that the unfrozen water content for a soil having an overconsolidated ratio of 8 can be estimated to be 2.5 times larger than for a normally consolidated soil.

POLLEN, FUNGI AND ALGAE AS AGE INDICATORS OF DRAINED LAKE BASINS NEAR BARROW, ALASKA

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Surface pollen samples from drained thaw-lake basins near Barrow, Alaska were collected and analyzed. The basins represent an age continuum defined by the degree of vegetation succession and geomorphic development since lake drainage. The different phases of the thaw-lake cycle are accompanied by changes in plant composition. Pollen analysis of the surface samples has been enhanced by the analysis of fungi and algae.

Young thaw-lake basins have characteristic pollen assemblages, as compared to basins of intermediate age which, in turn, have a distinctive signature compared to old basins. The variation from recent to old drained thaw-lake basin *surfaces* is the spatial expression of a temporal pattern which we should see preserved as a pollen sequence in a drained thaw-lake sediment core. Our findings indicate that we are developing a strong diagnostic tool for the paleoecological interpretation of vegetational succession associated with the thaw-lake cycle.

THE DISTRIBUTION OF PERMAFROST IN SOUTHERN NORWAY - A GIS APPROACH

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The paper discusses the generation of a permafrost map of Southern Norway, which shows the lower limit of discontinuous permafrost at a regional scale. This map is based on field investigations of permafrost occurrence in 15 different high-mountain sites, a grid-based mean annual air temperature (MAAT) map and spatial analysis of the relationship between permafrost occurrence and MAAT. The hypothesis that regional permafrost distribution in Southern Norway can be modelled by MAAT as the main influencing factor is supported, and the proposed -4°C boundary of King (1983) and Ødegård et al. (1996) was verified. The approach opens possibilities for analyses of past and future climate change consequences on regional permafrost distribution in Southern Norway.

OBSERVATIONS OF PERMAFROST-LANDSCAPE DYNAMICS RELATED TO ANTHROPOGENIC DISTURBANCES, YUKECHI STUDY SITE, CENTRAL YAKUTIA

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This paper presents results of field observations of permafrost-landscape dynamics in central Yakutia on the Yukechi site, situated 50 km southeast of Yakutsk on the right bank of the Lena River. The analysis emphasizes the rate of surface subsidence, rate of evolution of young thermokarst topography, and characteristic features of the recovery of the ground thermal regime after forest cutting and forest fires.

The Yukechi location is a typical alas landscape of central Yakutia. The purpose of the observations is to study the rate of disturbance and recovery of landscapes in order to assess their resistance to anthropogenic effects and climatic change. Quantitative data on subsidence rates of disturbed sites were obtained for each initial form of thermokarst relief during the five-year observation period. Ground temperatures were measured in the main post-disturbance vegetation successions.

This study is relevant to environmental control and rational landscape management in permafrost regions.

EXPERIMENTAL INVESTIGATIONS OF GOLD MIGRATION IN FROZEN MASSIFS

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This paper presents the results of an experimental study of the vertical migration of gold in artificial samples of frozen sand (t=-6.5°C). Each sample consisted of a lower and an upper part, the latter containing interlayers of alumina (Al_2O_3) or humic acid (HA).

Four kinds of experiments were carried out, each under different conditions. The pH values of the pore solution was either 3-4 or 6-7. The sand was saturated with NaCl (10^{-2} or 10^{-1} mole/l) or KBr solutions (10^{-2} mole/l). Gold (10^{-4} mole/l) was present only within the pore solution in the lower parts of the samples. It was found that the gold migrated to the upper parts of the frozen sand samples, and especially the Al_2O_3 and HA interlayers, became enriched in this element. The effective coefficient of gold diffusion in sand that was obtained, $n10^{-7}$ cm^2/s, is characteristic of the chemisorption elements.

CUMULATIVE IMPACTS OF VEHICLE TRAFFIC ON HIGH ARCTIC TUNDRA: SOIL TEMPERATURE, PLANT BIOMASS, SPECIES RICHNESS AND MINERAL NUTRITION

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Persistent changes in tundra vegetation and permafrost soils have often been reported to occur within the ruts caused by vehicle tracks. Less well-known are the cumulative effects of these ruts where they traverse gentle slopes which characterize many northern landscapes. Previous research has documented shifts in albedo, soil moisture, pH, and active layer development. Reported here are patterns of near-surface soil temperatures, above-ground vascular plant biomass, total species richness and mineral nutrition of the dominant vascular plants. Measurements were made 21 years after the initial disturbance along transects through hummocky high arctic tundra meadows which included upslope (undisturbed) areas, vehicle ruts, and downslope areas which have been drained by the ruts. It was determined that even a single passage of a tracked vehicle in summer can result in cumulative impacts at the community level which may persist for decades.

INDUCED POLARIZATION AND RESISTIVITY LOGGING IN PERMAFROST

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Induced polarization (IP) and resistivity logs were carried out in a permafrost plateau near Umiujaq, Northern Québec, to outline the permafrost dynamics. A permanently buried multiconductor cable into permafrost, with regularly spaced electrodes and thermistors, was used for IP, resistivity and temperature logging.

The cryofronts in the active layer and at the permafrost base corresponded to resistivity values around 500 ohm-m. A basal cryopeg was clearly delimited between 21 and 22.7 m in depth by a sharp decrease in resistivity from 2000 to 500 ohm-m close to 21 m and a sharp increase in total chargeability from -4 mV/V in permafrost to values over -16 mV/V in the basal cryopeg. The freezing-point depression due to overburden pressure at the base of perennially frozen layer is evaluated to be -0.2°C. Resistivity values higher than 60,000 ohmm were measured in permafrost. Decrease in resistivity with time was monitored due to permafrost warming during summer 1990.

THE ROLE OF NEOTECTONICS IN PERMAFROST ORIGIN AND FEATURES OF THE BAIKAL-AMUR MAINLINE REGION, RUSSIA

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The Baikal-Amur Mainline (BAM) of Siberia was characterized by differential tectonic movements during the Neogene and Holocene (Nikolaev and Naimark, 1979). This mountainous region can be subdivided into: the Riftogen zone (with alpine relief and narrow intermontane depressions); Platform zone (plateaus and lowlands) and Orogen zone (combining features of the first two zones).

Different levels of heat exchange between the atmosphere and the earth surface in each zone, due to the interaction of relief and climate, lead to variability in permafrost conditions. Two extremes are: alpine permafrost of the Riftogen type with altitudinal zonality prevailing, and plateau permafrost of the Platform type with the greatest difference between the "cold" valleys and "warm" interfluve areas.

Patterns of permafrost distribution are generalized in a classification of permafrost features and in a geocryological regionalization map of the BAM. Various permafrost species were characterized by both generalization of borehole data and modeling of ground temperature.

PERMAFROST INVESTIGATIONS WITH GIS - A CASE STUDY IN THE FLETSCHHORN AREA, WALLIS, SWISS ALPS

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To quantify the impact of predicted climatic change on the distribution of Alpine permafrost it is vital to know its present-day conditions and distribution patterns. This knowledge will allow comparisons with the situation in the future. In the study area, an inventory of periglacial landforms - such as rock glaciers, perennial snow patches and spring temperatures - has been established from interpretation of aerial photographs and field analyses. All data were integrated into a GIS-System. The field data were then used as indicators to verify two existing digital permafrost models. The evaluation of the models showed that they correspond well with the empirical data at high altitudes, whereas the accuracy of the estimations diminishes towards lower altitudes. Especially at a local scale, further information such as seismic soundings, geo-electrical measurements etc., is needed to make exact statements about the local permafrost distribution.

Key words: Rock glacier inventory. Permafrost modelling. GIS-analysis.

TWENTIETH CENTURY VARIATIONS IN THE SOUTHERN LIMIT OF PERMAFROST NEAR THOMPSON, NORTHERN MANITOBA, CANADA

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Air temperatures for varying periods from 1910-1993, recorded from a number of weather stations in Manitoba, have been analyzed together with ground temperature data collected from 4 closely spaced sites at Thompson between 1969-1976. The predicted mean annual air temperature for Thompson has increased over the period 1910-1993 by approximately 0.5 -1.0°C. Geocryological parameters, such as predicted freezing and thawing indices, indicate that during this 80+ yr period, short-term (i.e. decade-duration) permafrost must have formed and degraded at the southern limit of sporadic permafrost in response to short term climatic fluctuations. This may explain why the marginal permafrost at one of the Thompson sites degraded during the 1968-197676 period and the two non permafrost sites showed slight warming.

New residential buildings, constructed in the 1990's on permafrost-free subdivision lots which initially possessed permafrost in the 1960's, are a second indication that permafrost bodies are degrading under present conditions.

Key words: Sporadic permafrost, twentieth Century, boreal forest.

PRINCIPAL PROBLEMS, PROGRESS, AND DIRECTIONS OF GEOPHYSICAL INVESTIGATIONS IN PERMAFROST REGIONS

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The paper deals with the principal aspects of successful application of geophysical methods to permafrost conditions. Firstly, it is discussed why neither the techniques nor tools developed, and the immense experience gained by prospecting geophysics can be directly applied to permafrost regions. Further, a number of the recent examples of the uses of geophysical methods to solve practical tasks in cold regions, such as cryopeg recognition, surveying for construction, buried ice layer delineation, evaluation of engineering geological parameters from geophysical data, ecological-geophysical monitoring etc., are presented and discussed. The main problems are examined and the most promising directions suggested for development and application of permafrost geophysics in the near future.

A CENTURY OF TEMPERATURE OBSERVATIONS OF SOIL CLIMATE: METHODS OF ANALYSIS AND LONG-TERM TRENDS

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We have considered the spatial and temporal characteristics of the temperature distribution in the active layer in Russia, where an annual cycle of long and deep seasonal freezing/thawing is a leading process. The results collected are unique in terms of period covered, the extent of territory, natural zones, type of soils, and wide spectrum of geographical conditions from polar lowlands to arid deserts and Central Asian mountains. The primary contribution of this collection from about 1000 stations is to studies of global change, because regular measurements at some of them were started in 1890, and the data cover almost 100 years. The present paper discusses the long-term soil temperature trends at depths 0.4, 0.8, 1.6 and 3.2 m from seven stations (mean annual and monthly data for January, April, July and October).

EXPERIMENTAL INVESTIGATION OF AIR CONVECTION EMBANKMENTS FOR PERMAFROST-RESISTANT ROADWAY DESIGN

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Air convection embankments have been proposed as a method for avoiding thaw-settlement of roadways in regions of warm permafrost. These embankments are constructed of poorly-graded open aggregate, resulting in a very high air permeability. Unstable air density gradients that develop within the embankment during winter result in buoyancy-induced pore air convection. This convection increases the heat flux out of the embankment and foundation material during winter months. During summer, the air density gradient is stable and convection does not occur. The net effect is an increase in winter cooling without a corresponding increase in summer warming and thawing is prevented in the permafrost layer beneath the embankment. The present study discusses thermal data collected from an experimental air convection embankment that was constructed at Brown's Hill Quarry near Fairbanks, Alaska and monitored over a two-year period. The results show a large cooling influence due to air convection within the embankment during winter.

RIGID-ICE MODEL AND STATIONARY GROWTH OF ICE

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A quasi-stationary version of the rigid-ice model that is a synthesis of models by Miller (1978) and Gilpin (1980) is analyzed. The model describes ice movement in a porous medium and its growth on the boundaries of the frozen fringe. The gradients of pressure and temperature are independent. Mass flows differ in the frozen fringe and the unfrozen zone. The solution of equations has one or three roots given stationary growth of ice. The solution with one root is stable. For the case with three roots, only the extreme two are stable. They differ from one another in their response to alternation of external temperature. The overburden pressure at which mass flow vanishes can always be found, but the temperature gradient in the frozen fringe and its length are not equal to zero. The calculated results were compared with data from modeling experiments.

ORIGINS OF GROUND ICE IN THE ICE-FREE LANDS OF THE NORTHERN FOOTHILLS (NORTHERN VICTORIA LAND, ANTARCTICA)

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This paper shows the main results of chemical and isotopic analyses of samples of ground ice collected from two debris-covered glaciers named respectively Boulder Clay Glacier and Amorphous Glacier and from two debris cones, located in these two areas not far from the Italian Station of Terra Nova Bay. The massive ground ice of Boulder Clay Glacier was probably produced near a fossil grounding line by the freezing of water derived in variable proportions from glacial meltwater and seawater or meltwater from marine ice. The ice collected from Amorphous debris-covered glacier is clearly continental ice.

The ground ice collected from the two debris cones seems to result from melting and refreezing of these two different kinds of massive ground ice with an input of fresh water. This fresh water is produced by snow melting, which suggests a periglacial origin for these landforms.

DELINEATION OF DISCONTINUOUS PERMAFROST AT SCHEFFERVILLE USING RADARSAT IN INTERFEROMETRIC MODE

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The coherence of interferometric synthetic aperture radar (InSAR) is adversely affected by snow added into the radar path between two successive imaging events. This feature of InSAR can be employed to map those parts of open terrain which do not retain snow at a given time of the winter. Differential InSAR can thus be used to identify areas where the difference between average long-term air and near-surface ground temperatures due to insulation by the snow cover is small. In locations where the average annual air temperature is below 0°C, permafrost is usually present in those parts of the terrain where there is no snow retention.

Two RADARSAT InSAR coherence images were computed for the Schefferville Digital Transect. These images show that areas which do not retain snow over the imaging interval can be identified. A comparison with a regional permafrost map produced by the Iron Ore Company of Canada (IOCC) shows a strong spatial correlation between the distribution of high-coherence zones and discontinuous permafrost.

DANGEROUS MOVEMENT OF AN ANTHROPOGENIC "ROCK GLACIER", NORILSK REGION NORTHERN SIBERIA.

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In mountainous regions, dangerous phenomena can occur as result of anthropogenic activities. This paper deals with the problems of waste dumps sliding down the slopes of mountains. Permafrost degradation in industrial zones strengthens the development of such dangerous processes. The movement of a large waste dump on Rudnaya mountain in Norilsk is analyzed. A similarity to the embankment of a rock glacier is shown. It was established that the average speed of movement is 40 mm/day, with maximum rates up to 800 - 1000 mm/day. Three modes of movement were revealed. A forecast of dump displacement was developed and practical proposals given for the stabilization of the slope.

Key words: Technogenic rock glacier, glacial and permafrost conditions, movement, destruction of structures.

PHASE EQUILIBRIUM AND KINETICS OF SALINE SOIL WATER FREEZING

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A thermodynamic model of phase equilibrium and kinetics of saline soil water freezing and thawing was developed and verified. X-ray studies of pore ice formation in water-saturated clays were carried out. The ice phase existence in freezing soils was studied. The experiments showed that after soil thawing the ice phase in pores exists up to +1 to +3 °C. In freezing soils, the ice phase appears at temperatures from -2 to -4 °C. During soil thawing the ice content decreased in a step-shaped manner. An electrometery technique for simultaneous measurement of local electrical conductivity and phase front temperature depression was developed. The dependence of the phase front temperature versus its velocity was obtained for fresh and saline water-saturated soils (clay, loam, sand). It was shown that the phase front temperature depression under equal freezing velocities is larger if the soil particle size is smaller and the salinity is greater.

DESIGN ASPECTS OF A BURIED OIL PIPELINE ON THE ALASKAN NORTH SLOPE

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The Badami oil pipeline originally involved a cool buried oil line along its 40 km length. Axial stresses can result from ice wedge cracking. A solution for stresses induced by ice wedge cracking is developed, and results indicate strains are within allowable limits for the pipe section.

The backfill over a cool buried pipe will thaw each summer, resulting in potentially high thaw settlements in the surface icy soils. Thaw settlement tests on excavated frozen soil allowed the development of a "Ditch Settlement Index" (DSI). Amounts of granular backfill to balance anticipated trench backfill settlement could then be estimated

Concerns for frost heave, and blockage of ground water flow due to chilled pipe operation in an unfrozen river bed were addressed. Frost heave tests indicated that such soils would not be susceptible to significant heave. Further, the convective action of flowing groundwater would cause the frost bulb to seasonally shrink, reducing the impediment to ground water movement.

CRYOSOL PROPERTIES ON PERMAFROST: STRUCTURE AND DYNAMICS

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The formation and development of recent cryosols is in a close dynamic relationship with the structure and properties of the underlying permafrost and especially with its iciness. A crucial role in these relationships is played by the ice layers contained in the upper part of frozen deposits. Their origin dates back to the periods of higher heat provision and deeper thaw in the Holocene. During contemporary permafrost thaw, the availability of ice layers is conducive to active restructuring of the diurnal surface, dramatic increase in the saturation of lower profile parts, enhancement of their gleying, and in some instances, to active degradation of the soil cover. Thawing of the upper horizons of permafrost deposits induces changes in soils, which are of a rapid and large-scale character and often result in substantial modification of their taxonomic and classificational position.

THE ROCK GLACIER INVENTORY OF THE ITALIAN ALPS

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An inventory of rock glaciers in the Italian Alps has recently been compiled. It contains data on 1594 rock glaciers. The rock glaciers were identified by aerial photo interpretation and some field surveys. Two hundred and ninety-seven (19%) of these landforms were considered active and 914 (59%) inactive. The total area occupied by these rock glaciers in the Italian Alps is about 220 km^2 and the total volume of permafrost estimated on the basis of geophysical investigations carried out in the Upper Valtellina is at least 10^9 m^3. The rock glaciers are concentrated mainly in the central part of the Alps with a maximum density of features of 1 per 9 km^2 in the Atesine Alps. Rock glacier distribution is affected by lithology, glacial history and climatic conditions (especially insolation and precipitation regime).

ICE FOOD DEPOT COOLED WITH A HEAT PUMP: A PRE-FEASIBILITY STUDY

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Pre-feasibility studies of an ice food depot using a heat pump for cooling were undertaken following an application by a Russian native organization.

The site is on the coast of the Sea of Okhotsk, about 200 km east of Magadan, within the discontinuous permafrost zone. Quantitative interrelationships, based on analytical solutions and computer modeling, were obtained between climatic characteristics and structural parameters. It is proposed that the extracted heat will be mainly used to heat a greenhouse. To maintain the necessary thermal regime in both the greenhouse and refrigerated depot, the total heat pump power is to be in the range of 73-146 kW. It is expected that operational expenses will be compensated entirely by food production from the greenhouse.

To enhance the energy and economic efficiency of the cooling-heating system, the combined scheme uses alternate heat sources when cooling of the ice depot is not required.

PROBLEMS OF INTERACTION BETWEEN STRUCTURES AND PERMAFROST: THE EXAMPLE OF HEADFRAME FOUNDATIONS

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The problem of foundation construction for heavy tower headframes, located in a talik zone adjacent to a shaft, is discussed for various permafrost-soil conditions. Previously known and design variants of headframe foundations are analyzed, their advantages and disadvantages are compared, and the conditions for the use of different types of foundations are described. A general flow-chart is proposed for solving the problem of foundation construction for headgear buildings that depends on the industrial technology of the shaft-headframe complex with respect to specific engineering-geological situations in the shaft mouth zone.

ANALYSIS OF THERMAL MEASUREMENTS ACQUIRED IN NUNAVIK: COMPARISON OF FIELD DATA WITH NUMERICAL MODELS

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Ground thermal data from the Centre d'Etudes Nordiques study site at Manitounuk Sound along the Hudson bay coast were used for validation of two numerical thermal models designed at France's C.N.R.S. The numerical results obtained with the models show good agreement with the field measurements. As the models are sensitive and precise, the results also show that precision in calculated results strongly depends on detailed inputs of ground ice stratigraphy.

TEN YEARS AFTER THE DRILLING THROUGH THE PERMAFROST OF THE ACTIVE ROCK GLACIER MURTÈL, EASTERN SWISS ALPS: ANSWERED QUESTIONS AND NEW PERSPECTIVES

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During the 10 years following the 1987 core drilling through the active rock glacier Murtèl (Swiss Alps), systematic observations in the instrumented borehole and at the surface of the rock glacier opened new perspectives concerning thermal conditions, material properties, rheology, geomorphological evolution and environmental significance of creeping mountain permafrost. The presently available knowledge and process understanding provides the basis for numerical modelling of the partial systems involved (debris production, freezing/thawing, deformation, material redistribution, age structure). Principal open questions concern the energy and mass transfer within and across the boundaries of the creeping permafrost, the various processes involved with ground ice formation in scree slopes, the development of ground thermal conditions and material properties with anticipated atmospheric warming, and the complex flow dynamics at rock glacier fronts and within complex 3-dimensional landforms.

GGD-BROWSE: BRIDGING THE GAP BETWEEN DATA DESCRIPTIONS AND DATA

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The World Data Center-A for Glaciology, in cooperation with the International Permafrost Association (IPA), has developed a data discovery tool for the frozen ground scientific community. The Global Geocryological Database (GGD) contains data and descriptions for world-wide frozen ground observations. The GGD-Browse tool provides data search and retrieval capability based on extensive metadata in the GGD. This browse tool is designed primarily for use through the World Wide Web (WWW), but it can easily be adapted for use on portable media such as CD-ROMs. Search capabilities based on commonly used parameters such as principal investigator, region, geographic area, and topic are included within the system.

The number of data sets, modeling packages, and other information contained within the GGD continues to grow, and GGD-Browse is designed to grow as well. By combining a relational database with the WWW, extension of the interface is designed to be a simple process.

MEASUREMENT OF SOIL MOTION IN SORTED CIRCLES, WESTERN SPITSBERGEN

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Direct measurements of soil displacement patterns and related characteristics shed considerable light on the processes active in established patterned ground, and provide clues about the origin and development of patterned ground. Extensive observations and measurements of sorted circles have been made in western Spitsbergen. Herein, automated measurements of soil motion are described: soil heave, settling, and subsurface rotational motion. They are invaluable in providing continuous information that permit linking certain displacement patterns to particular times and to specific physical states and processes. A simple coherent picture of frost-induced size segregation and convective soil motion both in the fine-grained centers and in the gravel borders emerges from our field studies. Numerical models by B. Werner and his co-workers are powerful aids in understanding the processes governing sorted patterned ground.

THE EFFECTS OF THE 1994 AND 1995 FOREST FIRES ON THE SLOPES OF THE NORMAN WELLS PIPELINE

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Interprovincial Pipe Line (NW) Limited (IPL) operates a crude oil pipeline through an area of discontinuous permafrost in the northwest of Canada. The pipeline is the first, fully buried pipeline in permafrost in North America and has operated successfully for over 12 years. During the 1994 and 1995 forest fire seasons, fires traversed the pipeline right-of-way in two main areas, which included a number of permafrost slopes insulated with wood chips to compensate for construction disturbance.

This paper briefly reviews the original design basis for the permafrost slopes and the effects of the fires on the pipeline right-of-way and slopes, and some of the impacts on adjacent slopes. The paper also discusses remediation measures and the ongoing monitoring of the effects of the forest fires.

PERMAFROST AGE AND THICKNESS AT MOSKUSLAGOON, SPITSBERGEN

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Permafrost thickness in the Adventfjorden area of Spitsbergen was estimated, and the age of permafrost occurrence was estimated based on the permafrost thickness. At the Adventdalen area, there was no pre-existing permafrost under the sea bottom and permafrost thickness is interpreted to reflect the duration of exposure to the subaerial temperature regime. Permafrost thickness was estimated to be 31.7 m for Moskuslagoon. A numerical calculation indicated that the time required to form permafrost with a thickness of 31.7 m is 533 years. This age appears to be reasonable compared to the age of 240±50 yr B.P derived from the radiocarbon dating of sediments.

PRESSURES RECORDED DURING LABORATORY FREEZING AND THAWING OF A NATURAL SILT-RICH SOIL

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Porewater pressures in a natural silty soil were measured during seven cycles of downward soil freezing and thawing using Druck electronic pore pressure transducers placed at 50,150 and 250 mm below the surface. Surface frost heave/thaw settlement was monitored using LVDTs, and soil temperatures recorded using semi-conductor temperature sensors. A pronounced "zero curtain" was observed during both soil freezing and thawing, and pore pressure change followed a consistent pattern through each freeze/thaw cycle. Arrival of the freezing front led to a gradual fall in pressure to between -5 kPa and -15kPa. Just before the end of the "zero curtain" period pressures rose rapidly to between 15 kPa and 40 kPa, with higher pressures at greater depths. These high pressures were maintained as the soil cooled but fell when soil warming began. Warming ahead of the thaw front progressed rapidly through the frozen soil, leading to an accelerating fall in pressure. With the arrival of the thaw "zero curtain", pore pressures became strongly negative, then rose, and became positive again when soil thawing adjacent to the transducer was complete. Freezing processes responsible for these observed pressure changes are discussed in the context of the mechanisms of soil phase change and associated frost heaving and thaw consolidation.

NONSORTED CIRCLES ON PLATEAU MOUNTAIN, S.W. ALBERTA, CANADA

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Since 1979, raised, flat-centred, nonsorted circles averaging 1.5 m in diameter have been forming in felsenmeer at sites disturbed and then reclaimed, on top of Plateau Mountain. They take three to four years to form, spreading by gelifluction during thawing of the active layer. The surface becomes stable, but telescoping heave probes reveal that there is a winter circulation underneath them taking place in the upper part of the active layer. Annual movement averages 12 mm/a and the material cycles in 300-400 years. The soil is fairly dry, but development of ice segregation under the raised centre appears to be the driving force. The width to depth ratio of the circulation is about 2.57, since it extends under the surrounding soil. A typical diameter for a cell is 240 cm. The name, xeric nonsorted circle, is suggested to differentiate them from nonsorted circles described from the wet arctic lowlands.

Key words: nonsorted circle, patterned ground, ice segregation, patterned ground circulation, xeric nonsorted circle

STATISTICAL ANALYSES OF FROZEN SOIL CREEP PROPERTIES

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Based on the statistic analyses of uniaxial creep tests, it is found that the mechanical creep properties of frozen soils have stochastic characteristics . Twenty samples, with the same dry density of 1.6 g/cm³ and identical water contents of 25%, were tested at the same temperature of -5°C and under the same loading stress of 2.85 MPa. Among the three creep failure parameters of failure time, failure strain and minimum creep rate, the minimum creep rate showed the smallest variation. Thus, it is a better parameter to reflect the mechanical properties of frozen soils. Failure time and strain have greater variability. The exponent "n" in the creep failure criterion has $\left(\dot{\varepsilon} t_f^n = \varepsilon_f\right)$ a small variation and obeys the normal frequency distribution. The creep failure criterion is suitable for frozen soils based on statistical analysis of the exponent "n".

SEISMIC EVIDENCE FOR THE DEPTH EXTENT OF PERMAFROST IN SHELF SEDIMENTS OF THE LAPTEV SEA, RUSSIAN ARCTIC?

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Some 7000 km of deep seismic reflection data have been acquired by the BGR, Hannover, in cooperation with SMNG, Murmansk, on the eastern Laptev Sea shelf and on the East Siberian Sea shelf in 1993 and 1994. The new seismic data from the Laptev Sea shelf reveal a 300 m to 800 m thick seismic sequence beneath the sea floor, characterized by a distinct high-reflective and mostly sub-parallel pattern. This distinct sequence crosscuts and masks real structural features, e.g., toplapping depositional units and anticlinal features at several localities. For this reason we infer that the distinct superficial seismic sequence images the permafrost layer.

A BIOGEOCHEMICAL SURVEY OF AN ARCTIC COASTAL WETLAND

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The "Betty Pingo" wetland study site in Prudhoe Bay, Alaska has been extensively studied for five years. The work discussed here examines the biogeochemistry of the tundra ponds and the drained lake basin marsh which constitute the major surface features of this area. Meteorological and hydrological data were gathered, and dissolved inorganic ions were sampled regularly during the summers of 1993 and 1994. Major plant nutrients such as NH_4^+ , NO_3^- and PO_4^{3-} were present in oligotrophic concentrations, usually <50 (g l-1. The major source of these inorganic nutrients is atmospheric - material arriving dissolved in precipitation or on the wind as dryfall.

SURFACE MOVEMENT AND INTERNAL DEFORMATION OF ICE-ROCK MIXTURES WITHIN ROCK GLACIERS AT PONTRESINA-SCHAFBERG, UPPER ENGADIN, SWITZERLAND

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Two boreholes were drilled into rock glacier permafrost on the Pontresina-Schafberg, Upper Engadin, Eastern Swiss Alps. The two permafrost bodies differ in temperature distribution, ice and debris content as well as surface and bedrock topography. The borehole deformation was monitored with a slope indicator (horizontal deformation) and with magnetic rings (vertical deformation). The average surface velocities observed are 3 cm/a at borehole 1 and 1 cm/a at borehole 2. The flow velocities appear to be correlated to the ground temperatures. In addition, photogrammetric investigation reveals the surface velocity field for the period between 1971 to 1991. All these measurements are in close accordance with each other and open new perspectives for the ongoing research at this site.

AN EVALUATION OF GROUND PENETRATING RADAR FOR INVESTIGATION OF PALSA EVOLUTION, MACMILLAN PASS, NWT, CANADA

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The utility of ground penetrating radar (GPR) for investigation of perennially frozen peatlands is examined. GPR data from two sites in the Macmillan Pass area, Northwest Territories, supplemented with conventional data, are used to infer palsa evolution. Data processing techniques adapted from seismic applications were tested. Resolution of peatland stratigraphy was improved through deconvolution and coherency filtering processes. However, migration processing was less effective. GPR consistently imaged sub-peat topography in palsas and unfrozen fen, and detailed fen stratigraphy. Orientation of strata within palsas, inferred from GPR data, may assist genetic interpretation. Domed strata and frost penetration into underlying mineral sediment are correlated with palsa genesis by ice segregation. Stratigraphic discontinuities in unfrozen peat are correlated with a known palsa collapse scar; this signature may contribute to reconstructions of peatland history. Thaw degradation at depth was imaged by GPR as a subvertical frozen - unfrozen interface, and corroborated by field and historical evidence.

GROUND THERMAL REGIMES AT A LARGE EARTHWORK RESERVOIR ON BAFFIN ISLAND, NUNAVUT, CANADA

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Seasonal and mean annual ground temperature (MAGT) trends (1988-1991) are described for undisturbed, disturbed, and embankment sites to depths of 15 m at a large earthwork reservoir on southeastern Baffin Island. At sites away from the reservoir, undisturbed and disturbed MAGT are similar, follow trends in air temperature, and indicate that climate has a greater influence on ground temperature than does thermal disturbance caused by land clearing. MAGT near the reservoir are warmest close to the high water line, and are cooler beneath a heated pumphouse, and under the crest of the embankment. Despite having the warmest absolute temperatures, water-side probes show the greatest and most rapid rates of cooling. This is attributed to the combination of climatically driven cooling trends and declining water levels in the reservoir. The validity of this hypothesis is confirmed by analytical models of temperature next to the water body.

THE ORIGIN OF LAKE-BED GROUND ICE AT WATER SUPPLY LAKE, POND INLET, NUNAVUT, CANADA.

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Cryostratigraphic and hydrochemical characteristics are described for in situ lake-bed ground ice exposed by excavations in a drained lake during construction of an earthwork dike at Water Supply Lake on northeastern Baffin Island. Ground ice occurs as ice lenses 5 mm to 0.5 m thick having cryostructures indicative of a segregation origin. The ice is ionically enriched and isotopically lighter than overlying lake water. These data, together with local changes in surficial geology, and dated wood fragments recovered from the site, are used to infer the origin of lake-bed ground ice. This ice is thought to be relic having formed 29 ka BP when the area last emerged from beneath mid-Wisconsinan Eclipse glacier ice. Permafrost aggradation and the growth of segregated ice lenses incorporated isotopically light meltwater that flooded the area during a still-stand of retreating Eclipse ice. Modern dike construction has raised water levels, submerging and thermally degrading the ground ice.

MECHANICAL AND THERMAL STABILISATION OF FILL MATERIALS FOR ROAD EMBANKMENT CONSTRUCTION ON DISCONTINUOUS PERMAFROST IN NORTHWEST RUSSIA

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Experience suggests there is a potential for innovative design and construction techniques to achieve significant cost savings in the development of road embankments over warm, discontinuous permafrost in the Timan-Pechora region, Northwest Russia. A design approach based on partial protection of the permafrost is advocated, involving control of permafrost degradation to eliminate or minimise bearing capacity and settlement problems. In this study, recommendations are made regarding the need for key meteorological and groundwater data, further thermal analyses for optimisation of design alternatives identified in this study, the development of project-specific selection criteria for geosynthetics, an evaluation of potential constraints on soil improvement by mixing with cement or bituminous products, and needs for thermal protection of culverts.

DEVELOPMENT OF A DISTRIBUTED HYDROLOGICAL MODEL FOR PERMAFROST REGIONS CONSIDERING 1-D HEAT AND WATER TRANSFER AND RIVER FLOW PROCESSES

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The purpose of this study is to develop a distributed hydrological model which can represent the heat and water transfer in permafrost regions. For development of the distributed model, a 1-D heat and water transfer model for permafrost is first developed. Next, a distributed model is developed by combining the 1-D model with the distributed model for river flow routing proposed by Lu *et al.* (1989). Finally, these two proposed models are applied to a permafrost region on the Tibetan plateau to evaluate the model performance. The results show that the calculated profiles of soil temperature and soil moisture, and the discharge from the entire basin, are in reasonable agreement with observed values. The capability to estimate the spatial distribution of the hydrological condition is also demonstrated by comparing the model estimated distribution of soil moisture with satellite observations.

AN IMPROVED STEP FREEZING TEST TO DETERMINE SEGREGATION POTENTIAL

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Although the Segregation Potential (SP) concept has contributed greatly to an engineering approach for frost heave, there is still concern regarding the consistency and reproducibility of SP in a laboratory freezing test. This arises from the uncertainty in the evaluation of SP from a step freezing test. In order to facilitate a consistent and reproducible measurement of SP, a laboratory research program was conducted in which three improvements were made to the conventional step freezing test. The improvements included: (1) the use of an accurate water intake measurement with an electric balance, (2) a shallower temperature gradient, and (3) the addition of a cold bath to facilitate ice nucleation. Based on the test results obtained, it was concluded that the improvements resulted in an accurate, consistent and reproducible determination of SP. In addition, a continuously recorded water intake velocity can provide useful information to identify the formation of the final ice lens.

BENCH STABILITY CONTROL IN A DEEP DIAMOND OPEN PIT MINE USING THERMAL INSULATION

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Several million cubic meters of saline water entered the deep (600 m) diamond open pit "Mir" (Yakutia) excavation during its reconstruction. Before renewal of mining, this water had to be removed and for that, a network of water pipes was created on the open pit slopes. The design of these pipes was highly problematic because thawing resulted in loss of support which in turn caused outflow at the pipe connections. Mathematical simulation of the heat exchange in the permafrost showed that thermal insulation would be effective against bench destruction. Thermoinsulated screens under a newly built section of water pipe at a depth of 550 m were made in 1995. Screens were made by spraying polyurethane foam. Failures of the water pipes with the thermoinsulated benches have not occurred since.

DESIGN AND CONSTRUCTION OF SEWAGE LAGOON IN GRISE FIORD, NWT

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Grise Fiord, NWT, is Canada's most northerly community, located at the south end of Ellesmere Island (latitude 76°25'N, longitude 83°01'W). In 1992, UMA Engineering Ltd. was engaged by the Government of the Northwest Territories to undertake the design of a new sewage lagoon system to serve this community of 140 people for the next 20 years. The preliminary engineering concluded that a long term earthen detention pond, with a seasonal effluent discharge, was the most appropriate and cost effective technology for the community.

UMA completed a detailed lagoon design. Construction of the lagoon began in 1996, employing a community negotiated contract. Difficulties were encountered because of the local construction experience, the site conditions, and the suitability and availability of local equipment. The constructability of the lagoon was reviewed based upon the local limitations and some variations were implemented to complete construction in 1997.

EVOLUTION OF A PERMAFROST-DOMINATED LANDSCAPE ON THE COLVILLE RIVER DELTA, NORTHERN ALASKA

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To help provide information essential for engineering design and evaluation of potential environmental impacts in preparation for oil development on the Colville River Delta, studies on soil stratigraphy and permafrost development were conducted during 1992-1996 to investigate the nature and distribution of surficial deposits in the delta. The studies involved investigation of stratigraphy of near-surface materials along numerous toposequences in the delta, classification and mapping of terrain units, classification and description of cryostructures, dating and analysis of material accumulation rates, and determination of erosion rates. After detailed classification and analysis of the microscale and macroscale differences in soil properties across this complex landscape, we synthesized the patterns and processes that we observed into a simplified conceptual model of the evolution of the deltaic landscape.

SURFACE DEFORMATION OF CREEPING MOUNTAIN PERMAFROST. PHOTOGRAMMETRIC INVESTIGATIONS ON MURTÈL ROCK GLACIER, SWISS ALPS

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Computer-aided aerial photogrammetry is applied to analyse surface topography and surface kinematics, i.e., changes in elevation and horizontal surface velocities, on Murtèl rock glacier (Swiss Alps) over the period of 1987 to 1996. Together with measurements of three-dimensional borehole deformation, the area-wide information about surface kinematics is used to estimate the magnitude of different components of the kinematic boundary condition at the surface. Analysis of surface kinematics along a longitudinal profile, which was measured with high spatial resolution, shows that transverse ridges on Murtèl rock glacier propagate down stream-leave with a velocity which approximately equals that of the surface rocks. The first appearance of the transverse ridges coincides with a point of a marked decrease in average slope. The subsequent increase in ridge amplitude seems to be related to general longitudinal compression. The formation and growth of transverse ridges towards their maximum amplitude takes several millennia.ß

RAINFALL RUNOFF OF A NESTED WATERSHED IN THE ALASKAN ARCTIC

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The runoff response to individual rain events is examined at three scales in a nested watershed on the North Slope of Alaska. These watersheds are treeless and underlain by continuous permafrost, with an average active layer depth of 30 to 50 cm by late summer. These results are unique for this region of the world because the watersheds studied are nested and the results are drawn from a range of scales. Streamflow was measured leaving Imnavait Creek (2.2 km^2), Upper Kuparuk River (146 km^2 and the entire Kuparuk River (8140 km^2). Rainfall was measured at 12 sites in the foothills and coastal plain of the Kuparuk River basin. In general, the runoff ratio decreases as the drainage area of the three watersheds increases, wet antecedent conditions enhance runoff and storms with larger cumulative rain result in greater percent of runoff because of limited subsurface storage in the active layer.

CHANGES IN PERMAFROST CONDITIONS ALONG LINEAR ENGINEERING STRUCTURES IN THE NORTH-TAIGA SUBZONE OF THE ARCTIC YENISEY AREA, RUSSIA

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Multi-year studies, carried out along linear engineering structures in the north-taiga subzone of the arctic Yenisey area, have revealed the following:

(1) contemporary degradation of permafrost due to clearing of forest tracts and disturbance of moss and lichen cover;

(2) steady-state permafrost with a tendency towards increases in temperature due to climate warming during the last decade;

(3) contemporary aggradation of permafrost on top of mineral frost mounds due to thinner and more compacted snow cover along linear engineering structures;

(4) degradation of permafrost along the abandoned Igarka-Sukharikha railway due to damming of surface water derived from rain and snowmelt, with resultant development of bogs and of thermokarst processes; formation of permafrost below the railway bed.

New data (9 years of observations) are presented on the change in thermal regime of an open talik beneath partially-drained Shchuchie Lake located at the Arctic Circle.

DEFORMATION ANALYSIS OF THE DOESEN ROCK GLACIER (AUSTRIA)

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In the framework of a multidisciplinary research project on high-mountain permafrost in the Austrian Alps, a comprehensive deformation analysis of the active Doesen rock glacier (Hohe Tauern range) was carried out using various geodetic and photogrammetric methods. In 1995 a monitoring program was established in order to obtain geomorphometric parameters of the Doesen rock glacier for the past, present and future. Precise geodetic measurements within an observation network are acquired on a regular basis applying classical and also navigation satellite-based methods. Aerial photographs (1954, 1969, 1975, 1983 and 1993) were photogrammetrically evaluated. The flow vectors reveal that the horizontal velocity observed in the center of the rock glacier has decreased from 29 cm a^{-1}(1954-1975) to 17 cm a^{-1} (1975-1993), whereas recent measurements (1995-1996) indicate a significant increase in flow velocity (29 cm a^{-1}). Furthermore, this analysis also includes an evaluation of volumetric changes of the Doesen rock glacier.

PERMAFROST MAP OF SWITZERLAND

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Recently, computer programs have been developed within Geographical Information Systems (GIS) for automated mapping of mountain permafrost in combination with digital elevation information. One of these programs, PERMAKART - which is based on empirical knowledge about topographic factors affecting the distribution pattern of discontinuous permafrost in the Alps - was used to compile a permafrost-map of Switzerland (altitudes above 2000 m a.s.l.) using a grid resolution (mesh width) of 100 m. The reliability of this map was statistically tested by comparison with a sample of 3943 BTS-measurements (bottom temperature of winter snow cover) as indicators for permafrost presence/absence. Mountain permafrost is estimated to be present beneath about 3.6% of the total area of Switzerland. Together with the 2.5% of transitional zone at the lower boundary of permafrost, this occurrence is slightly larger than the presently glacierized area.

USE OF COMPUTERS IN GEOCRYOLOGICAL ENGINEERING

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In this paper, we introduce four computer programs (WARM, TEM, PFL, NAST) created at Moscow State University for use in geocryological engineering. The program "WARM" simulates conductive heat transfer with phase changes to forecast the thermal and phase state of permafrost, and thawing and freezing soils when interacting with engineering structures and the environment. The software "TEM" is designed for processing bore-hole temperature measurements. The purpose of this program is to reveal the zones inside permafrost in which the difference between the actual temperature and the projected temperature is dangerous for structures. The software "PFL" represents a reference and teaching system. The program "NAST" calculates the reliability of the system "structure - foundation" and can reduce total costs by including the estimated cost of construction and the price of the risk (cost equivalent of the reliability).

PERMAFROST DISTRIBUTION AND IMPLICATIONS FOR CONSTRUCTION IN THE ZERMATT AREA, SWISS ALPS

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Zermatt is one of the prime tourist sites in Switzerland with a large number of structures built for transport and accomodation. The surrounding mountains reach altitudes of more than 4500 m a.s.l.and the areas above 3300 m are glaciated. Well developed periglacial forms and numerous rock glaciers are an expression of intense frost action. The permafrost distribution was calculated with different models and checked in the field with geophysical soundings, BTS-measurements and continuous ground temperature recordings.

The construction of larger buildings in permafrost areas has become more frequent in recent years, and these conditions demand careful considerations in environmental engineering. Whereas buildings constructed at the beginning of this century sometimes suffer from the melting of frozen ground, modern construction techniques are usually well adapted to the permafrost conditions. However, small disturbances of the permafrost environment may result in serious operation and maintenance difficulties.

OCCURRENCE OF SURFACE ICE AND GROUND ICE/PERMAFROST IN RECENTLY DEGLACIATED GLACIER FOREFIELDS, ST. MORITZ AREA, EASTERN SWISS ALPS

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Numerically simulated permafrost distribution patterns in the St. Moritz area, eastern Swiss Alps, suggest that most of the existing surface ice-bodies are situated in areas of potential permafrost occurrence. Under such conditions, surface ice is predominantly cold or polythermal and perennially frozen ground in recently deglaciated areas may either persist from previous subglacial conditions underneath cold surface ice or form after the disappearance of temperate surface ice.

The results of field investigations (BTS-measurements and electrical DC resistivity soundings) indeed indicate the local occurrence of permafrost/ground ice. Visible surface ice-bodies exist in one of the investigated forefields. The observed resistivity values at this site suggest a polygenetic origin of the ice with a close coexistence of high-resistivity sedimentary ice from snow/firn/ice metamorphosis and low-resistivity congelation ice (interstitial and segregation ice) from freezing processes in the ground.

LONG-TERM INFLUENCE OF ACTIVE-LAYER DETACHMENT SLIDING ON PERMAFROST SLOPE HYDROLOGY, HOT WEATHER CREEK, ELLESMERE ISLAND, CANADA.

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The effect of active-layer detachment sliding on snow accumulation and surface runoff, was evaluated in 1996 using nine runoff plots established on a range of recent and old slides and on undisturbed slopes. There was a strong positive relationship between snow accumulation and surface runoff for unvegetated recent slides and older partially vegetated slides. Detachment slide scars generally accumulated more snow than adjacent slopes and consequently exhibited higher runoff coefficients. Inter-year comparisons for two of the plots revealed both lower snow accumulations and less runoff in 1993. The minimum amount of end-of-winter snow needed to generate overland flow at vegetated sites was much greater than that for unvegetated sites. Rainfall-induced runoff also was greater at the landslide sites compared to adjacent vegetated areas. The higher amounts of runoff generated at detachment slide sites are partly responsible for accelerated erosion that maintains the bare scar areas.

RELATIONSHIP BETWEEN THE LITHOLOGY OF ACTIVE-LAYER MATERIALS AND MEAN ANNUAL GROUND TEMPERATURE IN THE FORMER USSR

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The accummulation of quartz particles within the 0.05-0.01 mm grain size fraction and of the feldspar particles within the 0.1-0.05 mm fraction due to freeze-thaw was confirmed by experimental data and laboratory investigations of cryogenic soils. A cryogenic weathering index (CWI) is proposed to estimate the role of cryogenic weathering in soil formation.

The general zonality of the CWI has already been defined. This permits one to express more precisely the relation between CWI values and mean annual ground temperature. This is obtained for different geocryological conditions.

PREDICTION OF FROST HEAVE INDUCED DEFORMATION OF DYKE KA-7 IN NORTHERN QUEBEC

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KA-7 was built between 1978 and 1981 with first filling of the reservoir occuring in June 1982. The operating level of the reservoir was reached in September 1984. The effects of permafrost were noticed several years later, especially through significant deformations of the downstream face. The deformations were suggestive of solifluction lobes caused by cyclic frost heave and thaw settlement of the downstream shell consisting of compacted till.

The paper focuses on the prediction of frost heave caused by the formation of ice lenses in the compacted till over several years of freezing and thawing leading to a progessive formation of permafrost, which, in turn, creates cumulative deformations. A model based on the segregation potential was used for one dimensional heat and mass transfer in association with temperature boundary conditions inferred from field data. The model showed that frost heaving of about 10 to 24 cm developed over 10 years using segregation potential values inferred from laboratory frost heave tests.

OIL AND GAS COMPLEX CREATION IN YAKUTIA: ENVIRONMENTAL ISSUES

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The creation of the local oil production and oil processing in the Sakha Republic (Yakutia) is considered. It is shown that permafrost underlies practically all the territory of the Republic, thus creating challenges to its oil and gas deposit development. The experience of Yakutian gas deposit development can be usefully applied to the development of the oil deposits. It is stressed that such detrimental geological processes as gullying, bog formation and thermokarst development are conditioned by anthropogenically-induced alterations of the natural environment. It is emphasized that environmental pollution would have disastrous consequences in Yakutia, more serious than in western Russia, because of the lower rate of biochemical oxidation in soils as well as the lower self-cleaning capacity of water reservoirs of the region due to low temperatures. The paper presents the conception of engineering and environmental security for the development of the oil and gas industry in Yakutia.

GRAVIMETRIC INVESTIGATION OF MOUNDED TILL DEPOSITS, CENTRAL VICTORIA ISLAND, NORTHWEST TERRITORIES, CANADA

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A gravimetric survey was conducted over an area of mounded till deposits on central Victoria Island, Northwest Territories. The reduction of measurements and the calculation of Bouguer anomalies permitted subsurface modelling. This modelling revealed that ice is present in significant amounts. Several possibilities for the subsurface configuration exist; dirty ice of density 1.30 could lie within icy sediments of density 1.90, pure ice of density 0.95 could lie within icy sediments, or pure ice could lie within ice-poor sediments. Maximum thicknesses are 60 to 100 m and minimum thicknesses are 10 to 40 m. There is no evidence from the local geology to indicate the age of the deposits, which may be either Early or Late Wisconsinan.

ANOMALOUS ELECTRICAL PROPERTIES OF SALINE PERMAFROST ON THE YAMAL PENINSULA, NORTH-WESTERN SIBERIA, FROM FIELD ELECTROMAGNETIC SURVEY

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The results of field electromagnetic (EM) surveys performed on the Yamal Peninsula with the aim of shallow permafrost investigations are presented. Anomalous frequency dispersion of electrical properties of frozen saline clay buried at a depth of about ten meters was detected from the joint interpretation of frequency and transient EM soundings results. Computer simulation of EM soundings with the aim to fit field data using Cole-Cole formula for the description of dispersion was attempted. Extremely high values of chargeability (0.4-0.9) and relative dielectric permittivity (~10^4) of clay were obtained. The approach of percolation theory is proposed to explain the anomalous dispersion. The fractal structure of permafrost and a possible mechanism of self-organised criticality in frozen saline deposits are discussed.

EXPERIMENTAL STUDIES OF THE PROCESSES OF ICE FORMATION AND EVAPORATION IN AIR THERMOSYPHONS

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The main factors are given which determine internal icing of air cooling devices of convective action - thermosyphons - used for soil cooling and freezing. It is shown that, depending on the climate conditions and on the design and cross-sectional dimensions of thermosyphons, there are three possible types of ice formation in them:

1) periodic ice layer freezing in summer with its total evaporation in winter;

2) formation of an ice cork over several years when the volume of ice evaporated in winter is less than that formed in summer;

3) formation of an ice cork in the first summer when the total thickness of the ice that forms equals the channel cross-section.

The ways to improve thermosyphon reliability are formulated. Design changes to decrease their icing are described. The method to calculate thermosyphon channel cross-section dimensions is presented, based on accounting for the parameters of ice formation and evaporation processes. Experimental data is analyzed on these processes in thermosyphons of various designs.

EVOLUTION OF FROST HEAVING STRESSES ACTING ON A PILE

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Foundation piles embedded in frost-susceptible soils can be subjected to large uplift forces resulting from frost heaving of soils. These forces can cause an upward vertical displacement of piles that are not embedded sufficiently deep below the frost depth, or do not have sufficient resistance to counteract the heaving forces. It is important for design engineers to be able to predict the magnitude and the distribution along the pile of these frost heaving forces. This paper proposes an approximate but closed-form solution for calculating the magnitude and the development of adfreeze frost heaving forces acting on a pile, that combines the effects of frost penetration rate, heave rate and soil temperature at any depth along the pile and at any time.

THAW DEPTH MEASUREMENTS IN MARINE SALINE SANDY AND CLAYEY DEPOSITS OF YAMAL PENINSULA, RUSSIA: PROCEDURE AND INTERPRETATION OF RESULTS

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Measurements of thaw depth in permafrost areas are possible using several techniques. Insertion of a metal rod is based on the change of mechanical properties at the transition from thawed to frozen ground. Temperature measurements and frost tubes use the phase transition temperature as evidence. Direct observations of a core take into consideration visual ice and other perceptible features. Measurements with the probe (metal rod) do not account for subsidence of the heaved active layer and underestimate thaw depth, excluding centimeters of winter ice from the reading. Frost tube measurements register subsidence by the lowering of the surface around the tube, and allow correction of thaw depth for the difference.

Maximum thaw depth in the study area during the period of observations was in 1995 when summer temperature was the highest. Vegetation is the main factor determining spatial fluctuations in thaw depth.

LATE-SUMMER SOLIFLUCTION AND ACTIVE LAYER DEPTHS, FOSHEIM PENINSULA, ELLESMERE ISLAND, CANADA

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Measurements of solifluction using electro-mechanical meters over a period of 5 years at Hot Weather Creek (80°N, 84°W) show that summers with deep thaw produce enhanced rates of movement throughout the active layer. Within a basal transitional layer, the soil thaws and moves in some years but remains immobile and frozen in others. Predictions from a simple model involving displacements in a shear zone at the bottom of the active layer agree with measured subsurface movements below depths of 35-40 cm. This indicates that a shear zone, whose location depends on the depth of thaw, can explain the lower part of the velocity profile in this area of two-sided freezing, but that other processes, notably frost creep and isolated shearing, are important nearer the surface.

MODELING AND PREDICTING PERMAFROST DEGRADATION DUE TO CLIMATIC WARMING IN THE HUASHIXIA VALLEY, EASTERN QINGHAI-TIBET PLATEAU

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The depth and temperatures of continuous permafrost in the Huashixia Valley in the eastern Qinghai-Xizang Plateau in China, and the future trend of the permafrost degradation are modeled and predicted by computer for the natural geographic and geologic conditions in the Huashixia Valley. The modeling results indicate that the position of the permafrost base in the Huashixia Valley is about 56 m deep, with a mean annual air temperature of -4.5°C. Degradation of the continuous permafrost in the Huashixia Valley is predicted using a mean annual warming rate of 0.04°C for air temperatures. After one hundred years, the depth to the permafrost base would decrease to 19.5 m, but the position of the permafrost table would be changed by only about 0.50 m. The maximum rate of decrease at the base of permafrost is 0.56 m/a.

Key words: Huashixia Valley Permafrost Degradation Modeling and Predicting Mean Annual air temperature]

SIMULATION OF THE THERMAL REGIME OF PERMAFROST IN NORTHEAST CHINA UNDER CLIMATE WARMING

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Numerical simulation indicates that the geothermal regime of permafrost in northeast China will change as air temperature continuously rises. Calculated results show that, when the initial surface mean annual temperatures, T_s, are 0.5, 0.0,-0.5,-1.5,-2.5, and -3.5°C and the annual range of surface temperature is 52°C, the mean annual ground temperatures at a depth of 14 m will correspondingly be -0.16, -0.70, -1.17, -2.10, -3.03, and -4.05°C, and the permafrost thicknesses respectively will be 16.9, 28.3, 38.3, 58.9, 81.3 and 121.5 m under equilibrium between the climate and permafrost thermal regimes. Fifty years later, the predicted temperatures at a depth of 14 m will rise to 0.0, 0.0, -0.17, -0.94, -1.83 and -2.83°C under the conditions assumed. When T_s is lower than -0.5°C, the depth to the permafrost table will increase by about 20 cm. If future air temperatures rise at a rate of 0.04°C/a or less, and the ground surface temperature changes at same rate, the decrease in the area of permafrost in Northeast China will be within the limits of the region where the mean annual surface temperature in the existing permafrost area is higher than 0°C.

RESPONSE OF PERMAFROST TO GLOBAL CHANGE ON THE QINGHAI-XIZANG PLATEAU- A GIS-AIDED MODEL

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On the basis of three-dimensional rules for high altitude permafrost, the "altitude model", a Gaussian distribution function used to describe the latitudinal zonation of permafrost, was adopted to develop a quantitative mathematical model. This model is executed within a Geographic Information System (GIS). The digital elevation data and the land-types were first converted to 0.5°X0.5° grids; then the "altitude model" was used to calculate the permafrost distribution on the Qinghai-Xizang Plateau. The third step was to determine the simulation accuracy by using spatial analysis in GIS. The last step was to simulate the response of high altitude permafrost to global change according to GCM forecasts of climatic change scenarios. The results show that the "altitude model" can simulate the high altitude permafrost distribution under present climatic conditions and under various scenarios of climate change.

HIGH-MOUNTAIN PERMAFROST IN THE AUSTRIAN ALPS (EUROPE)

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Permafrost research in the Austrian Alps (Eastern Alps) is based on a variety of methods, including at large scales, the measurement of the temperature of springs and of the base of winter snow cover, and at small scales, mainly an inventory of some 1450 rock glaciers. Taking all the information available into consideration, the lower limit of discontinuous permafrost is situated near 2500 m in most of the Austrian Alps. These results can be used for modelling the permafrost distribution within a geographical information system. Detailed investigations were carried out in the Doesen Valley (Hohe Tauern range) using additional methods, including several geophysical soundings. In this way, realistic estimates of certain permafrost characteristics and the volume of a large active rock glacier (some $15 \cdot 10^6 m^3$) were possible. This rock glacier has been chosen as a monitoring site to observe the effects of past and future climatic change.

ANNUAL WATER BALANCE FOR THREE NESTED WATERSHEDS ON THE NORTH SLOPE OF ALASKA

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Alaska's North Slope is underlain by continuous permafrost with an active layer varying in thickness from 25 cm to greater than 100 cm. We have been collecting snowpack, runoff, precipitation and meteorological data at three nested watersheds: Imnavait Creek Watershed (2.2 km^2), Upper Kuparuk Watershed (146 km^2), and the entire Kuparuk River Basin (8140 km^2). In 1993 we began collecting data for the Upper Kuparuk Watershed. Initially one precipitation gauge was located at this site. In spring 1996 five additional gauges were installed and we found considerable differences in precipitation across the watershed because of topography. We reconstructed the precipitation for 1993-1995 based on trends detected in the 1996-1997 data. From these data, we compare water balances at three different watershed scales between 1993 and 1997. During the ablation period, snowmelt-generated runoff dominates while evapotranspiration dominates during summer months, particularly in the low gradient coastal plain.

DYNAMICS OF PERMAFROST IN NORTHERN EURASIA DURING THE LAST 20,000 YEARS

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Changes in permafrost are considered by describing the permafrost situation during the last two epochs with extreme climatic conditions. The coldest period (the Last Glacial Maximum of Late Pleistocene, 20,000 - 18,000 yrs. BP) in Eurasia was characterized by the maximum extent of permafrost, accumulation of deposits with the highest ice content and massive ice, by the exposure of the continental shelf, its freezing and the accumulation of "the ice complex". The warmest period (Holocene Optimum, 6000-5000 (8500) yrs. BP) was characterized by the most northerly position of the southern permafrost limit, thawing of deposits, formation of thermokarst lakes and depressions at the north and thermokarst (postcryogenic reversed) relief in the south. Today, evidence for permafrost dynamics in each epoch can be found both within the area of recent permafrost and outside its limits.

PERMAFROST OF THE BAIKAL-PATOM PLATEAU

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An analysis of the current permafrost distribution and conditions, combined with reconstructions of the neotectonic and paleoclimatic regimes and paleogeocryological processes, has revealed the major formation and evolution stages of the permafrost zone of the Baikal-Patom plateau, a large morphostructure in the northern part of the Baikal mountain-fold system. The study established a relatively fixed correlation between permafrost occurrence and the thickness and temperature distribution at the depth of zero annual amplitude. The smallest permafrost thicknesses (as thin as 15 m) are characteristic of the sporadic permafrost region of the north-western low-mountain zone, while the greatest thicknesses (220-260 m) were established for the continuous permafrost region of the middle-mountain zone in the central part of the plateau.

EFFECT OF CONVECTIVE HEAT TRANSFER ON THAWING OF FROZEN SOIL

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Most analyses of the thawing of frozen soil are based on purely conductive heat transfer, a very good assumption in most cases, but vertical and horizontal water flows occur frequently in permafrost regions. The effect of vertical water movement on the rate of thaw and the thermal regime of the soil is quantified. An exact similarity solution only occurs when the vertical water velocity is proportional to the rate of thaw. This solution indicates that seepage flows (the magnitude of the water velocity is near that of the rate of thaw) have little effect upon the thaw process. Approximate solutions are also given for the case of constant water velocity, using the heat balance integral and quasi-steady methods; they agree with the exact solution if the Stefan number is not too large. Thaw can be greatly accelerated or retarded if the water velocity (Peclet number) is large. The effect upon thawing for the case of horizontal water flow is less than that for the same magnitude of vertical flow.

MONITORING THE CHANGE OF STRUCTURES IN FROZEN SOIL DURING THE TRIAXIAL CREEP PROCESS BY COMPUTER TOMOGRAPHY

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Monitoring and analyzing the change of structures of frozen soil during the triaxial creep process by computer tomography is presented in this paper. It was found that the confining pressure restrains the increase of cracks in frozen soil and enhances the strengthening action of the structure so that the strengthening of the structure occupies a dominant position at the unstable and stable frozen creep stages. With a further accumulation of non-elastic deformation in frozen soil, if the strengthening of the structure still occupies a dominant position, the creep deformation attenuates, and if the softening action can overcome the action of confining pressure, the creep deformation becomes an unattenuated one. Breaks first appear in the weakened area with low density within the sample, then tensile cracks found in the sample surface propagate inwards to cause an integral failure of the structure.

A CONSTRAINT TO THE METHANE GAS HYDRATE STABILITY FROM THE ANALYSIS OF THERMAL DATA THE NORTHERN CANADIAN SEDIMENTARY BASINS- ARTIC ARCHIPELAGO CASE

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A hydrate prone layer extending to as deep as 2 km beneath the Arctic Islands and 1.2 km below sea level in the channels has been found. Comparison of predicted maximum depths of methane hydrate stability with the maximum depth of hydrate occurrences detected from geophysical well logs shows agreement in 93 of the 148 wells analyzed. Means are: 0.9 km +/0.4km and 0.9 km +/0.5 km respectively.

The decrease in surface temperature during transition from a marine environment to a terrestrial one is a process ongoing since the early Holocene (Taylor, 1991). This process restricts upward migrating gases from reaching the surface. In contrast, other processes causing a reduction in subsurface pressure such as changes in water depth in shallow channels can potentially contribute to a degradation of hydrates, and a release of methane to the atmosphere and act as a positive feedback to the greenhouse effect adding to global warming.

THE ROLE OF DIURNAL, ANNUAL AND MILLENNIAL FREEZE-THAW CYCLES IN CONTROLLING ALPINE SLOPE INSTABILITY

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The instability of rock and debris slopes in the Swiss Alps was evaluated in light of the temporal and spatial scales of freeze-thaw processes. Diurnal freezing and thawing penetrate to centimeter-to-decimeter scale depths, producing rock debris mainly of pebble size or smaller on rock slopes and miniature patterned forms on debris slopes. Annual freeze-thaw cycles result in weathering and soil movement up to meter scale, supplying boulders to rock glaciers and developing solifluction lobes with risers of 30 cm or higher. The growth and decay of permafrost, originating from long-term climatic change, lead to freeze-thaw activity reaching meter-to-decameter scale depths. Permafrost melting can trigger cliff falls and debris flows in the thawing phase of millennial freeze-thaw cycles.

Freeze-thaw; permafrost; weathering; mass wasting; Alps.

UNITING BASIS FOR CREATION OF ECOLOGICAL MAPS FOR THE RUSSIAN CRYOLITHOZONE

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A set of nature-protection maps of the geological environment is a necessary component of atlases. The set of cryolithozone maps should include separate maps for cryolithological texture, ground temperature, active layer, physical-geological cryogenic (periglacial) processes, pollution of the geological environment and prediction of its stability. Only a geosystem (landscape) map, correlated with territorial units of GIS-hierarchy, can serve as a uniting basis for all the maps being a part of an ecological atlas. Electronic maps using a geosystem framework are being compiled in Russia; these include permafrost and ice content as a part of circumarctic map of the world (scale 1:10,000,000); physical-geological cryogenic (periglacial) processes (1:7,500,000) and landscape units for an ecological atlas (scale 1:4,000,000).

Key words: permafrost (cryolithozone) mapping, geosystems, landscapes, base map

MONITORING OF GROUND SURFACE TEMPERATURES IN VARIOUS BIOPHYSICAL MICRO-ENVIRONMENTS NEAR UMIUJAQ, EASTERN HUDSON BAY, CANADA

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We measured ground surface temperatures (1995-1996) on a number of land types representative of all the terrain conditions encountered in a study area in order to establish interpretation keys for permafrost regional mapping. Continuous soil surface temperature data were obtained using 15 micro-dataloggers set 5 cm deep in various biophysical micro-environments located in the Umiujaq area, on the eastern shore of Hudson Bay. Analysis of the mean temperatures and the ratio between the freezing and thawing indexes, combined with the cumulative degree-day curves and the frost and thaw penetration curves, allowed us to predict the existence of permafrost at 7 of the 15 sites monitored. Sites affected by permafrost are located only under low vegetation stands, independent of surficial deposit types. Except at some herbaceous sites, the minimum annual snow depth needed to prevent permafrost development in the study area is about 50 cm.

SPATIAL AND TEMPORAL PATTERNS OF SOIL MOISTURE AND THAW DEPTH AT BARROW, ALASKA U.S.A.

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Data on active-layer thickness and near-surface soil moisture content were collected in late summer 1996 and 1997 at 100-m intervals over a 1 km^2 area near Barrow, Alaska. Thaw depth and soil moisture data were mapped to facilitate interannual comparisons and to evaluate the effects of terrain and parent material on moisture content. Statistical analysis indicates that: (1) substantial differences in soil moisture and thaw depth occur in dissimilar terrain units; (2) soil moisture and thaw depth are relatively uniform within terrain units; (3) spatial patterns of thaw depth are consistent within the study area on an interannual basis; and (4) patterns of soil moisture and thaw depth do not necessarily show close spatiotemporal correspondence. Time series of soil moisture show large variations near the surface in response to precipitation and evaporative drying, but the lower part of the active layer remains near saturation throughout the summer.

Key words: active layer, Alaska, frozen ground, permafrost, sampling, soil moisture, tundra.

THERMAL ASSESSMENT OF PASSIVE COOLED FOUNDATION SOILS BENEATH THE TRAINS-ALASKA PIPELINE AT ATIGUN PASS

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The foundation of a section of the Trans-Alaska Pipeline was stabilized in 1981 using thermosyphons. Over the past 16 years, some of the thermosyphon radiators were damaged from avalanches and rock fall. A large avalanche in 1994 did significant damage to about 1/3 of the array. This potential reduction in the cooling capacity of the array raised concern about the long-term stability of the pipeline in this area. A field and modeling study was conducted to assess the current cooling capacity of the array and to predict the future thermal environment of the foundation soils. Thermistor strings were installed in existing vacant cased borings. A two-dimensional finite element thermal analysis was done, with the soil parameters calibrated to match the known temperatures. A multi-year model was run to help predict the future performance of the remaining portion of the array. Results of the modeling indicate that the remaining thermosyphons have sufficient capacity to maintain the foundation in a frozen state.

SVALBARD AIRPORT GEOTECHNICAL STUDY: ENGINEERING METHODOLOGY AND RESULTS

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The Svalbard Airport runway has experienced continual distress in the form of settlement depressions resulting in an uneven pavement surface, which has a significant impact on aircraft operations. A geotechnical study, contracted by Luftfartsverket (The Norwegian Civil Aviation Authority), was initiated in 1993 to define the cause of the problem and develop potential rehabilitation alternatives. This paper provides an overview of the study conducted. Attention is given to the techniques used during the site investigation, geotechnical instrumentation, and analysis. The proposed rehabilitation alternatives include: insulating additional areas, raising the runway grade, removal of ice-rich soil and replacement with thaw-stable gravel, continuation of patching and overlaying, and painting the runway surface white.

THE DEVELOPMENT OF TABULAR MASSIVE GROUND ICE AT PENINSULA POINT, N.W.T., CANADA

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By employing a recently developed technique for extracting and analyzing the gas content in ice, new information on the origin and age of the tabular massive ground ice body located at Peninsula Point, N.W.T., was acquired. The ice sublimation gas extraction technique was used to measure gas content, CO_2 and N_2O concentrations, and ^{13}C and ^{18}O isotope abundances. These data were supplemented by petrographic analysis of the ice core and ^{18}O measurements of the H_2O. From this new information it is apparent that the genesis of the ice body involves a complex history of ice segregation taking place as recently as 13,860 years BP.

IMPACT OF VEGETATION REMOVAL AND ITS RECOVERY AFTER DISTURBANCE ON PERMAFROST

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Long-term studies of vegetation and permafrost have been carried out in northern Siberia since 1962. Stationary plots were established both in natural and disturbed environments. The observations covered natural zones ranging from typical tundra to northern taiga. However, the longest series of observations was for northern taiga.

These investigations have documented the influence of vegetation removal and its recovery after disruption on active layer thickness, soil temperature and moisture, and cryogenic processes.

On the basis of the characteristics of vegetation recovery, the cryogenic geosystems (Melnikov, 1988) may be divided into three categories with different geocryological conditions. The first category embraces geosystems with the most rapid recovery of vegetation and minimal changes in permafrost. The second category encompasses geosystems with a slow rate of vegetation recovery and larger changes in permafrost. The third category embraces geosystems with an incompletely restored vegetation and the greatest changes in permafrost.

SOIL TEMPERATURE REGIMES AND MICROTOPOGRAPHIC CONTRASTS, BAFFIN ISLAND, N.W.T., CANADA

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Soil temperature regimes were studied on a southwest-facing slope at the southern end of Pangnirtung Pass on Cumberland Peninsula, Baffin Island, N.W.T., Canada. Soil temperatures at several depths were recorded with data loggers at two study plots, which are characterized by different microtopography and soil properties. In order to study the relationship of soil temperature to microtopography, one plot was established on near-level ground while the other plot was divided into two microsites, a small mound and an adjacent trough.

The calculated ranges for various soil temperature parameters at the study plots show similar patterns during the study period. At the plot where the effect of microtopography on soil temperature was studied, differences between soil temperatures were most evident when temperatures approached their extremes. In general, vegetation cover and thickness of the surface organic layer are the major factors affecting soil temperatures and, therefore, depth of the active layer.

Key words: Soil temperature, microtopography, soil properties, permafrost.

THE DATING OF THERMOKARST TERRAIN, PLEISTOCENE MACKENZIE DELTA, CANADA

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Radiocarbon dating in areas of ice-rich permafrost is often problematic because old organic material can be well preserved in permafrost and then redeposited during thermokarst activity. A case study from thermokarst terrain in the Pleistocene Mackenzie Delta, Canada, illustrates the potential application of optical dating of windblown sand in combination with AMS ^{14}C dating of in situ organic material. Optical dating of sand wedges provides a weighted mean age of 14.0 ± 1.0 ka, indicating eolian deposition toward the end of Wisconsinan time. AMS 14C age estimates of 9770 ± 160 BP and 9420 ± 110 BP from in situ rootlets near the base of an involuted palaeo-active layer in which the tops of the sand wedges are commonly deformed suggest that active-layer deepening had probably commenced by ~11,000-10,400 cal BP.

MICROSCOPIC OBSERVATION OF ICE LENSING AND FROST HEAVE IN GLASS BEADS

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Frost heave in soil is a complex phenomenon which involves movement of water through unfrozen soil to the freezing front. In order to clarify the frost heave mechanism, microscopic ice lensing in glass beads was observed using an apparatus which can control the temperature gradient and freezing velocity independently. As a result, it was found that, as in soil, artificial ice lenses can form in glass beads and that the thickness of the ice lenses depends on the freezing velocity. In addition, exclusion and encapsulation of glass beads particles were observed in freezing water-particles systems using the same apparatus. The results suggest that particle size and freezing velocity are important factors for ice lensing. Observing the ice lensing microscopically helps our understanding of the mechanism of frost heave.

DEVELOPMENT AND TESTING OF A THERMAL-MECIIANICAL NUMERICAL MODEL FOR PREDICTING ARCTIC SHORE EROSION PROCESSES

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A deterministic numerical model has been developed to simulate erosion processes along Arctic shores. This unique backshore and nearshore profile model combines both thermal and mechanical erosion mechanisms related to wave attack on permafrost shores. The mechanical processes include: random wave transformation, undertow, longshore currents and orbital velocities, sediment transport and profile change related to gradients in crossshore sediment transport. The thermal module accounts for melting of the permafrost by heat conduction when there is an overlying thawed layer and by convective heat transfer when the frozen sediment is exposed to seawater of given temprature and salinity. The model has been successfully tested using data on nearshore and subsurface conditions at four sites along the Canadian Beaufort Sea coastline. The model may be used as a tool to assess erosion under "what if" scnarios related to human or natural changes affecting wave and water level climate, seawater temprature and sand supply.

SPATIAL AND TEMPORAL ATTRIBUTES OF THE ACTIVE-LAYER THICKNESS RECORD, BARROW, ALASKA, U.S.A.

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Active-layer thickness was measured during the periods 1962-1968 and 1991-1997 in a series of 19 plots representing different landcover and terrain characteristics near Barrow, Alaska. Mean values in the 1960's were generally higher than in the 1990's. Climate Matrix Analysis (CMA) reveals strong internal consistency in the active-layer data. Plotted for the entire record, considerable scatter exists in the relation between active-layer thickness and the square root of the thawing index. Partitioning of the data into interdecadal segments, however, reveals very strong relations between these variables. This discrepancy may be an artifact of interannual or interdecadal variations in soil moisture, ice content in the uppermost permafrost, ground cover characteristics, and/or nonconductive heat-transfer processes. The Barrow active-layer record illustrates the value of systematic, long-term observations of thaw depth, currently being performed under the Circumpolar Active Layer Monitoring (CALM) program.

RUSSIAN AND NORTH AMERICAN APPROACHES TO PILE DESIGN IN RELATION TO FROST ACTION

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North American and Russian approaches to pile design are based on different views of the nature of the tangential frost heave force. In North America, the latter is associated with the long-term adfreeze bond. According to the Russian approach, the frost heave force is the result of friction from frozen soil sliding along a pile. Russian permafrost scientists have found that an adfreeze bond between a pile and frozen soil in the active layer is usually broken at the beginning of winter. Two widely used methods of design of foundation stability from frost action were analyzed. The first method is implemented by Russian building code (SNiP method), and the second one by the American manual "Arctic and Subarctic Construction Foundations for Structures" (TM-5 method). The SNiP method is reliable in most typical situations but has some limitations. The TM-5 method provides a safe design for practically all situations, but for most of them, it greatly overestimates the length of piles required.

DAMAGE MODEL OF FROZEN SOIL UNDER MULTI-AXIAL STATE STRESS

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In this paper, we derive the constitutive equations of creep damage for frozen soil subjected to multi-axial state stress. The equations obtained include damage evolution equation, the yield criterion for damaging frozen soil and an equation specifying the additional strain due to damage growth. These equations provide a uniform description of the creep process in frozen soil. We also analyze the rupture time in the case of sustained creep. To prove the validity of the proposed approach experimentally, a detailed analysis is made for uniaxial compression, and the results are compared with test data.

REGIONAL ACTIVE LAYER MONITORING ACROSS THE SPORADIC, DISCONTINUOUS AND CONTINUOUS PERMAFROST ZONES, MACKENZIE VALLEY, NORTHWESTERN CANADA

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Fifty-eight sites have been established along a 1200 km transect in the Mackenzie Valley to monitor processes linking climate, climate change, permafrost and the active layer. Annual maximum thaw penetration and surface movement are measured relative to thaw tubes anchored in permafrost. Active layer thickness, calculated from thaw penetration and surface movement, varies more with local soil properties, vegetation and microclimate than with regional atmospheric climate. While thaw penetration has increased at most sites over the last 4-6 years, this increase is not always reflected by an increase in active layer thickness because of thaw settlement. Air and shallow ground temperatures are measured every 2-6 hours at many sites. Air thawing degree-days (DD) are up to three times greater than ground thawing DD, an effect of surface vegetation and snow cover. Larger air thawing DD values are required in boreal forest than in the tundra to achieve similar active layer thicknesses.

PIPE UPLIFT RESISTANCE TESTING IN FROZEN SOIL

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The design of buried chilled pipelines in frost heaving terrain requires a knowledge of the uplift resistance of pipes buried in frozen ground. Higher uplift resistances will increase the severity of pipe curvatures and strains at frozen-unfrozen interfaces.

Twelve tests have been carried out in three different test programs, that provide the general shape of the load-displacement curve, and the effects of backfill type, cover depth, displacement rate and soil temperature. This paper includes a summary of 5 previous tests, and interprets the results of all 12 tests carried out to date.

Interesting crack patterns in the frozen soil around the pipe were observed, and their role in limiting peak and residual uplift resistance is discussed. Correlations have been developed that will allow pipeline designers to establish the load-displacement characteristics of a buried pipe displacing upwards through frozen soil, as required for structural analysis of chilled pipes in discontinuous permafrost.

RECENT APPLICATIONS OF GEOTHERMAL ANALYSIS IN NORTHERN ENGINEERING

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Geothermal analysis using a numerical model with phase change has been used to predict response to diverse engineering and development applications in permafrost and seasonal frost areas. One-dimensional analyses are used to assist in ground temperature monitoring for long term climate change. The addition of a convection option allows 1-D analysis for a heap leach gold mine in a permafrost area to be carried out. The final 1-D example involves a recent simulator developed for application to thermal analysis for tailings or embankment soils, where the upper surface increases in height with time. Predictions from this analysis illustrate how frozen layers can be embedded in a growing tailings or soil deposit with time. Long term thermal analysis is used to predict the eventual fate of these frozen layers, sandwiched between unfrozen layers.

Two dimensional analysis examples illustrate the versatility of modern thermal models. The applications included are frost heave beneath a pipeline and freezing around a pipeline buried in a stream bed with moving ground water. Results from a 3-D model for oil pipeline temperature predictions in permafrost are compared with observed pipe and soil temperatures. Finally, a general steady state 3-D model for permafrost distribution around complex surface water bodies is applied to a large northern diamond mine.

PERMAFROST DYNAMICS AT THE ROGOVAYA RIVER PEAT PLATEAU, SUBARCTIC RUSSIA

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Plant macrofossil and radiocarbon analyses are presented from the upper part of two peat sections from a peat plateau in subarctic European Russia. In addition, gross stratigraphic descriptions and radiocarbon date are available from four other profiles in the same area. The peatland area formed under permafrost-free conditions. Currently, permafrost underlies the peat plateau and some ombrotrophic depressions at plateau level, whereas thermokarst ponds and fen areas at thermokarst level are permafrost-free. The present-day peat plateau, which is characterised by relatively dry surface conditions, is 200-2800 radiocarbon years old. The oldest date for permafrost initiation at the study sites is 3100 BP. According to multi-proxy climate reconstructions, mean July temperature in the study area was 2-3 C° higher during the Middle Holocene.

PERMAFROST AS A FROZEN GEOCHEMICAL BARRIER

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This report considers the influence of the frozen and thawed soil interface on the distribution of mobile forms of chemical elements in permafrost affected soils. Three following levels of mobile chemical elements accumulation were described in the loam permafrost affected soil (Edomic suite, Kolyma Lowland, North-East Russia): the bottom of Holocene active layer, the upper part of ice rich transitive layer, the bottom of modern active layer. The mobile compounds migrate into the depressions of the permafrost table during infiltration of pore solute. Additional local concentration and separation of elements occur at the subsequent secondary freezing of soil. Zones of concentration mark the thawing levels of perennially frozen grounds at different stages of their development. The selective chemical sedimentation of chemical elements at the frozen barrier is described on an example of mobile calcium.

UPDATE OF PERFORMANCE OF SLOPES ON THE NORMAN WELLS PIPELINE PROJECT

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The Norman Wells pipeline is a buried warm crude oil pipeline that traverses 868 km of discontinuous permafrost in northern Canada. There are over one hundred slopes along the route that are in permafrost. In the period since the pipeline became operational in 1985, the operator has undertaken monitoring of the performance of many of these permafrost slopes with the aim of assessing the stability of the slopes as they experience permafrost degradation.

This paper reviews the general background of the design and construction of the pipeline, from a permafrost perspective, and updates the performance of the slopes in the past several years. The results of field testing to measure the lateral extent of the thawing around the pipeline, and the impact of this thawing on the stability of the thawing slopes are presented. A summary of the lessons learned from a geotechnical engineering perspective are also provided.

ESTIMATING THE MAGNITUDE OF COUPLED-FLOW EFFECTS IN THE ACTIVE LAYER AND UPPER PERMAFROST, BARROW, ALASKA U.S.A.

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Upward migration of soil water and its eventual evaporation near the ground surface cools the active layer above permafrost during summer. The thermal magnitude of these effects was estimated using a numerical model based on conductive heat-transfer theory and incorporating fusion effects. The model utilizes precision measurements of soil temperature as initial and boundary conditions to simulate the evolution of the thermal profile over the annual cycle. The simulation indicates that upward water movement and near-surface evaporation cools the active layer several degrees during summer and depresses the mean annual ground temperature by about 0.4°C. Nonconductive cooling of the active layer also attenuates surface thermal variations and moderates the thermal signal that penetrates the upper permafrost. Because the ratio of the heat of evaporation to the heat of fusion is approximately seven, an increase in summer temperature may not cause dramatic permafrost degradation and surface subsidence at poorly drained sites.

Key words: active layer, frozen ground, permafrost, sampling, soil water.

ACTIVE LAYER MONITORING IN NORTHERN WEST SIBERIA

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Long-term observations on the depth of seasonal thaw have been made in northern West Siberia. Results from two permafrost stations are analyzed: Marre-Sale (Yamal Peninsula) and Parisento (Gydan Peninsula). Thaw depths range from 0.3 to 0.75 m on polygonal peatlands and flat bogs, to up to 1.5 to 1.8 m on unvegetated sandy deposits. There is a strong relationship between summer thawing degree-days and depth of thaw. Inter-seasonal variations of depth of thaw can be greater than 15 to 20% of the mean. Depth of thaw poorly reflects contemporary climatic warming. Results from the past 15 to 20 years suggest a trend for an increase in thaw not exceeding 0.5 to 0.7 cm/yr. Analysis of thaw measurements from CALM grids indicate statistically similar values can be obtained from sampling on the 1000 m grid by reducing the number of probings by a factor of 2 to 2.5.

A LINEAR STABILITY ANALYSIS FOR THE INCEPTION OF DIFFERENTIAL FROST HEAVE

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A linear stability analysis was performed to determine whether one-dimensional frost heave has the propensity to evolve into multidimensional differential frost heave. Chena silt, Calgary silt and Illite clay, whose soil properties were obtained from literature data, were found to be unstable under a set of base conditions. Modeling the frozen layer as a purely elastic medium showed there is a most highly amplified wave number that is a function of the soil properties and environmental conditions. Sufficient surface load can completely stabilize the system. Increased frost penetration depth results in smaller wave numbers and, ultimately, stabilization. The most highly amplified wave numbers before stabilization correspond to wave lengths in the range of 2-10 meters which corroborates fairly well with field observations for patterned ground forms such as earth hummocks that are thought to arise from differential frost heave.

DRIVEN PILES IN WARM PERMAFROST

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Recently, pile driving techniques in permafrost have been developed and offer a fast as well as an economical solution to many foundation problems in warm permafrost conditions. Depending on the soil type and composition, temperature profile, logistics of economical transportation of pile driving equipment and so on, steel piles may be successfully driven for the foundation of single family houses to be constructed in warm permafrost regions.

Presented in this paper are two contrasting projects in warm permafrost single family housing in the Yukon-Kuskokwim Delta area, Alaska, where H and circular steel piles were successfully driven. Design approach and construction problems associated with H-type steel piles with heat tubes in one of the sites and circular steel piles without heat tubes used in the other site, are illustrated. Conclusions and recommendations are given for the proper installation of driven steel piles in warm permafrost.

A NUMERICAL MODEL FOR THE ORGANIZATION OF ICE-WEDGE NETWORKS

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Ice-wedge networks organize through feedbacks between thermal tensile stresses in permafrost and the developing fracture pattern. Questions concerning fracture geometry and pattern evolution require a modeling approach that includes time development of networks, the influence on fracture of complicated patterns of stress owing to pre-existing fractures, and the effects of stochastic material properties. To model an ice-wedge network through time, we simulate the development of the fracture pattern on a lattice in plan view. Modeled tensile stress in a cell is a function of pre-fracture thermal stress and position and orientation of nearby fractures. Fractures are initiated in randomly chosen cells exceeding a threshold of tensile stress, and propagation proceeds until a cell is reached where modeled stress falls below strength. The distributions of fracture spacing and relative orientation in model-generated networks closely resemble distributions from mature ice-wedge networks at two sites in northwest Alaska.

MASSIVE ICE FORMATION IN THE EUREKA SOUND LOWLANDS: A LANDSCAPE MODEL

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Massive ice is a commn constituent in fine-grained marine sediments situated below the Holocene marine limit in the Eureka Sound area of EUesmere and Axel Heiberg Islands. Its stratigraphie setting and character suggest it is intrasedimental in nature and formed as permafrost aggraded following Holocene mergence. This paper describes the relationship between ground ice occurrence and landscape volution on Fosheim Peninsula, with particular emphasis on the duration and extent of glacier ice cover, sea lever history, and the style and pattem of glaciomarine sdimentation in forinerly submergea basins. A two-phase model is proposed to explain the nature of ground ice distribution. In this model permafrost conditions associated with late Quatemary glacial, periglacial and emergent environments are considered. The volution of permafrost conditions is divided into two phases corresponding with: (a) prior to ~8-9 ka BP, and (b) post-glacial mergence after ~8 ka BP.

GEOMORPHIC AND HYDROLOGIC CHARACTERISTICS OF PERENNIAL SPRINGS ON AXEL HEIBERG ISLAND, CANADIAN HIGH ARCTIC

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This paper documents the hydrologic and geomorphic characteristics of perennial springs on western Axel Heiberg Island in the Canadian High Arctic. Two groups of mineralized springs occur near the McGill Field Station at Expedition Fiord. The first group is 3 km from the terminus of the White and Thompson Glaciers discharging at the base of the east side of Gypsum Hill adjacent to the floodplain of the Expedition River. The second site is at Colour Peak near the head of Expedition Fiord, approximately 10 km down valley from Gypsum Hill. Each spring group consists of 20-40 outlets spread over several hundred square metres. The mineralized nature of the discharge is responsible for a range of precipitates and travertine deposits. This paper documents spring discharge, water chemistry, and mineral precipitates associated with the springs.

FROST WEATHERING IN A MOUNTAIN PERMAFROST AREA (PLATEAU MOUNTAIN, ALBERTA, CANADA)

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The slopes of the mountains on and around Plateau Mountain (Canada) show very well developed block slopes, in contrast to the rocky mountain sides seen elsewhere in the adjacent Rockies. This study of the frost sensitivity of the limestones forming outcrops on the Plateau Mountain slopes combines field and laboratory experimentation. The distribution of water in blocks in the field and the weathering undergone by samples put on the block slope for one winter are measured. The first results indicate that bursting or scaling caused by frost action are not the main causes of the formation of these block slopes in this cold alpine environment, although frost weathering is often considered as an important process in periglacial environments.

MELTWATER FLUXES, HILLSLOPE RUNOFF AND STREAM FLOW IN AN ARCTIC PERMAFROST BASIN

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This paper integrates studies of snow distribution, snowmelt percolation, hillslope runoff pathways and stream flow in the continuous permafrost region of the Canadian western Arctic. Observations and model results showed high variability in the relative flow velocities and travel time within each flow component. Vertical flow through the snowpack is initially very slow, with a delay of up to 2 weeks in drifts. Once snow is thoroughly wetted, percolation is rapid (hours). On hillslopes, the reverse is true, with lateral transfer being rapid (hours) early in the melt period, but decreasing (days to weeks) as the active layer develops. Hillslope runoff accumulates as a saturated layer at the base of the deep snowpack in the stream channel. Initially, discharge through the snow-choked channel occurs through this layer, but as the snow is removed by thermal and mechanical processes, the flow velocity increases.

THERMOKARST VEGETATION IN LOWLAND BIRCH FORESTS ON THE TANANA FLATS, INTERIOR ALASKA, U.S.A.

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The thawing of ice-rich permafrost beneath birch forests in the Tanana Flats area of Interior Alaska has produced thermokarst features colonized by a range of species and wetland vegetation types. As the forest drowns along its border with fens, an open-water moat is colonized by minerotrophic species and a floating mat develops. At the same time, thawing in the birch forest interior produces water-filled thaw pits and collapse scar bogs in which ombrotrophic vegetation develops through several stages to *Sphagnum* bogs. As the thawing front moves into the birch forest from the fen, these latter features are incorporated into the floating mat, accelerating the expansion of fens.

EXPLORING THE LIMITS OF PERMAFROST.

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The T_T model expresses the mean annual temperature at the top of perennially frozen or unfrozen ground (at the base of the seasonal freezing/thawing layer) in terms of the annual regime of atmospheric temperatures, freezing and thawing n-factors and the ratio of thawed and frozen soil conductivities. This paper analyses the range and behavior of the freezing (snowcover) n-factor and the thermal conductivity ratio, in terms of the physical controls. The freezing n-factor is sensitive to both snow depth and the mean annual temperature; the thermal conductivity ratio is sensitive primarily to volumetric moisture content, and is quite insensitive to mineralogy. T_T values using climatic normal data are explored in light of this variability, in terms defining the limiting conditions for permafrost occurrence.

REGIONAL CHARACTERISTICS OF SUBFLUVIAL TALIK FORMATION AND STRUCTURE, YAMAL PENINSULA, RUSSIA

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Regional patterns in the formation and structure of taliks in Yamal valleys occupied by small rivers with seasonal run-off, are shown to exist from cross-section reconstructions using well logs. The dominant factor in talik formation is the warming effect of the snow cover, including its dynamics. The warming influence of snow in the river-bed, Dtsn = 5.8° C, reduces by nearly 60% the effect of the mean annual air temperature. The wide distribution of saline sediments leads to the formation of complex talik zones in river valleys. The outer boundary of a talik zone is the isotherm of soil transition to the plasticly frozen state, i.e. the isotherm at which ground freezing begins. The taliks have a horizontally stratified and vertically zoned structure. They include not only thawed sediments, but also unfrozen sub-zero sediments and plasticly frozen sediments.

Key words: talik, talik zone, frozen ground, plastic frozen ground, solid frozen ground.

MASSIVE GROUND ICE WITHIN EUREKA SOUND, ELLESMERE ISLAND, CANADA

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This paper presents observations from a natural exposure on the bank of Hot Weather Creek, Ellesmere Island, showing three distinct massive ice types: 1) discrete ice sills within poorly consolidated bedrock, 2) segregated massive ice, and 3) a large ice wedge within overlying unconsolidated fluvial sediments. Stratigraphic observations and hydrochemistry data indicate that the three ice types have different modes of origin and water sources. Ice wedge formation followed marine regression, which exposed unfrozen sediments to cold air and promoted the aggradation of permafrost. The formation of segregated ice was promoted by the downward progression of permafrost, an ample water source and the presence of a fine-grained capping layer. The downward aggradation of permafrost combined with the presence of a lower confining boundary likely resulted in the highly pressurized groundwater required to form ice sills in the already frozen bedrock.

UNDERGROUND ICE AND RELIEF EVOLUTION ON THE ISLANDS AND COASTS OF THE RUSSIAN ARCTIC

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Analysis of long-term field observations (1985-1997) of geomorphic processes, indicate that the intensity of the relief-forming processes depends on ground ice and ice-rich deposit distribution and on modern relief features. The most intensive erosional processes are characteristic of plains with massive ground ice bodies (Central Yamal, the northern part of Anabar-Olenek interfluve; Novosibirsky Islands) while erosional plains are characterized by a prevalence of sediments with low ice contents and erosional processes are correspondingly less active. Thermal erosion, thermal abrasion and "thermal denudation" are the most important and widespread processes in regions which are formed out of ice-rich deposits: the volume of transported material is up to 100,000 m^3/ km^2 per year and more. A comparison of the intensity of erosional processes in the various Arctic regions is presented.

REGULARITIES OF PERMAFROST INTERACTION WITH GAS AND GAS HYDRATE DEPOSITS

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Geothermal anomalies and anomalies of permafrost thickness are known to occur above gas deposits in the northern gas and oil fields of Russia (Baulin, 1985). A two-dimensional mathematical model was used to investigate the interaction between permafrost and gas/ gas hydrate deposits under the influence of long-term (periods of 100 and 40 Kyr) climatic fluctuations. Gas deposits at depths in excess of 800 m are affected by the longer 100 Kyr variation but exhibit only minor anomalies. In contrast, gas reservoirs at depths of about 400 m, i.e. near the base of permafrost, form anomalies comparable with those in nature. Positive and negative geothermal anomalies and anomalies of permafrost thickness appear during both its aggradation and degradation. Analysis suggests that these anomalies may be associated with the presence of secondary gas/ gas hydrate deposits formed above the primary gas deposits situated at depths of about 1000 m.

Key Word: permafrost, gas deposits, gas hydrates, geothermal anomalies, mathematical modeling

MAP OF PREDICTED OFFSHORE PERMAFROST DISTRIBUTION ON THE LAPTEV SEA SHELF

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One of the most striking natural features of the Laptev Sea Shelf (LSS) is the ice-bonded offshore permafrost. It has aggraded due to the exposure of the shelf during the Late Pleistocene glacioeustatic regression. It includes epigenetic saline frozen deposits unevenly overlapped by syncryogenic ice-rich deposits - "Ice-Complexes". At present, this permafrost is relic and degrading under the sea that flooded the shelf during the last transgression. Based on previous investigations, new field data, the compilation of paleo-environmental scenarios for the last glacioeustatic cycle and mathematical modeling of offshore permafrost evolution, a new model is presented of the distribution of ice-bonded permafrost and sub-sea taliks on the LSS. Ice-bonded offshore permafrost is relic and continuous, extending from the current shore line to the -60;-70 m isobaths and discontinuously to the -100 m isobath. Open taliks are linked with flooded valleys of main rivers and with active tectonic faults.

A MODEL OF QUATERNARY PERMAFROST EVOLUTION IN THE ARCTIC.

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The history of permafrost in the Arctic is reconstructed based on palaeogeographic and palaeoclimatic scenarios during two last glacial cycles. Circum-Arctic models of permafrost are created for each stage. The models show the distribution of various types of permafrost (subaerial, subglacial, submarine), and their temperature and thickness. Palaeopermafrost maps are presented for three stages : 1) Sangamonian - Mikulin (Oxygen Isotope Substage 5e, 125 ka BP), 2) late Wisconsin - late Wurm - late Valday (Oxygen Isotope Stage 2, 20-18 ka BP), 3) Holocene climatic optimum (Oxygen Isotope Stage 1, 9-5 ka BP). The model of permafrost evolution, which reveals cause-and-effect relations between permafrost and other natural factors, can provide a basis for a predicting the future development of Arctic permafrost.

TRENDS OF PERMAFROST DEVELOPMENT IN THE SELENGE RIVER BASIN, MONGOLIA

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The Selenge River Basin, Mongolia, is located in the southeastern part of Siberian permafrost. Ground temperature data collected during the past 15-25 years show that mean annual temperatures are increasing at rates of 0.01-0.02°C per year. Permafrost is degrading in about 75% of the areas of the basin where it currently exists. The current annual thaw rate is about 0.5-1.0 cm from the top and about 2-5 cm from the bottom. In the Khentei taiga, which covers about five per cent of the basin, permafrost is aggrading, especially where forests are dense and where moss is present. It is projected that most of the permafrost that is less than 15 m thick will disappear within 50 years which will decrease the entire area currently underlain by permafrost in the basin by 25-35%.

NUMERICAL MODELING OF COUPLED MOISTURE, SOLUTE AND HEAT TRANSPORT IN FROZEN SOILS

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Frozen barriers in a porous medium represent zones with an increased ice content in pore voids. Creation of such barries can be used as an effective tool for limiting moisture and contaminant transport in soils. We study in a local equilibrium formulation a one--dimensional problem that describes the dynamics of phase transitions at the interface between two water saturated porous domains with different temperatures and concentrations of solutes. To solve the resulting system of the equations we use a numerical fixed domain method based on a method of overrelaxation. The numerical experiments show the existence of three regimes. The first regime offers no frozen barrier formation, while in the other two regimes, a frozen barrier can be generated. Two types of frozen barriers are distinguished: static and dynamic. The first one is an ice-bonded zone which completely eliminates forced seepage. The second type represents a narrow frozen zone expanding with a rate proportional to $x/\sqrt{t}$, and allowing a small seepage flux through itself that is damped out in time as $1/\sqrt{t}$.

CRYOSTRUCTURE DEVELOPMENT ON THE FLOODPLAIN OF THE COLVILLE RIVER DELTA, NORTHERN ALASKA

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The development of a sequence of cryostructures on the floodplain of the Colville River Delta in northern Alaska was studied in 1995-1996 to provide information for engineering design and assessment of potential environmental impacts of the proposed Alpine Oil Development Project. Existing cryostructure classifications were modified to develop a comprehensive morphological classification that incorporates observations of cryostructures from 8 bank exposures and continuous cores from 40 boreholes in the Colville River Delta with observations from Russian and Canadian studies. The processes that affect cryogenic structure are floodplain evolution, syngenetic permafrost formation, and ice wedge development. The cryostructures on the Colville River Delta are compared with those described from other arctic deltas to evaluate the uniformity of arctic fluvial and cryogenic processes.

SOURCES OF NATURAL GAS WITHIN PERMAFROST (NORTH-WEST SIBERIA)

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Various aspects of sudden natural gas blowouts from within the permafrost sections of deep (greater than 300 m) wells at Yamburg and Bovanenkovo gas fields (northwest Siberia) are presented. Topics covered include: gas geochemistry, blowout intensity (gas flow rate), depth interval and permafrost rock peculiarities in places of these gas releases. The results are compared with similar studies in other polar regions. Although microbial gas is widespread within permafrost, thermogenic gas can also occasionally migrate from deep gas reservoirs along faults or be present locally in areas of gas reservoirs within the permafrost section. Gas can be preserved within permafrost in a free state as well as in hydrate form throughout the permafrost zone.

AIR AND SOIL TEMPERATURE RELATIONS ALONG AN ECOLOGICAL TRANSECT THROUGH THE PERMAFROST ZONES OF NORTHWESTERN CANADA

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Summary air and soil temperatures are presented for six sites along a transect covering scattered discontinuous permafrost near Whitehorse, Y.T., to continuous permafrost north of Inuvik, N.W.T. Data were collected over 12 months from screen-height air temperatures and soil temperatures at 20, 50, 100, and 150 cm depths. Annual and monthly mean temperatures, accumulated freezing and thawing degree-days and n-factors have been calculated. Annual mean air temperatures at the sites range from -2.4°C in southern Yukon to -8.6°C north of Inuvik, while annual mean ground temperatures at 50 cm depth decrease from -0.6°C to -5.8°C over the transect. The thaw season n-factor (N_t) is relatively constant along the transect. The freezing season n-factors (N_f) are considerably higher (>0.50) in tundra soils than forested soils.

RUSSIAN PERMAFROST MAP BIBLIOGRAPHY AND INDEX

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A bibliography of 730 permafrost maps published in the Former Soviet Union and Russia has been compiled from a review of over 1500 monographs, books, and papers. Maps published separately were included as well. The maps are classified into four types: geocryological conditions, regionalization, predictive, and special. These subdivisions follow the traditional Russian categories. The maps range in scale from Large (<1:5000) covering particular research or construction sites, to Small (1:400,000,000) with global or hemispheric coverage. Maps for a user's area of interest can be located with the indexing system which keys each citation to the International Map of the World quadrangle designation.

CRYOPEG RESPONSES TO PERIODIC CLIMATE FLUCTUATIONS

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The properties and classification of cryopegs and their relationship to periodic climate fluctuations is discussed. The formation of cryopeg lenses is determined by the Quaternary history as well as geological, physical and geographic conditions. In the Yamal Peninsula region, two groups, three types, six subtypes, and 10 classes of cryopegs have been identified. Cryopegs of the second group are found in zones influenced by long-term temperature fluctuations (30 to 90 years, or more than 1000 years). Periodic temperature fluctuations influence their physical and chemical characteristics. Cryopegs of the first group are found in permafrost that is influenced by temperature fluctuations with a period of 5 to 11 years.

ROCK GLACIERS ON JAMES ROSS ISLAND, ANTARCTICA

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Lack of glacier cover in north-western James Ross Island, favours the development of a number of periglacial landforms. Ice-cored rock glaciers, protalus lobes, and recently discovered protalus ramparts are some of the most conspicuous cryogenic features.

The ice-cored rock glaciers appear in a complex and genetically related landform system. Besides their morphological characteristics, these landforms are also differentiated by their dynamic behaviour. Mechanisms of ice and debris flow and debris extrusion are discussed in order to ascertain the initial age of the main rock glacier formation.

Protalus lobes and protalus ramparts, formed at the base of scree slopes and ephemeral snow patches with no relation to former glaciers, are also typical features of this environment. All these landforms were probably formed after the third Neoglacial, 1300-1000 years BP.

IMPACT OF SOIL FREEZING ON THE CONTINENTAL-SCALE SEASONAL CYCLE SIMULATED BY A GENERAL CIRCULATION MODEL

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Frozen ground can have great effects on energy and water cycles at a continental scale because of its large coverage, large thermal inertia due to latent heat of fusion, and impermeability. This paper assesses thermal and hydrological impacts of soil freezing, from an interactive point of view, using an atmospheric general circulation model with a multi-layer soil submodel. Experiments are conducted with and without the freezing process and the difference between them is examined.

Inclusion of the freezing process leads to lower surface soil moisture in summer in the frozen-ground region. It results in higher surface temperatures, leading to the stronger water vapor fluxes and larger precipitation associated with the stronger summer monsoon. In this way the climatic effects of frozen ground are found not only in the high latitudes but also in the lower latitudes.

EFFECT OF ATMOSPHERIC TEMPERATURE INVERSION ON GROUND SURFACE TEMPERATURES AND DISCONTINUOUS PERMAFROST, NORMAN WELLS, MACKENZIE VALLEY, CANADA

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Atmospheric temperature inversions, measured during weather balloon ascents, are particularly frequent in the Arctic because of the negative radiation balance over snow and ice. To study the effect of persistent atmospheric inversions on discontinuous permafrost, we established paired air and ground surface temperature instrumentation on a 15 km transect over the elevation range 60-969 m ASL at Norman Wells, Canada. Measured surface air and ground temperatures reflect atmospheric temperature inversions on a mean annual basis. Permafrost thicknesses at elevations above the valley appear to have been limited by the persistent atmospheric inversions of this region. Permafrost is 52-62 m deep in the valley bottom (~60 m ASL), thins to <45 m or is absent where the mean annual atmospheric inversion strength is the greatest (100-500 m ASL), and is estimated 200-300 m thick at the summit (969 m ASL). Numerous springs and icings 100-200 m ASL are geomorphic evidence for the thinning and perforation of permafrost.

SNOW SUPPORTING STRUCTURES IN STEEP PERMAFROST TERRAIN IN THE SWISS ALPS

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Snow supporting structures are widely used in the Swiss Alps to protect settlements and transport routes from avalanches. The structures can be located between 2500-3500 m a.s.l, in permafrost terrain. In order to monitor permafrost temperatures, boreholes were drilled in two slopes at 3000 m a.s.l and equipped with thermistors in 1996. Different types of supporting structures were constructed in 1997 with the aim of investigating two main problems: firstly, interactions between supporting structures and permafrost were studied using temperature measurements, to determine whether the presence of the structures induces thawing through heat conduction into the ground, which could increase the intensity of creep deformation or even cause local terrain instability. Secondly, construction techniques were tested and improved in order to avoid damage to structures built in creeping permafrost terrain. In particular, the setting behaviour of mortar for the construction of micropiles in permafrost was investigated.

CONSTRUCTION EXPERIENCE ON HYDRAULIC FILL IN A PERMAFROST AREA

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A unique experiment to use hydraulic excavation to produce artificial hydraulic fill for a construction site on permafrost, was undertaken in Yakutsk. The results of experiments and instrumental observations have established the following:

- the impact of the hydrological and temperature regime of the Lena River on the ground-water level;

- the influence of the hydraulic fill on the underlying permafrost;

- the common tendencies of development of thermal processes in permafrost

and the hydraulic ground fill;

- the behaviour of structures built on the artificial ground fill.

The data obtained allowed the formulation of major design principles, to deduce formulas of calculation of the underflooding zone and foundation settlements. The accumulated experience showed the efficiency of construction sites prepared by hydraulic methods in northern regions.

ROCK GLACIERS AND PERMAFROST RECONSTRUCTION IN THE SOUTHERN CARPATHIAN MOUNTAINS, ROMANIA

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Rock glaciers are indicators of discontinuous permafrost which permits them to be used in the reconstruction of the development of mountain permafrost. The mapping of rock glaciers in the Southern Carpathians allowed a clear differentiation between talus rock glaciers and debris rock glaciers, as well as their spatial and morphological relations with glacial deposits. Given the significance of rock glaciers in the glacial-periglacial landscape continuum, geomorphological analysis has led to the outlining of three evolutionary models.

Two major periods of development of rock glaciers were recognised: Wurm III - Older Dryas for forms below 1600-1750 m, and the Medium and Younger Dryas for features over 1800 m a.s.l.. During the Little Ice Age, features located above 2050 m were reactivated. Calculations were also made of the volume of mountain permafrost represented by the rock glaciers and the volume of ground-ice, as well as the evolution in time of the lower limits of continuous permafrost and widespread and patchy discontinuous permafrost in the Southern Carpathians.

THE APPLICATION OF POLLEN AND SPORES TO DETERMINE THE ORIGIN AND FORMATION CONDITIONS OF GROUND ICE IN WESTERN SIBERIA

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Pollen and spore spectra from various types of ground ice and their host sediments were studied to obtain additional information about formation features. A new approach for the pollen analysis of ground ice samples was developed and applied. Pollen and spore spectra from Holocene and Late Pleistocene ice wedges and their host sediments (300 samples from ground ice and 800 samples from host sediments) in Western Siberia are discussed and compared with spectra from firn. Also considered are pollen and spore spectra of epigenetic segregation, injection and infiltrated-segregation ice from the Yamal and Gydan Peninsulas in relation to water source and freezing direction. Pollen analysis is unsuitable for dating and for determining ground ice type. However palynology can provide additional information about ground ice origin.

OXYGEN - ISOTOPE AND ENZYMATIC ACTIVITY VARIATIONS IN THE SEYAHA SYNGENETIC ICE-WEDGE COMPLEX OF THE YAMAL PENINSULA

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The Seyaha syngenetic ice-wedge complex of the third lagoon-marine terrace in the Yamal Peninsula (North of Western Siberia) is of great interest to palaeogeocryological study due to its unique combination of various sediments and different kinds of ground ice including Late Pleistocene and Holocene syngenetic ice-wedges and massive segregation ice. There are two geocryologic parts evident in the section: the upper 9-12 m with enclosed narrow 1-1.5 m-wide ice wedges, and the lower 12-15 m with enclosed 3 m-wide ice wedges. Several different kinds of analyses were used to obtain oxygen isotope variations, to place them within an age scale, to reconstruct Late Pleistocene mean winter temperatures, and to assess the influence of the Ob Bay on the formation of the ice-wedge complex (using data on enzymatic activity and chemical composition). The difference between the lower and the upper parts is evidenced by the difference between the values of their enzymatic activity which depends upon conditions during formation of the permafrost sediments.

THE ROLE OF THE ZONE OF CONTACT OF FROZEN SOILS WITH FOUNDATION MATERIALS IN THE FORMATION OF ADFREEZING STRENGTH

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The influence of the structure and properties of the contact zone between frozen soils and foundation materials on the character of its failure under shear, and on adfreezing strength, is considered for a wide range of negative temperatures. Data obtained show that the character of failure in the contact zone varies and that there is a complicated temperature dependence of adfreezing strength at different ranges of temperature. A reversal of the pattern of values of the adfreezing strength of sandy soil and clayey soil is also observed. Analysis of experimental data shows that marked trends are affected by changes in the structure, properties and unfrozen water content of the contact zone with changes of negative temperatures.

BOREHOLE TEMPERATURES IN ALPINE PERMAFROST: A TEN YEAR SERIES.

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A 60 m deep borehole drilled in 1987 through the active rock glacier Murtèl-Corvatsch (Upper Engadin, Swiss Alps) has enabled collection of a 10 year long series of temperature measurements within creeping mountain permafrost, representing a regional signal.

Between 1987 and 1994, the uppermost 25 m rapidly warmed up. Surface temperature is estimated to have increased from -3.3°C (1988) to -2.3°C (1994), thereby probably exceeding previous peak temperatures during the 20th century. After 1994, within only two years with very little snow enabling intensive cooling of the ground, the temperatures declined, reaching values similar to those of 1987.

The variability of the observed permafrost temperatures is caused by several processes: (1) shorter periods of negative temperatures within the active layer due to long-lasting zero-curtains in the autumn; (2) global radiation and air temperature influencing temperatures mainly in the summer; (3) the history of snow-cover during the winter.

INFLUENCE OF GLOBAL WARMING ON THE STATE AND GEOTECHNICAL PROPERTIES OF PERMAFROST

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The paper examines potential changes in the thermal regime and geotechnical properties of permafrost in the permafrost regions of Russia as a result of future climatic warming. The investigations were conducted by mathematical simulation of these processes using a computer program, with increases in annual average air temperature of 2°C and 4°C by the middle of the next century. The entire permafrost region was divided into four geothermal zones based on the degree of sensitivity of frozen soils to thermal actions. The calculations were performed for 4 lines of longitude. The changes in average annual temperature, depth of thaw, long-term strength of frozen soils and bearing capacity of foundations caused by warming were determined for each geothermal zone. As a result, the potential changes in the state and propagation of the permafrost were demonstrated and their possible consequences for the durability of foundations were determined.

PLACING COLVILLE RIVER DELTA RESEARCH ON THE INTERNET IN A DIGITAL LIBRARY FORMAT

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The Colville River Delta, Alaska has been the subject of research by teams from Louisiana State University since 1961. Although nearly 200 articles, reports, theses and dissertations about the delta have been produced, much of the research is still unpublished.

In 1997, Louisiana State University initiated a long-term project devoted to the establishment of a digital library by utilizing Colville River Delta research materials. The objective is to make several thousand slides, black and white photographs, aerial photographs, diagrams, maps, and tables as well as publications available to students, researchers and other interested people via the internet.

To date (September, 1997) more than 1000 items (including a number of theses, dissertations and published articles) have been digitized and are available through the URL :
http://appl003.lsu.edu/lsudigit.nsf.

The procedures used and the infrastructure (e.g., equipment and computer programs) needed to support a digital library of arctic materials are being standardized at Louisiana State University.

CHARACTERISTICS OF PERMAFROST IN THE TANANA FLATS, INTERIOR ALASKA

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The Tanana Flats is a wetland region located on the distal slopes of an extensive alluvial fan complex built out of the Alaska Range. Vegetation in the Flats consists of a mosaic of fen, birch forest, black spruce forest, shrub, and bog. Permafrost is not present in the fen and bog areas, but it exists on the bordering forested or shrub areas 0.5 to 2 m above water level. Our studies show that permafrost in the Flats is relatively warm at -0.2 to -0.7°C, and that the distribution and characteristics of permafrost are related to the geobotanical conditions at a specific site. In general, permafrost is more ice rich and shows higher secondary porosity where finer-grained sediments (silts) are abundant. These are environments characterized by birch forest vegetation. Permafrost in areas of birch forest appears more susceptible to thaw and is currently showing signs of extensive degradation.

A STUDY OF THE MICROSTRUCTURE OF FROZEN SOILS

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Using an optical indicator and an electronic scanning microscope, the cryogenic structures of frozen soil were observed using different soils, water contents, temperatures, salts and overburden pressures. Results show that the microstructure of frozen soils changes from a massive structure or a layered structure to a more open, network structure. With the change in bearing forces among soil components, the micro structures change: aggregates may form, dislocation, cracking and fusion of ice crystals, folding and other changes can occur. The destruction of frozen soil develops in three stages under the action of different forces, i.e., particle dislocation, folding and micro fracture. The changes of microstructure of frozen soils reveal the destruction micro mechanism of frozen soil under different initial and boundary conditions.

RECENT GEOPHYSICAL INVESTIGATIONS AT A HIGH ALPINE PERMAFROST CONSTRUCTION SITE IN SWITZERLAND

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The construction work for the extension of the Sphinx observatory (3,550 m a.s.l.) at Jungfraujoch, Switzerland, was a geotechnical challenge with respect to alpine rock permafrost. In view of possible destabilisation, precise monitoring of rock temperatures and deformation around a 100 metre long elevator shaft with a diameter of 6.5 metres was necessary. Inverse correlation between temperature and deformation related to freezing and thawing was observed, as well as irreversible deformation as a consequence of the construction activities. To prevent further thawing, the elevator shaft is now actively cooled. The temperature history is modelled in a two dimensional north-south cross section through the rock ridge at Sphinx. The calculated permafrost thickness is more than 200 metres and the active layer is approximately 3 metres thick.

COASTAL PERMAFROST INVESTIGATIONS ALONG A RAPIDLY ERODING SHORELINE, TUKTOYAKTUK, N.W.T

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Rapid coastal erosion along a peninsula forming the seaward shoreline of Tuktoyaktuk has resulted in ongoing control measures since the mid-1970's. While wave-generated erosion is significant along this section of the Beaufort Sea coastline, subsidence resulting from thawing of massive ice beneath nearshore sediments is also suggested as a major contributory cause of recession.

This study presents the thermal and physical condition of subsurface sediments within the nearshore zone, where permafrost and massive ice was documented in 1974. Observations from six boreholes drilled in March 1994 indicate that alteration in subsurface thermal and ground ice regimes over the last 20 years has been significant. Thawing of ground ice likely resulted in nearshore subsidence in excess of 3 m. This subsidence may create a sediment demand, supplied by the shoreface, that results in ongoing erosion. This study illustrates the importance of linking thermal and mechanical aspects when assessing coastal instability in this environment.

MASSIVE ICE ASSOCIATED WITH GLACIOLACUSTRINE DELTA SEDIMENTS, SLAVE GEOLOGICAL PROVINCE, N.W.T. CANADA

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Discrete bodies of massive ice beneath a glaciolacustrine delta were investigated. The flat surface topography suggests that growth of massive intra-sedimental ice did not occur, although surface features indicate creep of underlying ice. Measured $\delta^{18}O$ values of -30‰ to -35‰ for an ice body indicate a cold-water origin, while a $\delta^{18}O$ - δD slope of 8.3 is consistent with glacially derived ice. This interpretation is supported by low cation concentrations, trace amounts of Si, Al and Fe, and lack of identifiable trends in element concentrations with depth.

Rapid deposition of sediments over glacially- or glaciofluvially-derived ice, followed by lake drainage and permafrost emplacement is hypothesized. Although massive ice has been uncovered in only a few locations in the region to date, buried ice may be common since surficial features attributed to partial thawing and creep of massive ice are regionally apparent

CHARACTERISTICS OF PATCHY WETLANDS IN A POLAR DESERT ENVIRONMENT, ARCTIC CANADA

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The occurrence of patchy wetlands in the polar desert is predicated upon focused water supply and a shallow frost table to inhibit deep percolation. Several such wetlands near Resolute, Cornwallis Island, Canada, are compared. Meltwater from a late-lying snowbank or suprapermafrost groundwater seepage creates high water tables in these wetlands. The wetlands have thin thawed zones compared with their adjacent non-wetland locations due to the insulation properties of the peat layer and because much heat is needed to thaw the abundant ground ice in the peaty soil. Internal processes and external disturbances can be deleterious for the saturated environment and modify the characteristics of these patchy wetlands.

METHANE HYDRATE FORMATION AND DISSOCIATION IN FINE SANDS AT TEMPERATURES NEAR 0°C

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In 1996, Canadian and Russian scientists collaborated to construct a laboratory test cell for producing artificially hydrated sediments. This paper presents results from an initial suite of experiments characterizing the formation and dissociation of methane hydrate in fine-grained sand at temperatures near 0C. Results indicate that P/T equilibrium conditions for hydrate stability in sand are slightly offset from values determined for pure-system hydrates, presumably due to porous media effects. Analyses of P/T response and measurement of gas yields suggest hydration efficiencies approaching 75%, with typical gas yields between 100-150 cm^3/g of soil water. Time series measurements reveal the complexity of hydrate formation/dissociation in natural soil media, with hydrate formation occurring over relatively long periods, while dissociation typically is more rapid. Multiple cycles of hydrate formation, freezing, thawing and dissociation suggest considerable influences arising from changes in soil structure and water memory effects

A MODEL TO EVALUATE THE ENGINEERING GEOLOGY ON FROZEN GROUND FROM XIDATAN TO WUDAOLIANG ALONG THE QINGHAI-XIZANG HIGHWAY USING GIS

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Based on a Geographic Information System (GIS) for frozen ground along Qinghai-Xizang Highway (QXH), a computer model for frozen ground was developed from regional ground temperature, latitude and altitude data. Using the computer model, an engineering suitability coefficient (K) of engineering geology for frozen ground was proposed. The K value was determined by the differences in engineering geological conditions (EGC), which were divided into five types: excellent (10 to 8), good (8 to 6), generally suitable (6 to 4), requiring protection (4 to 2), and requiring complete protection (2 to 0). Considering the type of frozen ground, water content, ice content, ground temperature, and the engineering properties of frozen ground, a regression model between K and all the parameters was proposed. Finally, using the data in the GIS and from the regression model, a computer model for the engineering geological evaluation of frozen ground was developed.

Key words: Evaluation model, Engineering geology, Frozen ground, Qinghai-Xizang Highway(QXH).

CRITICAL AND DESIGN HEIGHTS OF FILL MATERIAL IN PERMAFROST REGIONS ON NATIONAL ROAD 214, EASTERN QINGHAI-XIZANG PLATEAU, CHINA

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The artificial change of the permafrost table under fill materials in permafrost regions has been reported for forty years. Changes along national road 214 are reported in this paper. The conclusions of the research indicate that the critical height of the fill material is about 0.80 m, i.e., when the height of fill materials is more than the critical height of fill, the new permafrost table rises, when less, the new permafrost table descends. This is one of the important reasons causing frost heave in roads. Because of the influence of climatic warming, permafrost in the region is degrading and the natural permafrost table has dropped by 0.3 m during the last thirty years. Because of the rapid development of the economy and the increasing use of road transportation, the increase in the amount of frost heave in the road is greater than the above would indicate. Thus, the new permafrost tables must be raised in fill. The design height of the fill on national road 214 has been determined to be 1.6 m for gravel-paved road surfaces, and about 2.0 m for concrete road surfaces.

SOIL CARBON LOSSES DUE TO INCREASED CLOUDINESS IN A HIGH ARCTIC TUNDRA WATERSHED (WESTERN SPITSBERGEN)

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Carbon pool and carbon flux measurements of different habitats were made in the high Arctic coastal tundra of Spitsbergen. The studied catchment was situated on the exposed west coast, where westerly winds produce daily precipitation in form of rain, drizzle and fog. The storage of organic carbon in the catchment of Eidembukta amounts to 5.98 kg C m^{-2}, mainly within the lower horizons of deep soils. Between 5.2 - 23.6 % of the carbon pool is stored in plant material. During the cold and cloudy summer of 1996, net CO_2 flux measurements showed carbon fluxes from soil to atmosphere even during the brightest hours of the day. We estimate that the coastal tundra of Spitsbergen lost carbon at a rate of 0.581 g C m-2 d-1 predominantly as CO_2-C. Carbon loss (7.625 mg C m^{-2} d^{-1}) as TOC in small tundra rivers accounts only for a small proportion (1.31%) of the total carbon loss.

HYDROCARBON DEPOSITS AND ATTENDANT ANOMALIES OF PERMAFROST UPPER AND LOWER BOUNDARIES

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Most oil and gas deposits around the world are accompanied by positive temperature anomalies. In permafrost regions they are manifested by a decrease in permafrost thickness (H) (in case of fresh subpermafrost waters), and an uneven mosaic of both increased seasonal thawing (h) and higher ratios of h/H towards the most productive part of the hydrocarbon deposit. The reduction of permafrost thickness above hydrocarbon deposits is caused mainly by exothermic reactions. Anomalies of seasonal thawing are responses to separate unrelated and isolated surface heat sources, the genesis of which is connected with the oxidation of hydrocarbons in upper part of their dispersion halo, mostly in oxygen-enriched suprapermafrost waters. The contribution from the deep heat source to seasonal thawing above a hydrocarbon deposit is nearly the same for all its area.

Key words: hydrocarbon deposits; active layer; permafrost thickness.

THE GROUNDWATER HYDRAULICS OF OPEN SYSTEM PINGOS

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The characteristics of spring water from open-system pingos in interior Alaska and Svalbard were examined to elucidate the relationship between groundwater and open system pingos. Water from springs under pingos creates a variety of icing blister formations in the winter. It was concluded that pingo formation pressure varied from pingo to pingo, with artesian pressures sometimes less than 20 kPa. The pressure from ice crystallization is one of the important factors for pingo growth when artesian pressure was low. Springs warmer than 3°C or with discharge rates greater than 3 liters per second did not have pingos associated with them. Experimental evidence indicates that in order for pingo growth to occur, heat transferred to the pingo through groundwater discharge must be less than 37 kW.

EXPERIMENT STUDY OF POISSON'S RATIO FOR FROZEN SOIL

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A new method to measure Poisson's ratio for frozen soil is proposed. The test result indicates that the measured Poisson's ratio is correct only when the normal stress is less than 1.0 MPa at -2°C, and 2.0 MPa at -5°C. Poisson's ratio for frozen soil increases with elapsed time, but reaches its maximum value within a short time after application of loads. It decreases with decreasing temperatures with a maximum value of about 0.23 when the temperature is -2°C and 0.20 when the temperature is -5°C.

LATITUDINAL AND ALTITUDINAL TRENDS OF SEASONAL SOIL THAW IN YAKUTIA

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The change in calculated depths of seasonal soil thaw from north to south through central Yakutia (nearly 2500 km) was analysed for relatively dry and water-saturated sands and silty loams. For each of four soil types, three correlation relationships were obtained between the seasonal thaw depth and the geographic latitude and altitude of the area. The latitudinal gradients of change in seasonal thaw depth were found to be 0.05 - 0.08 m/° N.L. in the Arctic and 0.06 - 0.14 m/° N.L. in the continental sections of the transect. The depth of seasonal soil thaw for mountainous area (Southern Yakutia) decreased by 0.56 - 0.68 m/1000 m of altitude in silty loams and by 0.85 - 1.23 m/1000 m of altitude in sands.

TRANSIENT EM SOUNDING IN THE STUDY OF PERMAFROST

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In the paper, we consider the special characteristics of electromagnetic field behavior in permafrost conditions. In permafrost areas, induced polarization effects complicate electromagnetic field processes. A solution of the problem for horizontally layered dispersing media is presented. The high accuracy of the modeling is demonstrated for transient sounding in permafrost. A way of detecting of unfrozen rocks in permafrost is proposed. Testing of these methods on the Zapolyarnoe deposit allows us to detect unfrozen water in permafrost. Borehole data confirm the interpretation of lithological and hydrogeological structure of the section as well as the groundwater salinity.

GEOCRYOLOGICAL MAP OF THE USSR AT A SCALE OF 1:2,500,000

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A new Geocryological Map of the USSR at a scale of 1:2,500,000 results from research work performed by the Department of Geocryology, Faculty of Geology, MSU, over a 25-year period. This map shows: (1) geological formations of Pre-Quaternary rocks and genetic associations of Neogene-Quaternary deposits; (2) seasonally and perennially frozen ground, their composition, cryogenic structure, and volumetric ice contents; (3) mean annual ground temperatures; (4) permafrost thickness; (5) structure of the geocryological section; (6) distribution and thickness of earth materials with cryopegs; (7) distribution and thickness of relict (Pleistocene) permafrost, overlain by thawed ground; (8) cryogenic geological phenomena; (9) localities of underground water discharge and taliks.

The Geocryological Map of the USSR is supplemented by four general maps at a scale of 1:25,000,000 showing: (1) present environmental conditions; (2) permafrost thickness; (3) the cryogenic age of sediments and types of cryogenesis; and (4) a hydrogeocryological map.

POSTFIRE ALTERATIONS OF CARBON BALANCE IN TUNDRA ECOSYSTEMS : POSSIBLE CONTRIBUTION TO CLIMATE CHANGE

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The adaptation of tundra ecosystems to warming will involve losses of carbon from storage. There are two main mechanisms of carbon cycle change. The first one is related to adaptive alterations in ecosystem respiration and production. The second one is connected with fires, which are more likely under global warming. In this context, three ecosystems were investigated in the summer of 1996 in north-eastern European Russia: (a) undisturbed dwarf-shrub moss-lichen tundra; (b) site burned in 1994; (c) site burned in 1988. Total carbon pool in (a) was estimated at 5.87 $kgC \cdot m^{-2}$. Site (b) had 67% and site (c) about 70% of that amount. The net carbon flux at site (a) was +13.7 $gC \cdot m^{-2} \cdot day^{-1}$ (carbon source), at sites (b) and (c) -2.7 and -35.2 $gC \cdot m^{-2} \cdot day^{-1}$, respectively (carbon sink). The restoration period of the carbon pool is estimated at 60 years.

ANALYSES OF MICROSTRUCTURE DAMAGE FROM THE CREEP PROCESS IN FROZEN SOIL USING A SCANNING ELECTRON MICROSCOPE

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Creep tests on frozen loess were conducted and the microstructure damage from creep processes were examined using a Scanning Electron Microscope (SEM). Analyses of the SEM images show that the patterns of microstructure damage during the creep process differed greatly under different levels of loading: under medium levels of loading, there were various microcracks and traces of ice crystal sliding in the frozen soil samples; however, under high levels of loading, only large brittle microcracks developed and no sliding of ice crystals was observed. Under the same levels of loading, the development of microcracks in the various stages of the creep process was different. The production and extension of microcracks in the frozen soil samples dominate the creep process. The interactions between the mineral grains and the ice crystals in the creep process were observed.

ADFREEZE STRENGTH OF MODEL PILES IN FROZEN SOIL UNDER DYNAMIC LOADS

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Based on experiments, this paper discusses the adfreeze strength of model piles under dynamic loads. The test results indicate that the adfreeze strength under dynamic loading decreases rapidly with elapsed time under all test conditions, and that the decrease speed is faster than that under static loading. Under the same test conditions, adfreeze strength decreases linearly with increasing frequency of dynamic loading. The moisture content of frozen soil around model piles has a significant effect on the adfreeze strength. As the moisture content of frozen soil approaches the saturation value, the adfreeze strength of model piles reaches a maximum. The rigidity of the pile foundation has an obvious effect on the adfreeze strength of concrete piles: the greater the rigidity, the lower the adfreeze strength. This effect is not obvious for steel-pipe piles.

STUDY OF THE RELATIONSHIP BETWEEN THE UNFROZEN WATER CONTENT OF FROZEN SOIL AND PRESSURE

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The relationship between the unfrozen water content and pressure is important in studying the physical properties and mechanical behaviors of frozen soils under high pressure. We have designed an apparatus to determine the unfrozen water content of frozen soil at high pressures using a Nuclear Magnetic Resonance probe. The unfrozen water contents were determined at temperatures from 0 to -20, and pressures from 0 to 40 MPa. The experimental results show that the freezing point of soil decreases linearly with increasing pressure and that the unfrozen water content of frozen soil increases with increasing pressure in a non-linear manner.

SIMULATION OF FREEZING AND FROZEN SOIL BEHAVIOURS USING A RADIAL BASIS FUNCTION NEURAL NETWORK

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A radial basis function (RBF) neural network was applied to simulate soil freezing and thawing processes. The air temperature, soil depth, and time were used as inputs to the neural network, and soil temperature was the output. The relationship between soil temperature, air temperature, elapsed time, and depth was learned from the experimental data by training the RBF network. The trained network can predict soil temperature for new inputs of depth, air temperature, and time. In a second example, the RBF network was employed to simulate the dependency of frozen soil strength on confining pressure, strain rate, and soil temperature. By comparing with experimental data, it was shown that the network can yield a very satisfactory generalization of the frozen soil strength in relation to these variables.

EFFECT OF TEMPERATURE AND STRAIN RATE ON THE CONSTITUTIVE RELATION OF FROZEN SATURATED SILT

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Uniaxial constant strain-rate compression tests were conducted on frozen, saturated silt (Lanzhou loess) at various strain rates and temperatures. The average water content and dry density of the specimens were 24.5% and 1.58 g/cm^3, respectively. It was found from the test results that the yield strain of the samples was independent of the strain rate, and that the yield stress varies with temperature and strain rates. Based on regression analyses of the test data, the constitutive relation in uniaxial compression of the frozen, saturated silt is presented, and the effects of temperature and strain rates on the constitutive relation are quantitatively discussed.

Key words: constitutive relation, frozen silt, effect of temperature and strain rate

Extended Abstracts

NUMERICAL MODEL OF LAYER PRESSURE DYNAMICS BELOW PERMAFROST

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A one-dimensional numerical model of hydrostatic pressure field dynamics in subpermafrost thickness with its foot moving by the law defined as $h(\tau)$ (where h is foot depth and τ is time) is elaborated. The permafrost thickness is described as a semi-space filled with layered medium characterized comprehensively by layer thickness and two properties of permeability $K(x)$, m^2 and porosity $m(x)$ where x is a space coordinate and the ground surface is taken to be the origin at $x=0$. The model is built in two variants, (a) without and (b) with consideration of horizontal water exchange with an open talik. In variant (a), the pressure dynamics is simulated by the filtration equation

$$\frac{\partial\tilde{P}}{\partial\tau}=\frac{\partial}{\partial x}\frac{\rho K}{m\rho_0\cdot\mu\cdot\gamma}\frac{\partial\tilde{P}}{\partial x}, \qquad (1)$$

where γ is water compressibility; P_0 is atmospheric pressure; μ is water viscosity; $\rho=\rho_0[1+\gamma(P-P_0)]$ is water density; ρ_0 is ρ value at $P=P_0$; g is acceleration of gravity; $\tilde{P}=P-P_0-\rho gx$, i.e. the sought for pressure P is expressed as the sum of the hydrostatic component $\rho gx+P_0$ and the component $\tilde{P}$ (let us call it differential pressure) that defines the vertical water exchange.

At the lower boundary ($x\to\infty$), the boundary condition (BC) is prescribed, of the 1st or the 2nd kind, respectively:

$$\left.\begin{aligned} &P_{/x\to\infty}=\rho gx+P_0, \text{ or } \tilde{P}_{/x\to\infty}=0;\\ &\frac{\partial P}{\partial x}_{/x\to\infty}=\rho g, \text{ or } \frac{\partial\tilde{P}}{\partial x}_{/x\to\infty}=0, \end{aligned}\right\}; \qquad (2)$$

at the upper BC of the 2nd kind, being a mathematical notation of mass balance of thawing or freezing water at the phase transfer:

$$\frac{K\rho}{\mu}\cdot\frac{\partial\tilde{P}}{\partial x}_{/x=\bar{h}+0}=-m\rho\left(1-\frac{\rho_{ice}}{\rho}\right)\frac{\partial\bar{h}}{\partial\tau}; \qquad (3)$$

here (ρ_{ice}=917 kg/m^3 is the ice density, 0 is infinitesimal quantity.

The model presumes (and the physics of the process necessitates) that $\forall x,\tau$: $P \geq P_0$. Hence, it is postulated that at any point x adjacent to the front, when decreasing pressure reaches the value P_0, porous moisture is evaporated, resulting in the impossibility for further pressure decrease. This means that at $P_{/x=h(\tau)} \geq P_0$ the upper boundary $\bar{h}(\tau)$ of the countable area coincides with the given function $h(\tau)$; otherwise $\bar{h}(\tau)$ becomes unknown quantity, i.e. the solution of (1)-(3) is the field $P(x, \tau)$, in addition to such value of $\bar{h}(\tau) > h(\tau)$ of the upper boundary coordinate where $P_{/x=\bar{h}(\tau)} = P_0$. Subarea ($\bar{h}(\tau),h(\tau)$) becoming evaporation zone, is excluded from the countable area, and the pressure in all its points is taken equal to P_0.

As h(τ), is presumed to be a periodic function, initial conditions (IC) can be prescribed arbitrarily, whereas the desired solution finally comes to a periodically established pressure field; however, to speed up the transition, it is natural to assign BC corresponding to the pressure in the open talik, thus obtaining

$$P(x,0) = \rho g x + P_0 = \frac{\rho_0 g x}{1 - \rho_0 \gamma g x} + P_0 . \tag{4}$$

For the variant (b), assuming that the inflow rate follows Newton's law, we get

$$\frac{\partial \tilde{P}}{\partial \tau} = \frac{\partial}{\partial x} \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma} \frac{\partial \tilde{P}}{\partial x} - \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma \cdot L^2} (P - P_T), \tag{5}$$

L, m is a coefficient proportional to the distance to a talik; pressure P_δ (x) in a talik is distributed by (4). IC and BC are assigned as previously. Due to negligibility of γ and the weak dependence of ρ on pressure, it is possible, without loss of accuracy, to assume the differential pressure field in a talik $\tilde{P}_T(x) \equiv 0$ (the numerical experiment showed the lawfulness of such an assumption). Hence equation (5) takes the form

$$\frac{\partial \tilde{P}}{\partial \tau} = \frac{\partial}{\partial x} \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma} \frac{\partial \tilde{P}}{\partial x} - \frac{\rho K}{m \rho_0 \cdot \mu \cdot \gamma \cdot L^2} \tilde{P} . \tag{6}$$

Both equations are solved iteratively by the two-layer three-point finite difference pattern on a spatial mesh of "floating" length, reflecting the movement of $\bar{h}(\tau)$ point. The search of $\bar{h}(\tau)$ at the evaporation zone appearance is made by the method of "front catching in a mesh knot".

A number of solutions were made for various structures: homogenous, two- and multi-layered; with water inflow and without any water exchange; with different layer properties. The calculations showed either decrease or increase of the layer pressure at thawing and freezing, respectively, the pressure fluctuations being phase-shifted relative to the foot fluctuations.

APPLICATION OF MULTITEMPORAL AEROPHOTOGRAMMETRICAL MONOPLOTTING FOR MAPPING PAST, AND MONITORING PRESENT, ROCK GLACIER DEFORMATION

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Multitemporal photogrammetrical measurements were carried out on an active rock glacier in the Central Alpine cirque Ässeres Hochebenkar (Ötztaler Alpen). Six sets of aerial photographs at scales in the range of 1:15,000 to 1:30,000 cover a period from 1953 to 1997.

This investigation assessed the potential of the monoplotting technique for measuring superficial deformation velocities of an active rock glacier. Published geodetic data of this site by Pillewizer (1953) and Vietoris (1972), additional unpublished surveying data as well as extended permafrost mapping by Haeberli and Patzelt (1982), and new geophysical investigations, provide the opportunity to a) compare the displacement vectors derived by different methods and b) correlate movement data with permafrost occurrence and development.

Monoplotting is a computer-based fast and comparatively cheap technique to obtain distortion-corrected and georeferenced images from aerial photographs. The software applied in this investigation requires camera calibration data, a digital elevation model and ground control points to produce a monoplot.

Aerial photographs were scanned on a rotation drum scanner at the maximum geometric resolution of 1200 dpi and a spectrometric resolution of an 8-bit greyscale. Images were processed by use of an orthophoto software package (PCI OrthoEngine) and displacement vectors were registered by use of a GIS (ARC/INFO) on a workstation computer. The occurrence of large boulders with diameters of more than 2 m on the rock glacier surface provided good conditions for the recognition of identical objects in the multitemporal images.

For detecting and measuring the movements of this rock glacier in the meter dimension, geometric accuracies of less than a meter are required. The calculated precision of the iterative resection process given by the orthophoto software show excellent results in the sub-meter dimension. Accuracy is extremely dependent on the availability of precise and stable ground control points.

The geometric resolution of the image with pixel sizes in the range of 0.3 to 0.6 m on the ground is sufficient for this investigation. The precision obtained and the fast application of computer based monoplotting shows good potential for extended use in a planned monitoring project. Due to a major limitation of multitemporal photogrammetric analysis, the recognition of identical ground objects, a higher geometric resolution of the images is still desirable.

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LONG-TERM PREDICTIONS FROM THREE MILLION YEARS OF CLIMATIC, GLACIAL AND PERIGLACIAL HISTORY

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Climates depend not only on increases in greenhouse gas concentrations and earth orbital periodical changes, but also on changes in the positions of continents and global ocean circulation. The solid line of Figure 1 reflects the interactions of all the above-mentioned factors.

During the Pliocene Epoch the climate was cooling because the surface of the continents had increased and the common circulation of the ocean had been broken up. There are many reconstructions for the last glacial period. They allow the creation of new scales for the diagram which enhance the picture. When the global ocean circulation developed (3.1-2.7 Ma B.P.), the orbital oscillations changed the temperature of the ocean surface slightly (~0.5°C) because of the active circulation and the negative feedback. Later the circulation had limitations. About 2.6 Ma B.P., the North American ice sheet and permafrost developed at first, subsequently disappearing and re-appearing many times. The formation of durable snow-ice covers activated positive feedback which reduced the temperatures and increased their amplitudes (2.6-1.0 Ma B.P.). The situation changed about 0.96 Ma B.P. when the average temperature decreased. Ice sheets, permafrost, and eventually loesses began to expand. Their thicknesses (H_i) can be estimated with the equation $H_i = a_i T_i^{1/2}$, where a_i is a constant and T_i is the duration of process.

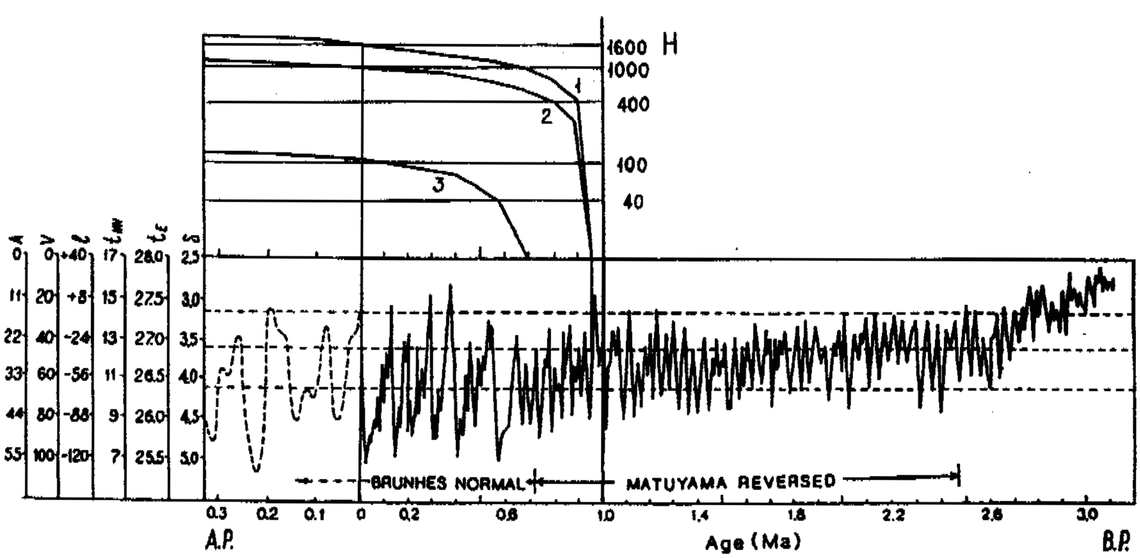

***Figure 1.** Three million years of the oxygen-isotope series $\delta^{18}O$(‰) (Raymo, 1992) and environmental reconstruction and prediction (Berry, 1996). t_EC - surface ocean temperature in the Equatorial belt; t_{NH}C - surface land temperature in the Northern Hemisphere; l (m) - level of oceans; V (Mkm^3) - volume of ice-sheets; A (Mkm^2) - area of ice-sheets; H (m) - maximum thickness of permafrost in Asia; (1) a_{PA} = 1.62; in North America; (2) a_{PNA} = 1.02; (3) loess in Tajikistan, a_{LT} = 0.129m/$y^{1/2}$.*

The turning point came when the Arctic Ocean was covered by pack-ice (0.7 Ma B.P.). Since then, the long glacier and short interglacial periods have determined changes in the land cover and the level of the oceans. Periodic fluxes of heat have destroyed the ice-sheets only for 10 ka, but could not eliminate the permafrost.

Northern expositions of ice sheets, including shelf glaciers, had permafrost conditions on the bottom. The southern boundaries of present-day latitudinal permafrost approximately coincide with reconstructed ice divides. This fact, the presence of permafrost in the subsea areas and in the regions which did not have ice sheets in the Pleistocene, and its thickness prove that permafrost conditions have existed for almost 1 Ma, that freezing is a relict and present process, and that the thickness of latitudinal permafrost has gradually formed since 0.96 Ma B.P. The permafrost under the southern slopes of the ice sheets was no thicker than 140 m and it thawed during interglacial periods.

The curve contains the orbital rhythms; therefore, we can approximate and extrapolate the homogeneous part of this oxygen-isotope series (0 - 0.7 Ma) using harmonic components (Berry, 1993). Humanity must be ready for some cooling after 4 ka and the next heavy cooling after a further 20 ka.

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INTERACTION BETWEEN BRINES AND PERMAFROST

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The permafrost base in fresh-water sections generally follows the surface relief and the position of the zero isotherm. Brine-bearing sections of permafrost are less well investigated, phase transitions of water occur at subzero temperatures, and the brine-ice (frozen ground) system under certain conditions is disturbed from an equilibrium condition, while the liquid and solid phases can actively interact with each other irrespective of changes in geothermal conditions. Such sections characterize the Siberian platform.

It is established that the brine-ice subzero-temperature system is classed with equilibrium-non-equilibrium systems. Under natural conditions, the co-existence of impermeable frozen rocks and subpermafrost brines with a hydrostatic head is widespread. Highly mineralized solutions have a well-known property of melting the ice in contact with them if the medium temperature is above the solution cryoeutectic point. In this context, it is very important to establish the reasons for the apparent equilibrium between cryogenic aquifuges and cryopegs during many hundreds of thousands of years.

The non-equilibrium state means that ice melts actively in the presence of brines, and as a result of this process, a layer of desalinated liquid appears between the phases. If such a layer is fixed, then its mineralization will be established equal to the cryoeutectic point, and ice melting will stop. Concentration diffusion at negative temperatures is decelerated abruptly and does not lead to salinization of the desalinated part of the water column. In the near-contact interval of the system, a state of self-regulating saturation exists and, as a consequence, an equilibrium state of phases is established. The existence of an equilibrium system is possible provided there is no outflow of the desalinated part of liquid from it. Convection is absent only in a gravitationally stable system, in which the light solution floats above the heavier one.

If the base of the ice body is removed from the horizontal position, then the equilibrium state is restored in the closed system. The desalinated layer at the phase contact also originates, but in this case it begins to move up, without protecting the ice from the aggressive influence of the brine. The melting of the lower part of the ice occurs, as well as the leakage and accumulation of the desalinated mixture in the upper part of the space where it subsequently freezes. The system reaches equilibrium when the boundary between the ice (primary and secondary) and the solution flattens and becomes horizontal.

The trends identified in this study permit us to refine the views of the spatial orientation of the permafrost base in geological sections consisting of continuous permafrost in contact with cryopegs. Under these conditions, the same processes must manifest themselves as those in an experimentally studied system.

The permafrost structure in the Daldyn-Alakit region is an illustrative example. The permafrost structure has the following features: (1) nearly horizontal position (at depths of 90-700 m) of the permafrost base with a contrastingly inclined occurrence of water strata; (2) piezometric level of the subpermafrost aquifer running generally parallel to this base.

Thus the following new elements can be added to the existing views of the structural features of the permafrost in brine-bearing regions. The interaction between permafrost and subpermafrost cryopegs shows itself in the formation of a leveled-off subhorizontal plane of their contact. The process of plane formation went on under the action of phase non-equilibrium and in condition of the original isolation of the zones of fresh-water and highly mineralized brines. With such a subhorizontal plane between the phases, the desalinated layer is conserved, and this is responsible for the equilibrium existence of frozen ground and the underlying cryopegs with a hydrostatic head.

ACKNOWLEDGMENTS

The study was carried out with the financial support of the Russian Fund for Fundamental Research (project 96-15-98509).

VEGETATION ANALYSIS AND MOUNTAIN PERMAFROST MAPPING IN THE ITALIAN CENTRAL ALPS

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This paper shows the results of a first attempt to map mountain permafrost distribution on active rock glaciers through the survey of vegetation characteristics and of their distribution. The methods usually employed to map mountain permafrost, such as BTS (Bottom Temperature of Snow cover) measurements (Hoelzle, 1992) and geoelectrical investigations (Guglielmin, 1997), examine geological or geomorphological characteristics but not vegetation.

The study area is located in Northern Italy, in the Italian Central Alps, in the Upper Valtellina, on two opposing slopes of Monte Foscagno where active rock glaciers (in particular, La Foppa I and Foscagno rock glaciers) are present. The geological, geomorphological and botanical features were described and discussed by Cannone *et al.* (1995). The vegetation was analysed by phytosociological relevés. From these data we carried out the following: (1) calculated the ecological indices according to Landolt (1977); (2) performed cluster analysis; (3) elaborated a permafrost map from the analysis of the distribution of the phytosociological associations and of some indicator species.

Landolt indices relate each species to soil and climate characteristics, such as moisture, nutrient content, humus and reaction. From the comparison of the ecological features of each species observed in each relevés, it is possible to obtain the value of each Landolt index and to determine the ecological conditions of the study site; yet, these indices are not useful for permafrost mapping.

For the cluster analysis we performed Principal Component Analysis (PCA) and Correspondence Analysis (CA) (ter Braak, 1987). PCA gave good results, especially in showing patterns of evolution, related to different Holocene glacial history and to a different degree of activity inside the two rock glaciers. (Cannone *et al.*, 1997). On the other hand, CA was not very useful, especially for Foscagno rock glacier. Cluster analysis, even if gives good results for the ecological description of the study area, is not a good tool for permafrost mapping.

For permafrost mapping, vegetation features were used to detect the presence and distribution of climatic and ecological factors involved in permafrost formation and/or conservation and to detect the presence of elements which could indicate permafrost presence and action.

In particular, the elements detected through vegetation survey are linked to presence and length of snow cover, soil moisture (related to thawing of the active layer), presence of surficial stress or movement (due to permafrost creep, solifluction, gelifluction or other instability processes), and degree of evolution of colonisation processes toward climax. For this aim, vegetation analysis was focused on particular elements: (1) phytosociological associations; (2) indicator species of surficial stress or movement; (3) indicator species of snow patches; (4) ground mosses (strictly related to high values of soil moisture).

The type of phytosociological associations (Braun Blanquet, 1964) and their distribution inside the rock glacier allowed recognition of areas with different degrees of evolution, probably related to the different impact and intensity of the periglacial processes. The indicator species were selected from the observed species on the basis of their ecological features, in particular: from some chionophilus associations related to different length of snow cover (Giacomini and Pignatti, 1955); from the scree slopes associations, from which were detected the species able to survive to stress or surficial movement conditions thanks to their physical structure or form of life (Somson, 1983; Cannone, 1997).

From the distributions of the vegetation associations and each indicator category, we obtained four thematic maps; by comparing these maps, we detected the areas with different permafrost conditions.

A theoretical model was developed as follows: (1) areas with evolved associations (near climax), with many indicator species of snow patches and absence of indicators of surficial stress or movement, have a high probability of permafrost absence; (2) areas with pioneer association, low presence of indicators of surficial stress and of snow patch indicators and high percentage of ground mosses have a high probability of representing permafrost with a thin active layer; (3) areas with pioneer associations, high percentage of surficial stress indicator species, low presence of ground mosses and low presence of snow patch indicators have a high probability of representing permafrost with a thick active layer.

The permafrost maps obtained by vegetation survey for La Foppa I and for Foscagno rock glaciers were compared to the permafrost map of the area obtained by the integration of BTS measurements and geoelectrical soundings. Even though the measurement points of BTS and geoelectrical soundings were not the same of phytosociological relevés (because these analyses were not linked together) we obtained a very good correspondence of the two permafrost maps.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF A POLYMERIC COATING FOR THE SOIL SURFACE TO PROTECT AGAINST EROSION CAUSED BY WIND AND WATER

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Ground and soil can be stabilized against failure using a low concentration of an aqueous solution of polyvinyl alcohol. The principal advantages of polyvinyl alcohol are its unique physico-chemical affinity for water and ice, high (up to 140 MPa) breaking strength, complete physiological safety, and certain other specific properties. The polyvinyl alcohol is chemically and biologically inert and does not react with acids, alkalis, and petroleum products. It is tolerant to light and non-susceptible to repeated freezing-thawing, wetting-drying, and to the activity of micro-organisms.

Changes in the water properties in the presence of polymer molecules result in a peculiar formation and growth of ice crystals. During the first stages of the ice growth, the polymer enters into it as a solute. As the temperature decreases, while the water molecules from the solvate coating of the polymer are arranged into a crystal, cryogenic crystallization of the polyvinyl alcohol occurs. Its molecules elongate and form fibres both inside the crystals and between them. Thus, an extended lattice forms and reinforces the ice.

The space between the basal planes is the most likely place for the polymer molecule to enter into the ice crystal. The molecular forces of ice are weaker here, while the distances between the molecules are greater. The ice crystal develops predominantly in the direction parallel to the basal planes. As a result, aggregated individuals form. The polymer occurs between them. A study of the optical properties of the crystal under polarized light showed that each molecule cluster represents a unit crystal, while the polymer molecules enter into its intermolecular space.

We studied experimentally compressive strength, shear strength and adfreezing strength of composites that were obtained by addition of the polyvinyl alcohol. The short-term shear strength of ice increased on average from 0.5 MPa (without the polyvinyl alcohol) to 4 MPa (with the polyvinyl alcohol), i.e., by a factor of 8, during layer-by-layer freezing, and from 1.8 MPa to 5 MPa, i.e., by a factor of 2.8, during all-round freezing of the polyvinyl alcohol solution. The same results were obtained for frozen ground.

The experiments showed that a pronounced difference occurred during testing for long-term and short-term adfreezing strength. The addition of polyvinyl alcohol to the ground solution increased the short-term adfreezing strength of loam by 30 to 50% and the ultimate adfreezing strength by 560%.

The polymer retains its binding power in thawed ground. The composite material turns out to be "sewed" by fibres and films of the crystalline polymer. The polymer only swells rather than dissolves later on, giving elasticity and cohesion to the material.

Laboratory and field testing was undertaken to determine the optimal concentration of the polyvinyl alcohol solution for ground stabilization against erosion. For the laboratory investigations, we used dusty sand from the Yamal Peninsula. The original ground was readily eroded by jet flow at a rate of 0.8 cm/s, since it was structurally discontinuous and not cohesive. When the polyvinyl alcohol was added in small quantities, the ground susceptibility to erosion decreased exponentially to zero.

A solid crust forms on the treated ground surface as it dries. Under repeated wetting, this crust becomes elastic and does not disintegrate. Thus, the subsurface ground particles are bound together and this prevents erosion by water and wind. The temperature and moisture conditions of the subsurface soil layer treated with the polyvinyl alcohol solution are favorable for rooting and growth of plants, while the nutrients are not leached out. The anti-erosion coating is non-frost-susceptible.

It was found that the ground stabilized by addition of the polyvinyl alcohol is sufficiently tolerant to light and non-susceptible to repeated wetting-drying and freezing-thawing. The protective coating creates a "green-house" effect in the subsurface soil layer. Thanks to this effect the temperature of this layer increased by 3 to 4°C, while the moisture content increased by 5 to 12%. As a result, the growing period of plants was lengthened.

These methods for ground stabilization are patented (Cheverev, et al. 1993, 1996).

ACKNOWLEDGMENTS

The work was supported by the Russian Foundation for Basic Research (project no. 97-05-64961).

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THE INFLUENCE OF WIND ACTIVITY ON SNOW COVER DYNAMICS, GROUND TEMPERATURES AND ACTIVE LAYER THAW PROGRESSION IN NE GREENLAND

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Snow cover is recognised as a highly sensitive climatic and geomorphic element, having a profound impact on microclimate, the global atmospheric circulation and many geomorphological processes. Variations in the duration of the snow-covered season affect the surface albedo, which in turn influences the local energy balance. For this reason data documenting spatial and temporal snow cover variations are needed.

Satellite data show a decrease of about 10 % in the Northern Hemisphere mean annual snow cover extent during the past 21 years, and snow-radiation feedback has amplified spring-time warming over the mid- to high-latitude land areas. The relationship between snow cover and the action of wind is, however, not so well described. In Greenland, the primary control on snow accumulation at the Ice Sheet over the past 18,000 years seems to have been the atmospheric circulation rather than air temperature. It is therefore important to document the effect of even small-scale interannual variations in winter wind speed on snow cover duration and distribution in Greenland.

Continuous monitoring of several meteorological variables (e.g., wind speed, precipitation and air temperature, ground temperature) has taken place since August 1995 in the Zackenberg area (74°30'N, 20°30'W), NE Greenland. This monitoring forms a major part of the GeoBasis program of the Zackenberg Ecological Research Operations (ZERO) run by the Danish Polar Centre. The Zackenberg area is located in the High Arctic continuous permafrost zone.

Regular spatial and temporal physical probings of the active layer thaw progression in the 1996 and 1997 summers were carried out at two different CALM grids, ZEROCALM1 and ZEROCALM2. The first grid is located on a topographically exposed level marine abraded meltwater plain, while the second grid covers a southward oriented topographical lee site with a seasonal snowpatch. The extent of the snow cover was likewise registered at both CALM grids throughout the summers. At different topographical locations in the Zackenberg Valley ground surface temperature data were obtained using miniature dataloggers, which enabled a registration of the winter snow cover duration for the periods September to August 1995-1997. This combination of data on various physical conditions enabled an analysis of natural interannual meteorological variations between the 1995-1996 and the 1996-1997 seasons, and the effect on snow cover dynamics, active layer development and ground temperature.

A contemporary 74 % reduction in the total amount of snow precipitation was recorded, while no other meteorological parameters changed significantly in the period. The increased average wind speed combined with several strong and lasting late-winter storms in the 1996-1997 winter, when most of the winter snow had accumulated in the landscape, caused distinctive changes in the snow cover distribution. Generally, snowpatches in topographical lee sites increased significantly in the downwind direction. One seasonal snowpatch was registered to have widened by 20-40 m in the downwind direction in early summer, primarily because of the increased interannual late winter wind activity. It existed for 31 days longer into the summer of 1997 than in 1996. Continuous winter snow covers at topographically exposed areas were at the same time much reduced. Only at topographically exposed sites with a large upwind snowdrift source area did a continuous winter snow cover accumulate in the 1996-1997 winter. The transition areas, some distance downslope of the snowpatches, experienced the greatest increase in snow cover duration.

The redistribution of the winter snow cover also affected the temporal progression of active layer thaw. In this continuous permafrost area, the active layer starts to thaw only when the winter snow cover has disappeared, following positive daily air temperatures in summer. In the 1996 summer the active layer thaw progressions in both CALM grids were nearly contemporaneous, while during the 1997 summer it was markedly different, with thawing delayed compared to the previous summer. The documented snow cover duration changes caused a mid-summer interseasonal delay of about 18 days in thaw progression in the ZEROCALM2 grid, where the snowpatch was significantly increased, while the delay was only 7 days at the topographically exposed ZEROCALM1 grid.

Average annual ground temperatures dropped characteristically and had a larger variation at topographically exposed sites in 1996-1997, due to the reduced winter snow cover compared to the previous season. At the ground surface around 20-30 m a.s.l. in the Zackenberg Valley, the average annual ground surface temperature was reduced by up to 1.65°C, while at 400 m a.s.l. it decreased by 3.25°C in 1996-1997 in relation to 1995-1996. Presumably, the ground temperature correspondingly increased beneath topographical lee sites, where larger snowpatches existed.

INFLUENCE OF CLIMATE FLUCTUATIONS ON SOLIFLUCTION: AN EXPERIMENTAL STUDY

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Solifluction is one of the most important mass movement processes within the active layer in permafrost environments (Egginton and French, 1985). Given an incomplete understanding of the relationship between solifluction rates and climate, it is difficult to effectively predict future rate changes as a result of climate fluctuations. The objective of this experiment was to simulate climate change and to directly examine the effect on solifluction.

The experimental site is located in continuous permafrost in the valley of Hot Weather Creek on the Fosheim Peninsula, Ellesmere Island. Five electro-mechanical meters (Lewkowicz, 1992) anchored in permafrost and thermocouple cables were installed close together on a planar portion of an 8° colluvial slope in 1992-93. The meters and cables were multiplexed to a data logger which acquired ground temperature and soil movement data continuously from August 1993 until August 1997. The soil at the site consists of a sandy silt (clay < 8%) with a liquid limit of 29% and a plasticity index of 12%.

During the summer of 1996, one meter was warmed using polyethylene (B), one wetted by manual watering of the slope (D), one treated to a combination of these treatments (A), one cooled by shading (E) and the last left as a control (C). The climatic treatments were successful in manipulating active layer conditions in 1996, as maximum thaw depths ranged from 72 cm at meter A to 54 cm at meter E. The control meter (C) thawed to a depth of 64 cm.

The increase in thaw depth had an impact on movement throughout the soil profile. Between January 1, 1996 and January 1, 1997, the blocks at Meter A indicated the greatest amount of downslope movement (Figure 1). The maximum amount of movement recorded, 34 mm, was at a depth of 26 cm, while movement at the other meters ranged between 12 and 16 mm at the same depth. Very little movement was measured at 66 cm (1 to 7 mm) at meters B, C and D, whereas meter A indicated 22 mm.

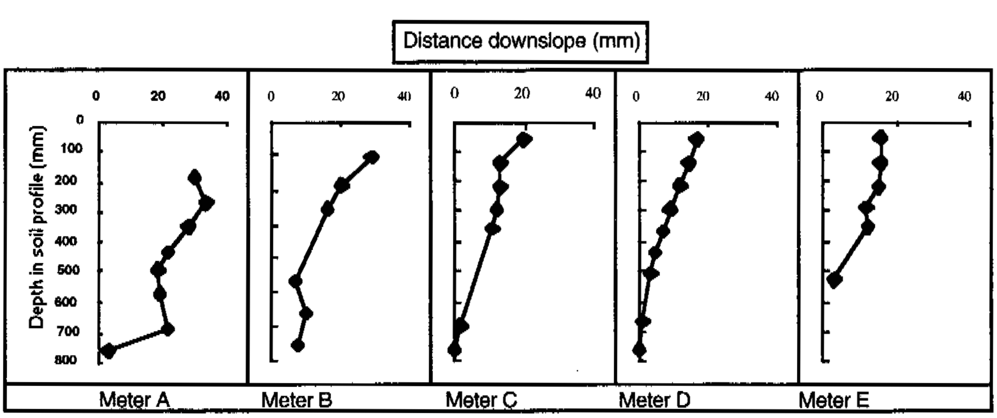

Figure 1. *Downslope movement (mm) recorded from January 1, 1996 to January 1, 1997*

Measurements of meter height above the ground surface suggest that much of meter A's movement may have occurred as a result of soil settlement, as the increased thaw depth allowed for the melting of an ice-rich zone. Between June 26 and August 9, soil surrounding meter A settled approximately 58 mm, whereas that surrounding meter E heaved approximately 10 mm.

The detailed nature of the data collected has highlighted the importance of considering both vertical and downslope movement throughout the soil profile when examining solifluction.

ACKNOWLEDGMENTS

The authors gratefully acknowledge support from the Natural Sciences and Engineering Research Council of Canada, the Polar Continental Shelf Project, Natural Resources Canada, the Northern Scientific Training Grant Program of Indian Affairs and Northern Development Canada, the Association of Canadian Universities for Northern Studies and the Royal Canadian Geographical Society. Financial assistance towards presentation of this poster by the senior author at the Seventh International Conference on Permafrost was provided by the Royal Canadian Geographical Society.

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FLUVIAL-THERMAL EROSION: LABORATORY SIMULATION

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Thermal erosion results from thawing of ground by heat exchange between water flow and frozen ground, followed by an immediate transport of unfrozen sediments. In Arctic regions, the strong flow of water during the spring and summer annually interacts with ground ice and other frozen obstacles. The large rising flood carries sediments and spreads them along terraces, especially at the river mouth. When thermal and mechanical erosion jointly operate, large collapses and rapid bank recession occur along Siberian rivers. Walker (1983) and Are (1983) have observed that the dynamics of these flows under cold climate induces the propagation of a thawing line in ground ice and rapid bank recession, with removal of sediments from 19 to 24 m a^{-1} (40 m a^{-1} in front of islands).

Ablation model

In order to specify the role and the relative efficiency of fluvial thermal erosion in Arctic regions, a mathematical thermal model was proposed (Aguirre-Puente *et al.*, 1994). This ablation model involves a constant heat flux in association with an immediate removal of thawed sediments. The model corresponds to a system undergoing a permanent thermal regime where the surface temperature is constant and equal to the phase change temperature (due to the immediate removal of thawed materials).

Laboratory simulation

To validate the model, laboratory simulation was used. An experimental hydraulic apparatus was set up in a 3.7 m x 3.5 m x 3 m high freezing room. The temperature could be maintained at regulated value ($\pm$ 0.5 K) both above or below the freezing point of water. The frozen sample (22 cm high and 20 cm in length), is in thermal contact with the water (velocity is constant) during the experiments and undergoes a strong thermal action. In order to monitor the ablation conditions, the ground ice sample is located in the upper level of a rectangular cross-sectional tube 2 m long by 20 cm across. The sample is fixed in the main axis of the hydraulic channel on a mounting support and can slide along a linear steel track. To maintain temperature conditions, the frozen sample is cooled from the top by an ethanol cooling coil. The propagation of the thaw front is monitored using 10 thermocouples installed vertically into the sample at specified positions. The loss rate of the frozen sample during the experiment is controlled by a laser beam connected to a data acquisition system. This laser system measures the thermal erosion and controls the vertical sliding of the frozen sample.

Results

In order to test the validity of the ablation model, about a hundred laboratory experiments were performed in which water temperature, ground ice temperature and ice content, as well as water velocity were systematically changed. Thermal erosion is linearly related to the water temperature as well as to the Reynolds number. The ice content has a major influence on the thermal erosion when the ice content is between 16% and 18%. These experiments showed that there is a hierarchy of parameters in term of efficiency of fluvial thermal erosion, in which water temperature seems to be the most important parameter and ground ice temperature the least significant. In general, these laboratory simulations demonstrated that the thermal erosion rate increases with the water and ground ice temperature, as well as with the Reynolds number.

ACKNOWLEDGMENTS

This work was carried out in association with the Centre de Géomorphologie in Caen where the laboratory simulations were undertaken. The research was supported financially by the "Programme National de Planétologie de l'Institut National des Sciences de l'Univers" (CNRS, France).

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STUDIES OF SOME RIVERS AND ASSOCIATED PERMAFROST IN NORTHERN BRITISH COLUMBIA AND YUKON

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This study involves aspects of flow and thaw regimes of rivers associated with permafrost in northern British Columbia, through the Yukon to the Arctic coast.

Results and interpretation

Within the sporadic permafrost zone of northern British Columbia, Smith (1975) measured a lag time of two days between the centroids of spring storm rainfall and resulting stream runoff. Northwards as permafrost becomes more extensive, the lag time became increasingly shorter, presumably as runoff is progressively confined to a shallowing active layer.

Although the basin areas vary in character, hydrographs for the Dezadeash River in southern Yukon, the Yukon River at Dawson in central Yukon and the Porcupine River in northern Yukon (Historical Stream flow Summary, 1980) show peak runoff becoming more intense northwards as it is confined to a shorter spring.

The hydrograph for the most northerly Porcupine River shows a secondary peak runoff in late summer. McDonald and Lewis (1973) have described similar late secondary peak runoffs for rivers on the Yukon coast plain.

Northern river flow is least, sometimes ceasing during winter when the river is frozen down to its bed. Some water can be injected from underground, free-flowing conduits that exist locally in the north. Underground water can be identified because it is poorer in oxygen and iron, and richer in salt compared with surface water (Scheier, 1978). Being warmer, this water will thaw river ice, locally overflowing between ice jams onto surrounding land as aufeis.

Rare catastrophic events will be superimposed upon these general trends. A Gumbel (1954) Analysis plot was made for the Dezadeash River, southern Yukon, using data from Historical Stream flow Summary (1980). The 1982 flood on the Dezadeash River was so great that only a gross estimate of the volume flowing could be made. The flood caused great damage to roads and bridges near Haines Junction.

Air off the Pacific looses its moisture on the windward side, and warms on the lee side adiabatically as it crosses the Saint Elias Range in the Kluane National Park, thawing snowfields. In 1982 this process was sufficiently excessive to create a catastrophic event.

Migration of a meander across the Indian River floodplain, central Yukon, has conducted summer warmth into the ground, thawing the permafrost (Crampton, 1987). Permafrost became re-established after about 100 years. Migration of a meander across the Eagle River floodplain, northern Yukon, has produced thawing and re-establishment of permafrost to create artesian pressure in the talik between the thawing and freezing interfaces (Crampton, 1979). Artesian pressure can also develop between such interfaces associated with pingos (Mackay, 1973).

Much more complex thawing and re-freezing states have been found under the constantly shifting bars and channels within braided river sections such as those of the lower Babbage and Peel Rivers in northern Yukon.

Summary

The lag time between centroids of heavy rainfall and subsequent river runoff decreases from northern British Columbia, through Yukon to the Arctic coast as permafrost increasingly concentrates runoff onto the land surface. A secondary peak runoff occurs in late summer on the Arctic coastal plain. Minimal river flow during winter can be augmented by injection of water from free-flowing conduits. Rare catastrophic flows are superimposed upon these flow regimes. Permafrost thawed by migration of a river meander across an area is replaced by new permafrost in the wake of meander migration. Artesian pressure can develop between thawing and freezing interfaces. Complex systems of freezing and thawing develop under braided rivers.

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THE MECHANICAL BEHAVIOR OF FROZEN MANCHESTER FINE SAND AT SMALL STRAINS UNDER HIGH-PRESSSURE TRIAXIAL TEST CONDITIONS

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Of all geo-materials, frozen soils are perhaps the most variable and difficult to understand and model due to the complex interactions between the soil skeleton and ice matrix which continuously change with temperature and stress level. This has prevented the development of constitutive relations to accurately describe the time and temperature dependent behavior of frozen soils. Thus, modeling capabilities for frozen soil lag far behind those for other geo-materials such as soil and ice.

In order to investigate the small-strain behavior of frozen sand, a fully automated high-pressure, low-temperature, triaxial system was developed. An extensive parametric study was conducted on a local material, Manchester Fine Sand (MFS), for wide ranges in relative density, confining pressure, strain rate, and temperature. These efforts led to an extensive database on the stress-strain behavior of MFS from very small to very large axial strains for both frozen and unfrozen states. Analysis of these unique data led to new hypotheses for explaining the physical mechanisms controlling the time and temperature dependent behavior of frozen sands.

The current combination of experimental and theoretical research is aimed at developing quantitative models for predicting the small-strain mechanical properties of ice-saturated natural frozen sand. Recent developments with on-specimen small strain measurement technology have allowed the reliable quantification of axial strains during monotonic loading to 10^{-6} on standard 3.5 cm diameter specimens with lubricated end conditions. On-specimen strain measurement is essential to the reliable determination of elastic properties and allows complete characterization of the stress-strain curve up to the upper yield stress, the point thought to reflect the onset of significant plastic deformations. In addition, strain rate control has been improved through the addition of a PID control algorithm. This has eliminated strain rate ramping caused by compliance in the loading system in the initial portion of the test. With these improvements it is now possible to investigate strain rate dependent trends in the small strain region.

These changes have lead to more consistent modulus values for MFS in triaxial compression. Variations of modulus with strain rate and temperature, as well as with confining pressure and relative density, have been investigated and are presented in comparison to previous results. These variables have been shown to have little to no effect on the elastic modulus. Application of a composite material model to the results is also presented. The model, which accounts for the different moduli and volume fractions of the particle and pore matrix, is generally quite good at predicting the initial stiffness based on the specimen's relative density.

In addition, the upper yield behavior of frozen MFS is thought to be dominated by the mechanisms controlling the behavior of bulk polycrystalline ice. Data are presented to illustrate that the trends in the behavior are similar to those in ice, but the presence of sand particles strengthens the overall matrix. Measurements also suggest that the frictional characteristics of the sand skeleton are not important in this region. Ongoing research attempts to further quantify the mechanisms of strength in frozen sand such that a complete description of the stress-strain behavior may be obtained.

GLOBAL CLIMATIC CHANGES, PERMAFROST AND GLACIATION OF THE ARCTIC REGION

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The relationship between transgressive-regressive phases of the Arctic Ocean and global climatic changes in the high and temperate latitudes of the Northern Hemisphere was revealed. Using the last Late Pleistocene cryogenic epoch (25-10 ka B.P.) as an example, we showed the interconnection between different aspects of the Earth's cryosphere: glaciers, permafrost, and sea ice cover. Periods of global climatic cooling correspond to major regressions of the Arctic Ocean and subaerial exposure of the continental shelf. The latter increases the isolation of the Arctic Ocean from the adjacent ocean basins, thus causing global cooling.

The last Late Pleistocene cryogenic epoch is one of the best known, as it yields abundant radiocarbon dates. Analysis of the published and our own recently obtained geological, paleogeographical, geocryological, and geochronological data suggests that the extent of the Arctic continental glaciation was rather limited, continental permafrost predominated, and marine glaciation was the second largest one. The article reviews the results of field investigations and computer calculations of permafrost temperature, thickness and extent.

The above data suggest that the combined influence of the following three factors can greatly reduce the average annual air temperature in Arctic: (1) considerable (and possibly complete) reduction of water-exchange with the adjacent oceans, (2) extension of continents and (3) growth of sea ice cover. For instance, the average annual air temperature in the northern areas of Western Siberia may have been 2-3 times lower than today, reaching -20°C in the regions where modern temperatures are -10°C, and -18°C where modern temperatures are -6°C. The average annual air temperature may have reached -25 to -30°C in the northern part of Middle and Eastern Siberia and adjacent shelf areas. In the central part of the Arctic basin, average temperatures were as low as -40 to -50°C, i.e., similar to modern temperatures of the interior of Antarctica. The increasing severity of climate was accompanied by growing continentality and aridity.

Calculations and palynological and cryolithological data suggest that during the last cryogenic epoch both the thickness of permafrost and its extent increased by two times. Approximate correlations between the distribution of permafrost, ice sheets, and sea ice cover may be reconstructed with the help of the method of analogs. Under present climatic conditions, the area of continental glaciation in the Northern Hemisphere is about $2x10^6$ km^2, the area of permafrost beyond the limits of glaciers is about $20x10^6$ km^2 (i.e., an order of magnitude higher), and the average area of multi-year sea ice cover is about $9x10^6$ km^2. Hence, the correlation between continental glaciation, marine ice cover, and permafrost is in the following ratio: 1:4.5:10. This ratio does not seem to have changed appreciably during regressions of the Arctic Ocean, global climatic coolings and sharp aridization. Cooling leads to a proportional increase of the extent of all kinds of glaciation. So, we can obtain the following characteristics for the last Late Pleistocene cryogenic epoch: the area occupied by permafrost on continents and shelves was about 40 $x10^6$ km^2, the area of sea ice cover was about 18 $x10^6$ km^2, and the area of continental glaciers was about $4x10^6$ km^2. Even if we assume (making concessions to the popular opinion) the latter value to be 2-3 times greater, the probable area of continental glaciers will equal $8\text{-}12x10^6$ km^2.

The above area estimates are in good accordance with paleocryogenic reconstructions, showing that during epochs of sharp climatic cooling and increasing aridization, glaciers appeared in northern areas having high precipitation, such as Scandinavia, islands of the western sector of Eurasian Arctic, the Polar Urals, the Putorana mountains in Middle Siberia, North-Eastern Siberia, Chukotka, Alaska. However, most continental regions of the Northern Hemisphere situated in the high and temperate latitudes together with exposed shelf areas were occupied by permafrost.

The above original concept suggests that cryogenic epochs were interrelated with regressive cycles of the Arctic Ocean which were caused by general neotectonic oscillating movements of continental margins rather than by accumulation of an extremely large Arctic ice sheet. Continental glaciers of the largest possible size appearing in the Northern Hemisphere during one of the most severe cryogenic epochs of the Pleistocene (at the very end of it) were unable to cause sea-level fall by more than 20 m. Hence, it was not continental glaciations, but tectonically induced regressions and increasing isolation of the Arctic Ocean with subsequent climatic deterioration in high and temperate latitudes of the Northern Hemisphere that caused these regressions within the Arctic shelf area. Increasing severity and aridization of the climate caused permafrost to grow in size and extent, and its temperature to fall.

CONCEPT FOR A SWISS PERMAFROST OBSERVATION NETWORK

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Efforts are presently being made to further develop a network for monitoring the long-term evolution of permafrost in the Swiss Alps. In such a temperate mountain region, glaciers and permafrost are close to melting conditions and, hence, become very sensitive to ongoing climate change. Moreover, because of increasing human activities, the reaction of the cryosphere to an atmospheric warming could generate stronger effects in the future than in the past. In order to document and to better understand the long-term behavior of the cryosphere in the Alps, the Glaciological Commission of the Swiss Academy of Sciences is reviewing its monitoring strategy. In addition to glacier parameters (fluctuation of the length and/or mass balance) recorded since 1880, permafrost parameters should also be monitored.

Alpine permafrost is characterized by a discontinuous distribution, mostly in bedrock or in block sediments, a deep active layer (1 to 5 m) and creeping processes (rock glaciers). The monitoring needs to be partially different relative to polar programs such as the International Tundra Experiment (ITEX) (Nelson *et al.*, 1996) and the Circumpolar Active Layer Monitoring (CALM) (e.g., IPA, 1997) developed for tundra regions. The foundations for a mountain permafrost monitoring network in the Swiss Alps were laid by Haeberli *et al.* (1993) at the Sixth International Conference on Permafrost in Beijing (China). A review of the concept is presented in this poster.

Researchers working on different topics of mountain permafrost have been interviewed to evaluate priorities of the network, potentially monitored variables and methods, financial requirements and data management. A workshop was held in March 1998 to discuss these issues and to jointly improve the concept.

Monitoring in Switzerland began more than ten years ago and in particular, has provided a better understanding of processes related to active rock glaciers. Further activities will consider sites with non-creeping permafrost and even with degrading permafrost. Monitoring will focus especially on the thermal state of the upper part of the ground and on the near-surface energy fluxes. Besides the temperature profile from the ground surface to the permafrost table, the most important parameters to be observed are the thickness, temperature and duration of the snow pack, as well as the air temperature.

Three alternatives for measurement are proposed, depending on cost:

(1) The "low cost" proposal consists of the annual observation of permafrost extent using both continuous and single measurements of the temperature at the base of the winter snow cover (BTS) (20 to 50 sites). The build-up of this "low-cost network" will start in summer 1998.

(2) In the "medium cost" proposal, the temperature profile from the ground surface to the permafrost table and the snow cover conditions are monitored (10 to 15 sites in non-creeping permafrost). Thus, shallow boreholes are to be drilled reaching depths of 5 to 10 m. The sites must be evaluated. The first drilling is planned for the summer of 1999.

(3) The "high cost" consists of deeper boreholes (more than 20 m) and energy balance stations (3 to 5 sites; e.g., existing boreholes at the Murtèl/Corvatsch and Schafberg/Pontresina rock glaciers).

At some sites, other types of permafrost modifications (deep long-term processes, mechanics, geometry, etc.) and associated phenomena (hydrology, snow patches, biology, slope instability, debris flow, etc.) are observed. Photogrammetric and geodesic surveys, as well as deformation measurements in boreholes, which offer important information on long-term permafrost creep processes, are performed at a few rock glaciers (5 to 8 sites).

The proposed network needs several years to be achieved. The concept represents a first step towards an official Swiss Permafrost Observation Network and will be adapted and refined regularly. It could serve as a prototype for other alpine regions. An international coordination between both scientists and mountaineering associations should also allow this concept to represent a first step towards a Mountain Permafrost Monitoring Network in the Alps.

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GROUND ICE AND FROST ACTION IN SURFICIAL MATERIALS, SLAVE GEOLOGICAL PROVINCE, NORTHWESTERN CANADIAN SHIELD

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Ground ice is prevalent in surface materials in areas of current mining activity and proposed infrastructure development in the western Canadian Arctic mainland. Surficial geology mapping and detailed site investigations have shown that some relationships can be drawn between regionally mappable material types and certain ground ice conditions. The amount and type of ground ice, and resultant behavioural characteristics of materials, depend on rock types underlying and outcropping in the area, and the nature of unconsolidated surface deposits. The cryo-geotechnical properties of glacial and postglacial deposits depend on the provenance of materials, depositional conditions, and postglacial climatic history.

While ice contents in rock are generally low, significant frost heaving of bedrock is pervasive in extensive areas of Archean schist and along linear belts of Proterozoic argillite, where rocks are weaker and fractures are more abundant than in other rock types. Scattered rock burst features, resulting from excessive water pressure during freeze-back, are present where igneous rocks lie at the surface.

Glacial till is the most prevalent surface material, and most till veneers and blankets have low ground ice contents. Large solifluction lobes have developed on till blankets, but thermokarst features are absent. Till derived from granitic and gneissic sources is less frost-susceptible than siltier till derived from pelitic metasediments and dolomite. Well-defined belts of hummocky till have distinctive surface relief characterized by small kettle lakes or depressions, rim-ridges, and shallow thaw flowslides, which can be attributed to massive ice, possibly remnant glacial ice. Although most eskers appear to be well-drained near the surface and have low ice contents, massive ice in excess of 5 m thick can occur in eskers, and is responsible for regional occurrences of thermokarst, slope movement and collapse features in some features. Broad-crested eskers in the south, near Jolly Lake, are silty and contain both ice crystals and segregated ice laminations; these materials make poor aggregate sources. Up to 10 m of massive ground ice, possibly of glacial origin, have been documented in one ice-contact outwash deposit; sediments of similar genesis in other places that exhibit kettle lakes and circular thaw lakes may have similar ground ice conditions. Outwash deltas and postglacial sandy raised marine deposits contain polygons that are in the order of 10 m diameter, with troughs about 0.5 m deep. Active ice wedges underlie the troughs, although ice contents are low in polygon centres. Larger polygons, up to 100 m diameter with troughs 2 m deep, appear to be relict features, although small active ice wedges are inset within them. Silty marine deposits inland from Coronation Gulf form surface deposits or underlie thin, sandy, marine sediments. They range from the coast up to an elevation of 170 m near Coppermine (Kugluktuk) in the west, to 210 m at Tree River in the east. These sediments are saline, and contain segregated ice in the upper few metres of permafrost. Retrogressive thaw slumps are common features along river banks and active layer detachment slides occur on moderate slopes where coarse littoral sand overlies frozen silty clay marine sediments having a wide range of ice contents. Slope stability problems are due to excessive ice.

Particular ground ice conditions give rise to distinctive surface features such as ice-wedge polygons, solifluction lobes, retrogressive thaw slumps, thermokarst, and active layer detachments. Many features can be regionally mapped using air photographs, while others are too small, and require detailed ground observations. An understanding of glacial history, maps of surface materials, together with observations on small-scale surface features serve as a preliminary guide in assessing potential for ground ice and active periglacial processes prior to detailed geotechnical investigations wherever mining activities or infrastructure development are planned.

MATHEMATICAL MODELING OF THERMOMECHANICAL BEHAVIOUR OF BUILDING-GROUND SYSTEM IN CRYOLITHOZONE

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A mathematical model for predicting stress-strain relationships and temperature field exchange during the interaction of buildings and permafrost is presented. The influence of the thermophysical processes parameters on the stress-strain state evolution is related to the ice content and type, the ground temperature and salinity. Heat transfer is described by an equation of heat conductivity with pore water freezing over a range of temperatures and conjugated heat boundary conditions. We considered rods, plates, shells and massive elements as building components. The ground is described by the theory of visco-plasticity with micro-deformations and micro-fractures. Quantitative forecasting of the physical parameters is achieved using a finite element method to solve the model equations. Examples of thermomechanical behaviour prediction using the model are presented. We have calculated the deformation of a real 9-floor building on piles given uneven thawing of frozen soil at its base (Figure 1). The model can also be applied to thawing around excavations in frozen soil. We have added a mathematical model of the soil thermomechanical behaviour by a tensor of the porous moisture phase transition volumetric deformation introduction in coordination with the direction of a normal to the phase transition front.

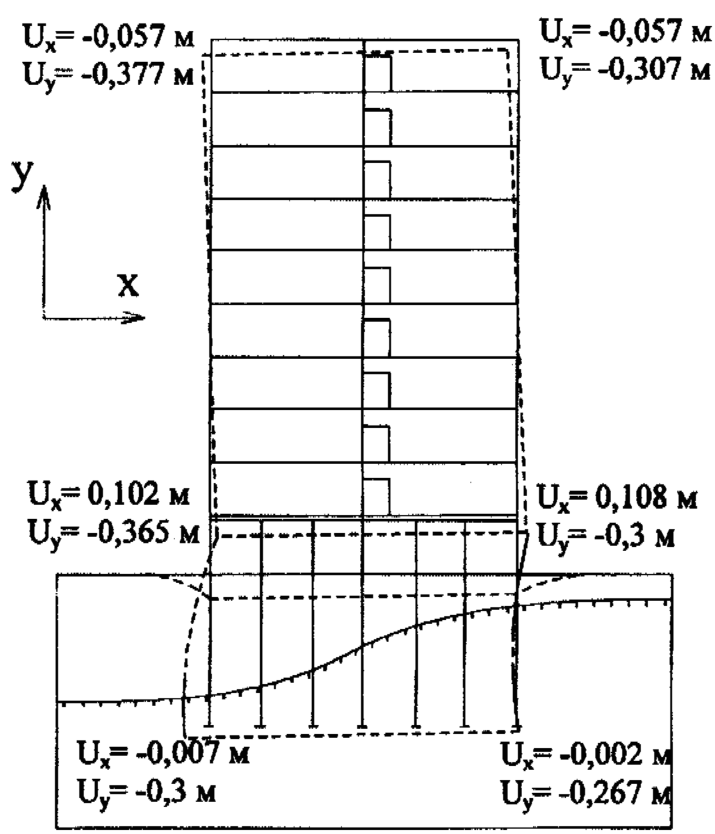

Figure 1. Uneven thawing effect on system ìbuilding-groundî. Solid line shows initial state. Dashed line shows final position. T-shaped line shows thaw front.

PHASE COMPOSITION AND THERMAL PROPERTIES OF FROZEN SALINE SOILS OVER A WIDE RANGE OF NEGATIVE TEMPERATURES

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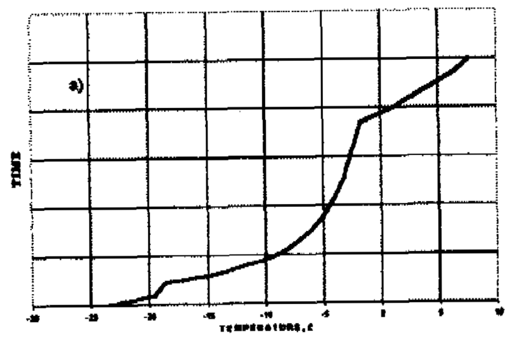
In spite of intense interest in thermal properties, moisture phase composition, and freezing temperature of saline ground in the last few years, the available data refer, mainly, to the sodium chloride type of salinization. New or improved methods are needed to study frozen saline ground. We developed a procedure for determining the thermal capacity and the enthalpy down to a temperature of -125°C using a dynamic calorimeter IT-S-400 and a differential scanning calorimeter "Mettler TA2000B". We proposed a combined procedure using the cryoscopic and the contact methods to study the freezing and thawing temperatures and the phase composition of moisture in fine-grained soils. This procedure allows the leveling of an unequal error of the determination using these two methods in various temperature intervals. An estimate of the extent of application of methods of heating up and heating (cooling) at a constant rate to determine the thermal properties, shows that in the temperature interval below the freezing temperature but above the eutectic one, for a salt solution that dominates in soil, the experimental data can be processed with an error not higher than that for non-saline soils.

The dependence of unfrozen water content, freezing-thawing temperature, and thermal properties on the composition of frozen saline fine-grained soils was studied. A decrease in freezing temperature and in heat conductivity and an increase in unfrozen water content is observed from sand to loamy sand to loam to clay, from kaolinite to hydromica to montmorillonite; from sulfates to carbonates to nitrates to chlorides, when the samples are affected by salt solutions with the same cation Na^+ ; and from sodium to potassium, when the samples are affected by salt solutions with the same anion Cl^-.

The thermal conductivity and the thermal diffusivity of frozen moisture-saturated saline soils are higher than those of thawed ones, when their samples are affected by Na_2SO_4 and Na_2CO_3. When the soil samples are affected by $NaNO_3$ and NaCl of particular concentrations, the heat-conducting parameters of thawed soils are close to those of frozen soils, or even somewhat higher. The unfrozen water content in soils of various composition increases with pore solution concentration up to temperatures that correspond to eutectic ones. Two temperature depressions were observed in thermograms for thawing. The first depression is associated with thawing of free moisture, while the second one is observed in the range of temperatures close to the eutectic temperatures of aqueous solutions of these salts (Figure 1a). There are two heat release peaks in the curves for temperature versus heat capacity (Figure 1b). The first peak is determined by freezing of free water. The second peak is observed for a number of saline soils (sand, loam, kaolinite clay) in the range of eutectic temperatures, corresponding to free salt solution. A clearly defined hysteresis of both heat release peaks during cycles of cooling and warming is observed. A heat effect was observed in the cycle of thawing at -10°C to -12°C, when the ground samples of a particular salinity and moisture content were affected by KCl, and in the cycle of thawing at -21°C to -23°C and in the cycle of cooling at -29°C to -39°C, when the samples were affected by NaCl. The rate of the temperature change was of 0.1 - 2°C/min. A combined study of the temperature dependencies of moisture phase composition, thermograms for thawing, and enthalpies of saline frozen soils supports our hypothesis for the presence of a process, which we associate with formation and disintegration of NaCl cryohydrate, in the range of eutectic temperatures (Figure 1). This effect and this hypothesis was first discussed in our paper in 1988.

D.M. Anderson and A.R. Tice (1971) reported the presence of the second heat release peak at 35-65°C for kaoline and halloysite and three peaks for Li, Ca, and Na forms of montmorillonite.



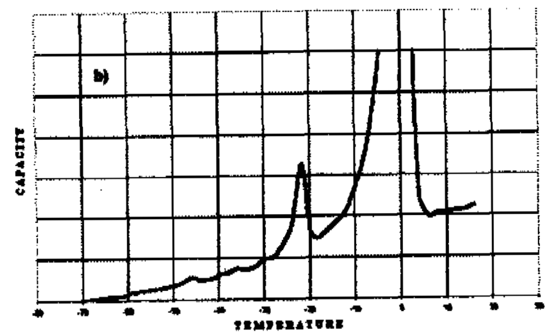


Figure 1 Representative thermogram for thawing (a) and temperature behavior of heat capacity (b) in a sample of kaoline affected by NaCL solution.

ASPECTS OF ROCK GLACIER AND MOUNTAIN PERMAFROST HYDROLOGY: CASE STUDIES IN THE VALAIS ALPS, SWITZERLAND.

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Active rock glaciers are the most famous diagnostic features of mountain permafrost. Rock glacier hydrology, however, is an almost untouched field of scientific investigation and the influence of alpine permafrost on the hydrological system has received little attention. There are few studies on this topic and most of the hypotheses proposed by researchers are based on theoretical concepts.

The purpose of the present poster is to illustrate some characteristics of rock glacier and mountain permafrost hydrology from data obtained at two sites in the Swiss Alps. The aim of the study was to quantify the hydrological characteristics of mountain permafrost and, in particular, the hydrogeological functions of rock glaciers and the existence of aquifers within these forms.

Springs and streams originating from the permafrost of active and inactive rock glaciers were studied in the areas of Réchy and Fontanesses, Valais Alps, Switzerland. Measurements of discharge, water temperature, conductivity and dissolved load were carried out in these two alpine periglacial catchment areas for several months between 1994 and 1997. Climatic data such as air temperature and precipitation from climatic stations represent an additional set of information for hydrological measurements.

Geophysical measurements (Bottom Temperature of the winter Snow cover measurements and DC resistivity soundings) show the presence of discontinuous permafrost above about 2650 m a.s.l. in Réchy and about 2700 m a.s.l. in Fontanesses. DC resistivity soundings permit a rough modeling of the structure of the Becs de Bosson (Réchy) and Cassorte (Fontanesses) rock glaciers (active layer, permafrost, unfrozen sediment or bedrock) and show the presence of ice-cemented permafrost with specific resistivity values ranging from 30 to 1,500 kohmm and a thickness between 15 and 50 m. These resistivity values indicate a periglacial origin of the ice, i.e. congelation ice commonly encountered in alpine permafrost.

Runoff regimes of streams emanating from the investigated rock glaciers are of the nival type with characteristic minimal discharge during the winter season. During this time, the snowmelt stops and the water retained in snow patches and in the active layer at the end of the autumn is frozen and cannot flow. The winter water that flows in the streams can only be attributed to a deeper (subpermafrost) groundwater aquifer. Higher discharges occur at the beginning of the snowmelt season. A diurnal periodicity in the streamflow and conductivity pattern is observed for these streams during summer. This shows that the rock glacier's hydrological system is more responsive to short-term variation of meteorological conditions than sometimes suggested in the literature.

Water emanating from the rock glaciers of Réchy and Fontanesses present a combination of dilute, surface or near-surface snowmelt water flowing in the active layer and a solute-rich water component flowing more slowly through the subpermafrost aquifer. The discontinuous distribution of permafrost in these two catchment areas permits the infiltration of the water into the ground. Hydrological processes are therefore not confined to the surface and the active layer but are also involving groundwater flow in the subpermafrost zone. This differs from colder high-latitude or high-altitude periglacial zones (e.g., Tibet) with a less rugged topography, where permafrost is continuous and where hydrological processes are predominantly active above the permafrost table.

The data from Réchy and Fontanesses allow for a better understanding of rock glacier hydrology. The results obtained so far still have a preliminary character and do not permit a generalization at larger scales.

There remains a lack of data concerning the position and geometry of possible taliks linking supra- and subpermafrost water and about the presence of a deep-seated aquifer. Rock glaciers represent a complex hydrological system with a combination of intricate pathways for water flow, the details of which remain unclear. Information on various topics concerning the subsystems (cliffs and talus, surface, subsurface and groundwater) is still missing and thus several questions remain unanswered. The uncertainties are mainly due to the scarcity of available geological information (geometry, structure, grain size distribution, etc.) about the studied rock glaciers and about rock glaciers in general. Most of the information is based on indirect prospecting methods, such as geophysical soundings, and only in a few cases on direct evidence from borehole investigations. Further research on the processes and phenomena involved must be carried out, including and combining geological, geophysical and hydrogeological approaches. Local case studies such as those performed in the Valais Alps, will improve general knowledge in this field.

GLOBAL CLIMATE WARMING AND FUTURE TEMPERATURES IN NORTH AMERICA

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Scholars from many countries are engaged in developing scenarios, models and defining concrete characteristics of the future climate. Recent data were summarized in the joint Soviet-American report on climate and its changes (*Predicted Climate Change, 1991 - in Russian*). On the basis of the predicted climate change, the author presents a scenario of future air temperatures by the mid 21st century assuming global climate warming of 2°C and 4°C. This has been done earlier for the northern Eurasia, whereas here it is applied to North America (15 maps).

Absolute values have been calculated by the equation « present temperature + warming » for the series of territory squares. The present data have been taken from monthly maps published in « World Agroclimatic Atlas » (*1972 - in Russian*), yearly data - from the authorís map (*Gavrilova, 1993, pp. 99-111*). The warming values have been adopted from the charts of the above-noted 1991 report.

At present, i.e., in the mid century, North America has air temperatures in the coldest month that range from -38°C in the northern part of the Canadian Arctic Archipelago to 22°C at the Gulf of Mexico coast; in the warmest month, the range is from 2°C on the northern islands to 28°C on the Gulf. Annual temperatures vary from -20°C at 82°N to 26°C at 20°N.

At 2°C global climate warming, winter and summer temperatures will increase by 4-5°C in Alaska and northern Canada, but they will fall in the south. Hence, average annual temperatures will change in a similar pattern. Thus, there will be -28°C in the Arctic to 21.5°C on the Mexican Gulf coast in the coldest month and 7°C in the north to 22-28°C in the south in the warmest month. Average annual temperatures will be -15.5°C in the Canadian Arctic Archipelago and 22-24°C along the southern coast.

At the predicted 4°C global climate warming, winter temperatures will rise by 8-18°C, summer temperatures by 4-6°C, and average annual temperature by 6°C in the southern part of the North and by 12°C in the Arctic North. As a result, temperatures will be -20°C on the northern islands to 25°C on the Mexican Gulf coast in the coldest month and -12°C on the islands to 25°C in the south. Annual temperatures will vary from -8°C in the Arctic to 24°C in northern Mexico. Summarizing, the results are as follows. The annual zero isotherm bordering the distribution area of the perennially frozen ground now passes along the Pacific coast approximately from 58-62°N, descends to 56°N in the mountains and then follows the latitude slightly north of 50°N in the plains. At 2°C global climate warming, it will move northward by 2-4°N. The maximum shift (5-6°) will occur on the southwestern coast of Alaska (Figure 1). At 4°C global climate warming, in North America the annual zero isotherm will shift from its current position by approximately 16° northward, i.e., it will follow the latitude of 68-70°N. Average annual air temperatures in Alaska will be positive and sub-zero annual temperatures will remain only in the Canadian Arctic Archipelago (Figure 2).

The expected climate warming will have consequences over environment factors such as vegetation, hydrologic regime and permafrost stability.

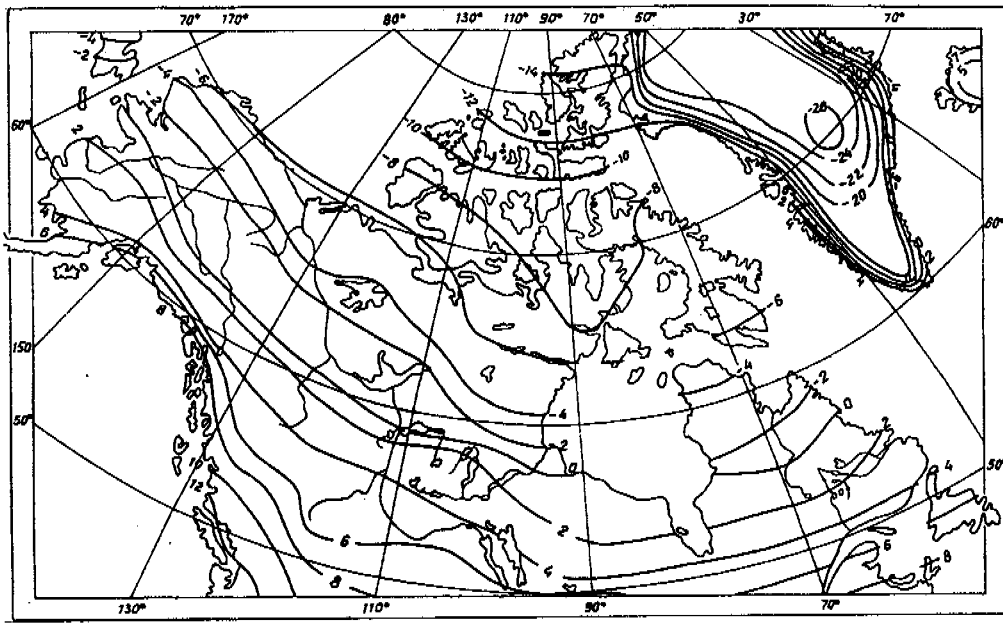

Figure 1. Annual air temperatures (°C) in the northern part of North America in the mid 21st century under a scenario of global climate warming by 2 °C.

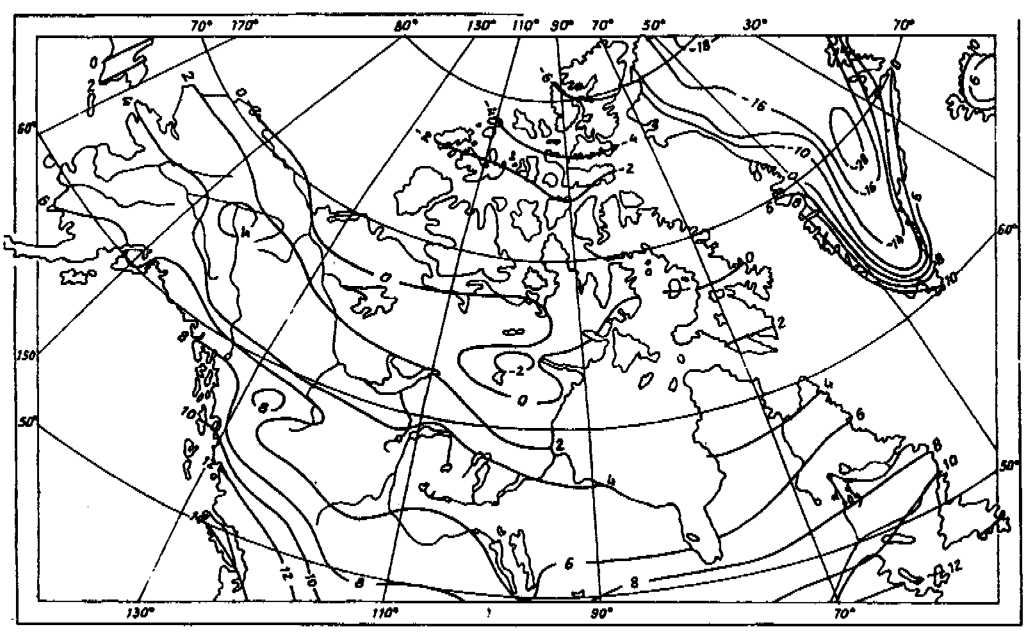

Figure 2. Annual air temperatures (°C) in the northern part of North America in the mid 21st century under a scenario of global climate warming by 4 °C.

CIRCUMPOLAR ARCTIC VEGETATION MAP: AN OVERVIEW AND PROTOTYPE MAPS FOR THE NORTH AMERICAN ARCTIC

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A new vegetation map of the Arctic is needed for a wide variety of purposes related to anticipated global changes, land-use planning, and education. It will provide for generalization and extrapolation of results of numerous ongoing international arctic research programs. The circumpolar arctic vegetation map (CAVM) will provide a variety of mapped vegetation and terrain information for the region based on our most recent scientific understanding. A plan for making the map involves coordination of mapping teams in North America, Europe, and Russia. Synthesis activities for the North American portion of the CAVM will take place primarily at the EROS Alaska Field Office, Anchorage, AK.

Final products of the project will include: (1) an enhanced false-color infrared image (CIR) derived from a mosaic of cloud-free Advanced Very High Resolution (AVHRR) images, (2) a relative-greenness image derived from a time series mosaic of maximum-NDVI pixels from the AVHRR image, (3) a topography and hydrology map derived from the digital chart of the world (DCW) information, and (4) a circumpolar arctic vegetation map derived from image interpretation of the AVHRR CIR image in conjunction with a wide variety of ancillary map data. The vegetation map will include a geobotanical database that will synthesize available information into a single map with a common legend. All map products will be at a scale of 1:7,500,000.

Progress to date includes the production of: (1) a CIR image of the circumpolar region, (2) a map of maximum-NDVI during the summer, (3) a prototype integrated vegetation map of northern Alaska, (4) a boundary-area map for the Canadian Arctic, defining the study area for Canada, with the northern limit of trees defining the southern boundary, and 5) prototype maps of selected portions of Alaska, the Canadian Arctic, and Geenland. We also indicate locations of major study sites and ancillary map data on which the integrated components of the vegetation map and geobotanical database for North America will be based. It is hoped that this ancillary data will encompass our most recent understanding of large-scale patterns in vegetation, satellite imagery, surficial and bedrock geology and soil geochemistry, topography, and hydrology of the region.

PREDICTING THE STRENGTH OF FROZEN COAL-BEARING ROCK IN THE SOUTH-YAKUTIAN COAL FIELD BY BOREHOLE LOGGING

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The South-Yakutian coal-field is the main base of coking coal in eastern Russia. The area of the coal field within the borders of development of Mesozoic coal-bearing deposits is 26,000 km^2. Discontinuous permafrost varies from a few metres to 200 m in thickness.

There is a 30% increase in the strength and elasticity indexes of frozen rock compared to thawed rock. Natural gamma-intensity I_y does not undergo significant changes in the process of epigenetic transformation of rock and cryogenic processes, while the rest of above mentioned parameters change (Table 1). Consequently, gamma-ray logging (GL) within boreholes allows argillaceousness and lithologic composition to be evaluated, and these have a dominant effect on rock strength.

Table 1 Average values of physical and mechanical properties of the frozen rock in the South-Yakutian coal field (Elga coal deposit).

Phys.-mech. Properties	Coarse grained sandstone		Medium grained sandstone		Fine drained sandstone		Aleurolits		Coal A^d = 15% absolute	
	thawed	perma-frosted	thawed	perma-frosted	thawed	perma-frosted	thawed	perma-frosted	thawed	perma-frosted
V_p, m/s	4100	5000	4570	5200	4700	5600	2850	4500	2200	3500
ρ, Ωm	750	4950	450	2930	275	1520	150	1200	7500	9000
I_γ, pA/kg	0.5	0.5	0.72	0.72	0.86	0.86	1.08	1.08	0.36	0.36
$\chi \times 10^{-5}$ unit CI	8	8	12	12	18	18	38	38	3	3
δv, g/sm^3	2.45	2.45	2.58	2.58	2.63	2.62	2.61	2.61	1.37	1.37
σ_{cm}, mPa	57	79	65	87	72	91.3	50	72	-	-
σ_t, mPa	6.3	9.2	7.8	11.0	10.3	12.1	6.7	9.9	-	-

Note: thawed -t > 0° C, frozen 0° > t < -4° C, elastic wave propagation velocity, ρ - electrical resistance, I_γ - natural radioactivity, χ - magnetic susceptibility, δ_v - volume density, σ_{cm}, σ_t - compression and tensile strength limits.

The structure and texture characteristic properties of the section are evaluated using borehole gauging. Borehole diameter variation during the drilling process may be regarded as an integral characteristic of rock strength. Therefore, variation of natural radioactivity of rocks and borehole diameter depend on rock strength, and utilizing multimeasuring correlations between geophysic parameters I_y, d_v and strength properties of rock δ_{cm} and δ_t, it is possible to forecast the strength properties of coal-bearing rock within permafrost by logging.

For the Elga coal deposit the following equations for evaluating evaluation δ_{cm} and δ_t apply:

$$\delta_{cm} = 0.4605 \times 10^{4.1 - \frac{d_y - 0.5\Delta H^{0.63}}{d_r}} + 0.4605 \times 10^{-2.3\Delta I_y + 3.1} \qquad (1)$$

$$\delta_t = 0.5 \times 10^{3.1 - \frac{d_v - 0.5\Delta H^{-0.63}}{d_r}} + 0.5 \times 10^{-2.3\Delta Iy + 2.1} \qquad (2)$$

where: ΔH is the difference between borehole depth and depth of virtual measurement being conducted;

ΔI_y is the normalized value of natural radioactivity, in relative units;

d_r and d_v are the rated and virtual borehole diameters.

The reliability of the evaluation of strength by logging was checked by comparison with the results of laboratory core testing. The percentage root-mean-square errors of strength property evaluation are: δ_{cm}- δ = 13% and δ_t- δ = 11%.

PERMAFROST THERMAL MONITORING AT TERRA NOVA BAY AREA (ANTARCTICA)

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During the XII Italian Antarctic expedition of 1996 (PNRA - National Program of Antarctic Research) an automatic station for monitoring ground thermal regime was installed at Boulder Clay Glacier, (74°44'45"S, 164°01'17"E), 205 m a.s.l., near the Italian Antarctic Station of Terra Nova Bay. The data logger (MTX1440) records air temperature, global radiation and ground temperatures.

Surface temperatures recorded during 1996-97 season ranged from 10.7 to -35.3°C, with a mean annual value of -16.7°C. The air temperature ranged from 5.4 to -38°C and the global radiation from 0 (during the winter season) to 36.932 MJ/m^2.

From a geophysical point of view, the site has been characterized using vertical electric soundings, which indicate the presence of a thin layer of frozen glacial drift (whose thickness ranges from 0.5 to 2 m) overlying massive ground ice with a not very high resistivity value (ranging from 0.9 to 1.8 MΩm).

Ground temperatures were recorded at 6 different depths: 2 and 30 cm in frozen till, 60 cm near the upper boundary of a massive ground ice layer, and 160, 260 and 360 cm in massive ground ice. A very good correlation (r^2= 0.934) between air temperature (Ta) and surface temperature (T_s) was found. In fact, considering all 366 data points, the resulting linear regression is:

$$T_s = 0.958 + 1.11 \text{ Ta} \tag{1}$$

The surface temperature regime of this area seems to be strongly controlled by the air temperature, even though the variations of the snow cover could explain some great variations of the surface temperature occurring especially during winter.

The thermal regime of the site is shown in Figure 1: the daily maximum values of temperature at 30 cm of depth are always below 0°C and the thickness of active layer is 18 cm. The "zero curtain effect" is apparently negligible: in fact, freeze-thaw cycles are limited in the upper 18 cm; moreover, an appreciable period with temperatures near the 0°C does not exist in the surface temperatures regime. A possible explanation is the very low ice content in the thermal active layer, caused by wind-induced sublimation of ground ice in the top soil. From these data, we also calculated the depth of Zero Annual Amplitude (ZAA) and the permafrost thickness as approximately 11 m and 1002 m, respectively.

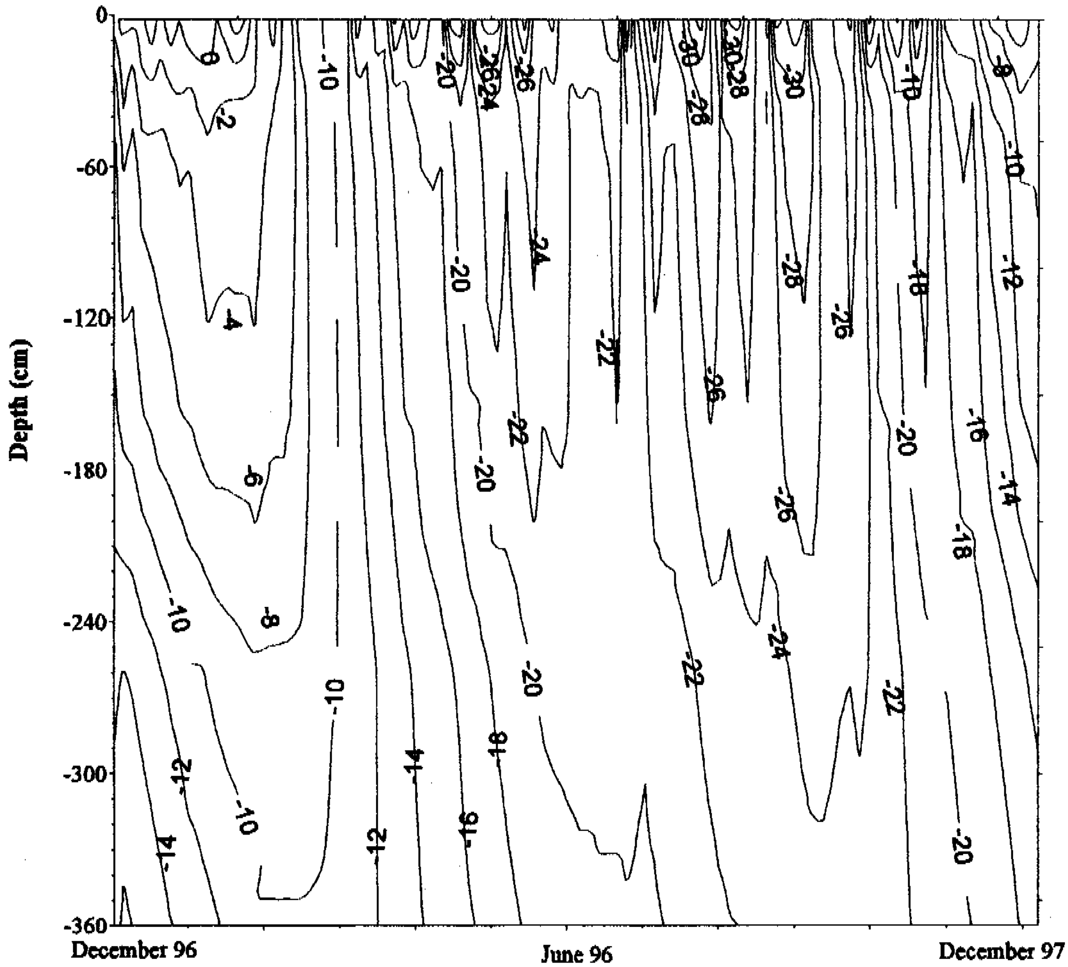

Figure 1. Thermal regime at Boulder Clay Glacier in 1996-1997 season.

NIVATION OR CRYOPLANATION: IS THERE ANY DIFFERENCE?

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'Nivation' and 'cryoplanation' are terms indicative of two distinct process-landform associations. In some discussions there is a time-process continuum between the two defining terms but the threshold of transition and the resulting process-landform difference is not clear. For example, many discussions on 'cryoplanation' resort to the role of 'nivation' in the early stages but the actual threshold of transition and the character of process and landform change at this transition are not explained. Some authors suggest the difference appears to be no more than size or maturity. The absence of objective, quantified thresholds with respect to size or maturity prohibit these attributes from distinguishing between features and, at a fundamental level, how can size or maturity be used to justify two distinct terms even if such thresholds could be established? Further, where palaeo-reconstructions are undertaken, is it possible to distinguish between the fossil forms of a 'cryoplanation terrace' and a 'transverse nivation hollow'? Despite this duality of terms, both groups utilize the same basic processes and the resultant landforms may be very similar, if not identical.

Comparison of the literature on nivation and cryoplanation serves only to confuse rather than enlighten. Nivation is clearly described in its literature as exploiting *pre-existing* hollows to produce the nivation hollow or bench. Cryoplanation in its literature is seen as an initiator, the end result of which is the cryoplanation bench. Thus it would *not* be possible for nivation to initiate cryoplanation on an otherwise undifferentiated slope as is suggested in the cryoplanation literature. Further, nivation requires snow, usually in some quantity, which must suffer melt, whilst cryoplanation is said to characterize arid or semi-arid regions. A number of authors associate permafrost with cryoplanation whilst this has never been the case with nivation and so the transition between the two process-landform suites may be problematic. Lastly, as both concepts utilize the same basic suite of processes so the question arises as to what is, then, sufficiently different to justify the respective terms?

With regard to processes, both concepts (nivation and cryoplanation) identify frost weathering as the dominant, if not sole, cause of rock breakdown; some authors even identify the resultant landforms as indicative of a "frost-shattering zone". Conceptually, the questions arise as to why fost weathering, is there any proof for this and, what is the implication if it is *not* frost weathering? To compound the problem, there is no way to determine whether bedrock fragments are the product of frost weathering and recent studies in cold, arid environments suggest that thermal stress may be the dominant weathering process. Failing unequivocal identification of frost weathering, then both concepts lack a working operational definition.

The proposition is made that the two terms and their respective concepts are obsolete. Rather, 'nivation' and 'cryoplanation' are the two end members of the same process-landform continuum. With the transition from nival to arid conditions, so there is a decrease in the action of water and, likely, an increase in the *potential* for permafrost (due to the diminished insulation from snow cover). The "core" processes remain the same as, in essence, does the landform: the 'transverse nivation hollow' - 'the cryoplanation terrace'. Whilst mechanical weathering may predominate, there is no necessity for it to be frost weathering. The continued use of two terms, particularly if associated with climatic, size or age considerations, only serves to confuse. Rather, we have a single process suite that has end members that are 'wet' and 'dry' and, probably at distinctly different rates, produce similar landforms. It is here suggested that all such features could be called "periglacial mountain benches", this having no process connotation beyond the association with a 'periglacial' environment and no form linkage other than it is a 'bench' in the 'mountains' (resulting from unspecified periglacial processes - i.e. it is not a glacial bench).

Key words: Nivation Cryoplanation Weathering Periglacial mountain benches

SOME OBSERVATIONS AND THOUGHTS REGARDING ANTARCTIC CRYOGENIC WEATHERING

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Studies that either directly or indirectly deal with weathering in cold regions generally assume mechanical processes dominate, that the prime process is freeze-thaw and that the resultant products are angular. Recent observations regarding weathering in the Antarctic question these assumptions and the application of rock fracture mechanics indicates that curvilinear, rather than sharply angular, fracture patterns need not be unusual. Rock temperature data collected at one-minute intervals indicate that thermal stress/shock can play a major role in rock breakdown and the steep temperature gradients in the outer few centimetres of the rock would be conducive to spalling. The aridity of the present study area (Alexander Island, Antarctica) argues against freeze-thaw weathering except in very site-specific locations easily identified by visible water. Detailed rock temperature data, including for a significant part of two winters, clearly show an absence of snow (and hence moisture), the occurrence of $\Delta T/t$ values that exceed the threshold for thermal shock, a marked, but varying, aspect influence and steep thermal gradients with significant subsurface fluctuations (Hall, 1997 a & b, 1998).

Classic Griffith fracture theory expresses that a certain combination of excess pressure and crack length (or diameter) is required to keep a crack open or to increase its dimensions. Linear elastic fracture mechanics (LEFM) show very clearly that cracks may curve during propagation in response to a changing stress field; microfissures in the rock can also greatly influence crack direction. In fact, curvilinear (mixed-mode) crack propagation is common in rock mechanics as a crack will propagate in the direction the tensile stress in the crack tip vicinity is maximum. However, LEFM approaches assume that stress-intensity is decreasing with increasing crack length and that cracks may influence each other's stability and trajectory. In essence, there is no reason why curvilinear cracks may not occur as a result of stresses induced by mechanical and/or chemical weathering (particularly as in stress corrosion crack tip propagation). Non-cubic rock forming minerals show thermal expansion anisotropy. When the total linear thermal expansion of a mass becomes equal to the critical crack opening displacement, $\Delta_t=\Delta_c$ (where Δ_t is linear thermal expansion and Δ_c is critical crack opening displacement), the centre of the mass originally subjected to a compressive stress will now be subjected to uniform tension. When those initial stresses are very high so the shape will be selected to minimize stress concentrations. As cyclic variation in temperature induces alternating tensile and compressive stresses, particularly along the boundaries of inhomogeneities, there is no reason why the resultant fractures should not be curvilinear. That being so, why should the assumption be that mechanical weathering will only produce angular forms?

Evidence from the weathering of sandstones on Alexander Island (Antarctica) clearly demonstrates the production of rounded forms and debris as a result of mechanical processes, mainly thought to be thermal stress fatigue. This concept of thermal stress fatigue being the cause of breakdown fits well with the available temperature data plus LEFM theory (e.g., Rossmanith, 1983) and results from artificial weathering studies that investigated physically-induced stress-fatigue microcracking (Blaga and Yamasaki, 1973). Further, despite the frequent association of mechanical weathering processes with taffoni development, it seems never to have been questioned that taffoni are rounded forms. Data collected from the same area on taffoni size and Schmidt hammer rebound values for different aspects show that there is an aspect influence on weathering. It is concluded that, in this area of Antarctica, mechanical processes other than freeze-thaw dominate, that forms other than angular can be produced, and that taffoni development shows a distinct aspect influence.

Key Words: Weathering Thermal conditions Rock fracture mechanics Taffoni Antarctica

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THE GEOMORPHIC SIGNIFICANCE OF ROCK GLACIERS

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An inventory of about 400 individual rock glacier sites in West Greenland (70°N) was carried out by means of field studies and analysis of aerial photos and topographic maps. A number of supplementary sites with other depositional landforms such as ice-cored moraines were included. The estimated rock glacier debris volume was compared with the size of the source headwall, using available knowledge on the internal rock glacier structure partly obtained by direct field observations in the study area, partly derived from published information obtained by geophysical means in other regions with active rock glaciers.

The results of the inventory suggest that the presence of rock glaciers, in general, indicates very high retreat rates for the rock free faces above. Mean headwall retreat rates of 2-15 mm/yr appear to be quite common during intervals of the Holocene. Headwalls at sites with glacier-derived rock glaciers represents the most intensive Holocene rock weathering environment, and the critical altitudinal range for maximal rock weathering in Disko Island is delimited by rock free-faces with northerly aspects and ranging from 450±50 to 750±50 m a.s.l. Both lower and higher headwall altitudes apparently result in lower weathering rates, and are associated sites with talus-derived rock glaciers and ice-cored moraines, respectively. The upper limit of the range of maximum weathering is close to the modern regional glaciation level within the study area, and the lower limit is close to the late Holocene range of equilibrium line altitudes, as represented by modern and Little Ice Age ELAs.

The apparent altitudinal relation of the zone of maximum weathering to glaciological concepts such as the regional glaciation level and ELA, suggests that the net accumulation of snow (representing a moisture source) exercises some direct or indirect control on the rate of rock free face weathering. Field measurements document that the bedrock (gneiss and basalt) in Disko Island is able to exchange significant amounts of moisture with the surrounding air masses, even on a time scale of just a few hours. This phenomenon is not confined to above-freezing meteorological events with liquid precipitation, but operates very efficiently also for below-freezing events with snow precipitation, snow drifting and fog, or just periods with significant variations in atmospheric relative humidity. Meteorological events such as these are likely to be frequent throughout the year for rock free faces rising somewhat above the ELA, and by this, such headwalls are exposed to both a high mean and significant variability in the degree of water saturation, both of which promote rapid rock breakdown.

Meteorological measurements indicate that the modern regional climate within the critical altitudinal range of maximum weathering in Disko Island is characterised by a mean annual air temperature (MAAT) of about -9±2°C and an annual precipitation of about 600-900 mm w.e. A supplementary inventory of available published knowledge on climate at sites with active rock glaciers suggest that these, in general, signal a permafrost environment with a regional annual precipitation not exceeding about 1700 mm w.e. In a global geomorphological context, this presumably outlines the essentials of the climatic background for extraordinarily high bedrock weathering rates, and, by this, outlines an environment of considerable importance for understanding long-term cold-climate high-relief landscape evolution. The common denominator for maximum cold-climate geomorphic activity appears to be represented by rock free-faces rising to a certain critical altitude, determined by a specific combination of precipitation and air temperature, and with effective local transport agents such as glaciers and rock glaciers located below.

Rock glaciers also have a specific sedimentological role to play. While normal glaciers act as temporary storage units for new sediment, which soon is released and transferred further downvalley by meltwater streams, this is not the case for rock glaciers. Water draining from rock glaciers tends to have a low sediment content (ignoring solutes), and most of the debris produced from the headwall remains within the rock glacier body for an extended period, as much as several thousand years, even though the rock glacier on a local scale is efficient at transporting new talus away from the foot of the headwall. The debris is stored within rock glaciers during interglacials, and is presumably transferred significantly further downvalley only in connection with the evolution of big valley glaciers during glacial periods. This may have implications for the interpretation of interglacial and interstadial marine sedimentology along coasts where numerous rock glaciers are present in the hinterland.

GROUND ICE AND SLOPE FAILURE IN THE CANYON WALLS ON MARS.

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This project will study and attempt to model the connection between ground ice and mechanical soil strength in the steep canyon walls found on Mars. Especially interesting is the change in mechanical soil strength that occurs when the ground ice layer migrates, a possible contributing and precipitating factor in slope failures.

The areas of study in this project are the loss of ice from the ground ice layer, evolution of the canyon walls, north facing versus south facing canyon walls, insulation effects, and the causes and effects of slope failures. Factors in slope failures include slope angles, mechanical soil strength, and any reinforcing mechanisms that may exist.

Parameters useful in describing the consequences of slope failures include changes in slope angles, any other changes in topography, the volumes of land slides, and the thickness lost in the canyon walls. One interesting and promising possibility for learning about reinforcement effects of the ground ice layer is to study part height slides, seen in some images of Mars canyon walls.

Modeling tasks include: rates of ice loss at the top of the ground ice layer; rates of vapor cold trap at the bottom of the layer; thermal effects of wall collapse/slope failure on the ice layer; the effects on mechanical soil strength from migration of the ice layer.

Core topics are: rock wall strength and ice layer sublimation; thermal consequences of loss of ice from canyon walls, and thermal stability; re-distribution of water/ground ice; volatile response to thermal effects.

Figure 1 below shows the cycle of ground ice sublimation, slope failure, and ground ice layer migration. After a slope failure event, the ground ice layer will eventually adjust to again roughly follow the topography. Geological structure and stratigraphy complicates this situation.

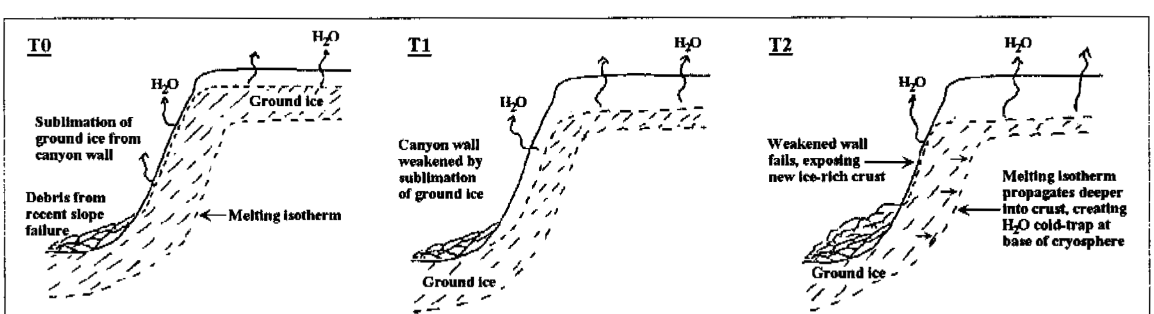

Figure 1. Cycle of sublimation, slope failure, and ground ice migration (adapted from drawing by Stephen M. Clifford, LPI)

PRELIMINARY STUDY ON METHANE FLUXES FROM AN ALPINE WETLAND ON THE QINGHAI-TIBET PLATEAU

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The total area of the cold regions wetlands on the Qinghai-Tibet Plateau is estimated as 0.12×10^6 km^2. Most of these wetlands are peat bogs. The development of these wetlands is closely related to the presence of permafrost, favorable topography, cold climate and the comparatively high net primary production. Due to the combined influences of climatic warming and human exploitation, the natural wetlands in the cold regions have shrunk remarkably during the past 30 years. As a result, the alpine wetlands on the Qinghai-Tibet Plateau might contribute significantly to the global methane budget in the middle latitudes, and are experiencing important changes under a warming climate in relation to permafrost. In order to estimate the methane emissions, and their possible change, a flux transect study was conducted near the Huashixia Permafrost Station in the eastern Qinghai-Tibet Plateau during July-August 1996, and a study of fluxes through time was undertaken at four permanent sites near the Station during April-July 1997.

The Huashixia Permafrost Station (35°39'N, 98°48'E, at an elevation of 4,320 m), is located on the edge of a small wetland overlying degrading permafrost. Permafrost can be detected only at the bottom of the flat valley in the study area. Icy peat and silt are the major soil types in the active layer of the wetlands. TDR-measured volumetric soil moisture within 20 cm of the surface ranged from 38.9% to 58.9% during the observation period in 1996. The mean annual air temperature and precipitation in 1996 were -4.2°C and 1075.4 mm; from October 1996 to September 1997 they were -4.8°C and 823.1 mm, respectively. The relative humidity ranged from 31% to 89%, with an average of 54.2% during observations in 1997.

Acrylic resin chambers (40x40x40 cm) and stainless steel collars were used for the field observations. A tube for air sampling and a needle-type thermometer were installed on the chamber. The stainless steel collars were set into soils in the wetlands at least two hours in advance of sampling in 1996; the collars were fixed at permanent sites during observations in 1997. The gas samples were withdrawn from the chambers using a 100-ml plastic syringe through rubber caps. The gas samples were then stored in vacuumed 12-ml vials. For each site, gas samples were collected four times within 30 minutes, with a time interval of about 10 minutes (one sample was collected immediately when the chamber was set onto the collar). Many observations were carried out randomly in similar environments in the transect flux studies in summer 1996 to get a representative flux for the environment. The gas samples were analyzed using gas chromatography (HP6890) with a Fire Ion Detector in the Laboratory of Ice Core and Cold Regions Environments, LIGG, CAS. Methane fluxes were calculated using the slopes of methane concentrations versus time, assuming the methane concentrations in the chamber changed linearly during the first 30 minutes after the chamber was enclosed. Only sample groups with a regression confidence level over 95% were considered logically authentic. However, all four samples do not always have such good slopes and sometimes slopes for the site were derived from only three samples.

The measurements during the summer of 1996 indicate that average methane fluxes at sites in wet meadow, peat bog, secondary bog, and thermokarst scar pond were (3.82~105.27) ± (3.16~22.63), (3.58~18.76) ± (4.31~64.73), (27.06~18.76) ± (4.31~ 4.59) and -0.28 ± 3.00 mg m^{-2} d^{-1}, respectively.

The observations during the summer of 1997 gave average fluxes of 4.98 (ranging from -2.423 to 38.823) mg m^{-2} d^{-1} for moist meadow, 154.98 (ranging from 25.872 to 347.148) mg m^{-2} d^{-1} for wet meadow, 10.31 (ranging from -28.051 to 63.277) mg m^{-2} d^{-1} for vascular plant in thermokarst depressions, and 77.98 (ranging from 0.753 to 183.641) mg m^{-2} d^{-1} for floating plants in small thermokarst ponds. During the observation period from April to July 1997, the methane fluxes at the moist meadow site were greatest in April, while at the other three sites the largest fluxes generally occurred in May. It seems that the spring thaw can release substantial amounts of methane in alpine wetlands environments, especially in wet meadow soils. The correlations between the methane fluxes, either from different sites or the similar ecosystems, and environmental factors, including the soil temperatures and moistures, pH, thaw depth, and electrical conductivity, are poor. Generally, the greatest methane flux was produced by the wet alpine meadow. Analysis of the seasonal (April-September) variation of methane fluxes at the four sites at the Huashixia permafrost Station are continuing.

GENESIS AND PALEOGEOGRAPHICAL CONDITIONS OF MASSIVE GROUND ICE FORMATION, THE TAB-SALYA SECTION, NORTHERN YENISEY, RUSSIA

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Thick sheets of injection ice are widely distributed in the study area. These bodies of injection ice vary widely in age, morphology, size, depth of occurrence and means of injection. They formed during epigenetic freezing of water-bearing taliks in closed, semi-closed and open systems under very high water pressures. The largest and most representative sheet of injected ice is exposed in Tab-Salya.

This section, first examined in 1977 (Karpov, 1982, 1986), is located on the left bank of the Yenisey River, North of Brekhovskiye Islands (delta), 40 km southwest of the settlement of Innjkentievsk (Figure 1). An impressive 20 m high section of ribbon clays is exposed along the Kargin terrace within the vast Yanato-Mongoche glaciodepression. Five meters of massive ice is exposed at the base of outcrop (Figure 1), but the bulk is at elevations below the water level. Drilling data indicated that ice in the central part of the outcrop exceeds 15 m in thickness. The apparent length of the ice is 1070 m.

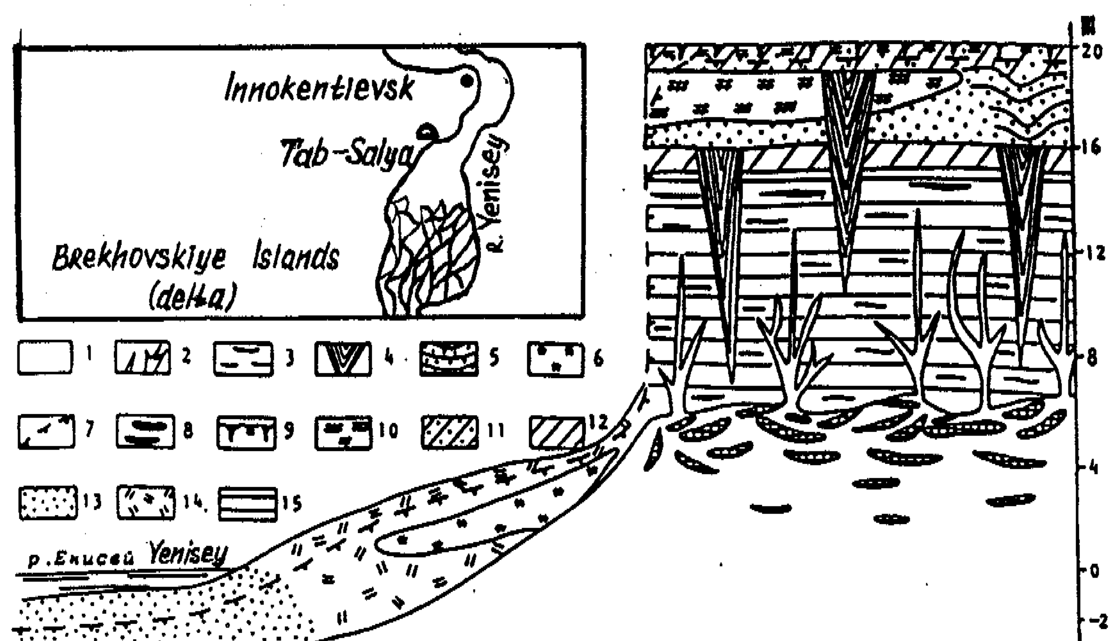

Figure 1. Cryolithological cross-section of the Tab-Salya outcrop with massive ground ice as of August 1, 1978. 1 - sheet ice; 2 - fissure ice; 3 - horizontal layers of segregated ice; 4 - polygonal wedge ice; 5 ice wedge cast; 6 - buried snow patch at the outcrop foot; 7 - upper limit of permafrost; 8 - inclusions of light grey varved clays in splintery-textured ice; 9 moss vegetation cover; 10 - peat; 11 - covering suglinok; 12 - lake suglinok; 13 - sand; 14 - slope deposit; 15 - varved clay, dark grey.

The sheet ice rests on a layer which grades downward into sands. Between the sand and ice, there is a cavity (0.5 m) with deep hoarfrost. Lying over the sheet ice is a thick (10 m) lacustrine deposit of an ice-blocked fresh-water basin, i.e., typical varved clays similar to those found in the INIMS underground laboratory, Norilsk depression, and the Bolshoy Shar outcrop near the Turukhansk settlement. These clays grade upward into indistinctly bedded lake suglinok (1-2 m) of the final stage. Depression in the surface of the lake deposits are filled, in an upward direction, with sand (1 m), peat (up to 8 m), and a layer of covering suglinok (0.5-1 m). Two horizons of pre-Holocene epigenetic ice wedges occur in the upper part of the section that had formed before and after the Holocene optimum.

The injected nature of the massive ice is indicated by (1) its occurrence above water-bearings and beneath impervious clays; (2) the appearance of the ice: glassy clean, unlayered, with no bubbles, containing sand particles only close to its base; (3) intrusive character of the ice roof; and (4) a relationship between the massive ice and severely fractured texture of the varved clays. Between the ice sheet and lake deposit is an « intermediate horizon » of ice with « floating » angular blocks of clays in it. The lake sequence is injected by large fissures that issue from the ice forming the sheet.

The injected origin of the ice is also evidenced by its $\delta^{18}O$ of -16.3 ‰to -18.7 ‰. These values differ from those of the Ledyanaya Gora glacier ice (-21.2 ‰) and segregated ice (-14.1 ‰) of the INIMS underground laboratory, but are closed to those of subsurface waters from which the sheet ice was formed. Changes in the amount of mineralization throughout the massive ice are also indicative of its injected origin.

Samples collected from the Tab-Salya section give an idea of the character of changes of permafrost conditions and the chronology of events of this area. According to our estimates, the varved clays were deposited over a period of 4500 years. Wood samples, taken above the massive ice date at 12340± 400 years (IM - 622). It follows that the varved clays started to form after draining of the ice-blocked basin with epigenetic freezing of the varved clays as early as pre-Holocene times.

CALCULATION OF PALEOCLIMATE TEMPERATURES FROM BASIC PHYSICAL THEORY OF SEGREGATION ICE LENS FORMATION

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A calculation of paleo-temperatures is based on the physical model of segregation ice formation upon freezing of fine-grained soils (Grechishev, 1979; Derjaguin and Churaev, 1984; Konrad, 1994). A simplified model of freezing of fine-grained soil in an open system is shown in Figure 1.

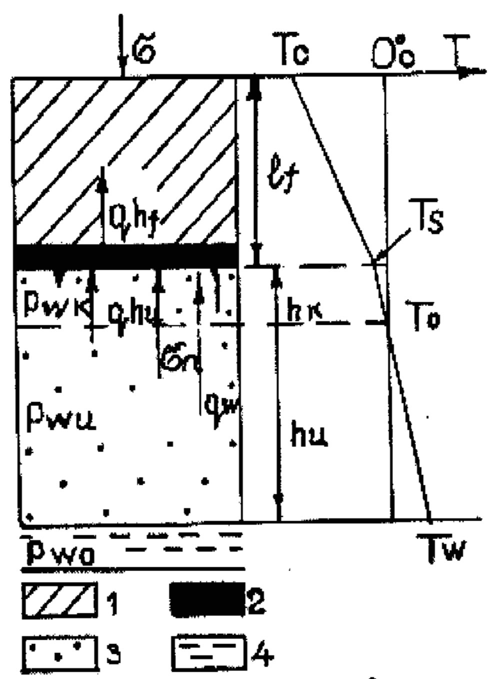

Figure 1. Simple model of fine-grained soil freezing with formation of segregated ice lens.
1 – frozen soil; 2 – ice lens; 3 – unfrozen soil; 4 – water– bearing horizon; σ – external pressure; σ n – disjoining pressure in pellicles of bound water; hk – frozen fringe; hu – unfrozen soil; lf – frozen soil; Pwk, Pwn and Pwo – hydrostatic pressure in frozen fringe, in unfrozen soil and water – bearing horizon; qhf and qhu – thermal flows in the frozen and unfrozen zones; qw – external migration moisture flow; Tc and Tw – temperatures on the upper and bottom surfaces of specimen; To – temperature 0 °C; Ts – segregation – freezing temperature.

At the moment when the thermal condition at the ice segregation front takes the form $q_{hf} > q_{hu}$, cooling and phase transition of water–films takes place. These water–films separate ice lenes from soil mineral particles. Under the influence of crystallization pressure, ground heaving takes place. Simultaneously hydrostatic pressure in pellicles of bound water drops at the expense of G_n. In such a way, the freezing zone takes place $P_{wk} < P_{wu}$.

$$\Delta P = P_{wk} - P_{wu} \qquad (1)$$

A degree ΔP and thickness h_k are defined by a degree and thickness in the layer h_u.

The Stefan thermal condition at the base of an ice lens, when it grows continuously is generally known as:

$$q_{hf} = q_{hu} + q_{wL} \quad (2)$$

where q_{wL} is the thermal flow needed for run off heat crystallization.

To check these theoretical statements, segregation ice lenses up to 0.05 m thick have been grown by the author in Igarka clay with external pressures from 0 to 1 MPa (Kazansky, 1996, 1997). It proved possible to control the process of segregation lens formation with the help of a change of Tc. On this basis, the deduction about the possibility of calculating Tc in natural conditions is being explored, if all the rest parameters of freezing system are defined.

Darcy's equation is used to calculate moisture flow from the water - bearing horizon to the segregation ice formation:

$$q_w = -(K_u / \gamma_w) \cdot \text{grad } P \quad (3)$$

where q_w is the moisture flow; Ku is the hydraulic conductivity; γ_w is the specific water weight; grad P is the gradient of hydrostatic pressure.

Dependence of degree Ku from shrinkage under pressure is defined by laboratory research.

More problematic is the definition of ΔP ("suction" force) in the freezing zone. In the author's calculations, ΔP is assumed equal to minus 50 KPa on the basis of our measurements and the experimental results of others (Kaplar, 1970). Geocryologists will learn in future to calculate the ΔP more exactly on the basis of conditions of freezing and soil characteristics.

According to thermodynamic laws, the temperature of phase balance at the base of the lower lens (T_s) depends on external pressure and drops within 0.9 °C by raising G on 1 MPa (Grechishev, 1979). Thus T_s is defined from calculations of the pressure from the frozen ground layer.

The value q_{hu} in the calculation is standardized for the region.

In the equation (2)

$$q_{hf} = \lambda_f (T_s - T_c) / l_f \quad (4)$$
$$q_{wL} = q_w \cdot L \quad (5)$$

where λ_f is coefficient of thermal conductivity of frozen ground; l_f is thickness frozen ground; L is specific heat of water crystallization.

q_{wL} is defined by "suction" force and the quantity of hydrostatic pressure of the ground water. The mean annual temperature at the permafrost table (T_c) is defined from equation (4)

$$T_c = T_s - (q_{hf} \cdot l_f) / \lambda_f \quad (6)$$

The mean annual temperature of the air is defined by a method to calculate the thermal influence of natural elements (e.g., snow, vegetation).

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A MODEL FOR SORTED CIRCLE FORMATION AND EVOLUTION

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Many hypotheses for the mechanisms underlying sorted circle formation have been proposed; however, measurements that can discriminate between these hypotheses have not been realized. For example, predictions of aspect ratio from a model of free-water convection (e.g. Gleason *et al.*, 1986) are consistent with field measurements of sorted circles; however, no predictions have been provided that can distinguish this model from other convection models with fundamentally different driving mechanisms. Current models treat either small amplitude initial patterns or the dynamics of fully developed forms without regard to temporal evolution. In our computer model of active layer dynamics, which includes only the effects of frost-heave and surface gravity transport, forms resembling sorted circles are generated from an initially random configuration of stones and soil. Because time evolution is treated explicitly, detailed quantitative predictions regarding the formation of individual circles, the development of patterns composed of many circles, and the influence of environmental conditions are possible.

Underlying our modeling approach is the hypothesis that feedback mechanisms between transport, sorting, and morphology are sufficient to produce the most prominent characteristic of sorted circles: a central soil domain surrounded by a border of stones. Additional features, which might be specific to local conditions, include: elevated stone borders; convex soil domains; an aspect ratio of approximately 3/1; and soil domain circulation that is radially outward at the surface. A model for sorted circles should reproduce these features and predict their dependence on specific active layer and environmental conditions.

Three physical mechanisms underlie the stone and soil interactions that give rise to patterns in our three-dimensional computer model: gravity-driven surface transport, ice-lens-induced sub-surface displacements, and frost-heave-driven stone uplift. Downslope surface transport is modeled with a discrete two-dimensional diffusion equation. The freeze front and associated frost-heave are calculated using a discrete three-dimensional heat diffusion equation including a latent heat term. Differences in the conductivity and latent heat of stones and soil give rise to locally non-horizontal freeze fronts and the consequent lateral transport of material. Ice lenses displace stones and soil perpendicular to the local freeze front, either toward the free surface or toward unfrozen compressible soil regions. The rate of stone uplift is proportional to the local concentration of ice lenses.

Initial results indicate that the mechanisms included in the model are sufficient to produce the features and behaviors of sorted circles given above. Four sorted circles from Western Spitzbergen are shown in Figure 1. A plan view of the model after 500 freeze/thaw cycles is shown in Figure 2. Stones are represented as small gray circles; darker squares represent soil elements. Elevation is indicated by shading, with lighter shading indicating higher elevation. Well-developed stone/soil patterns, circular convex soil domains, and elevated stone borders are observed in natural sorted circles and in the model.

Owing to the dependence of freeze front inclination on lateral sorting in the model, ice lenses push soil toward regions containing more soil. Small soil concentrations are unstable; they expand by soil influx, eventually reaching the free surface. In addition, displacement of material from the freeze front toward the free surface elevates stone borders around soil accumulations. These straightforward feedbacks give rise to the characteristic form of sorted circles.

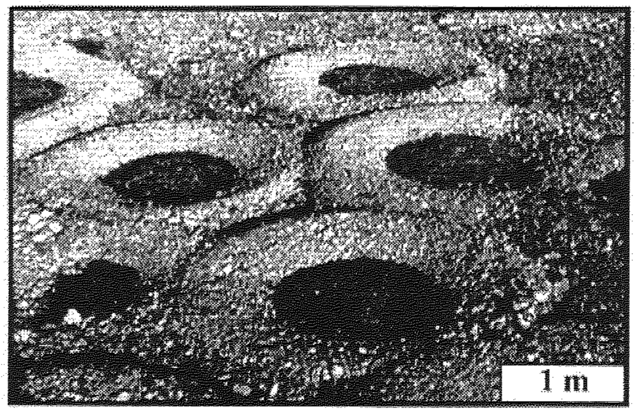

Figure 1: Sorted circles in Western Spitzbergen

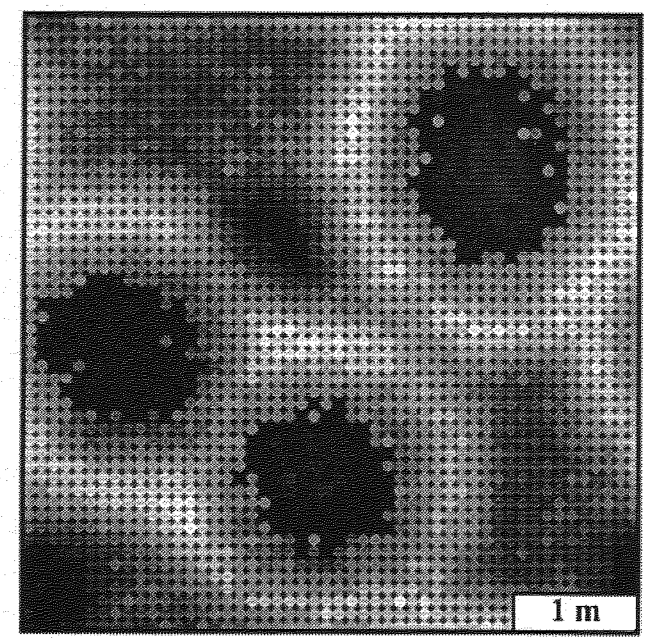

Figure 2: Plan view from model

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LATE QUATERNARY PALEOENVIRONMENTAL RECONSTRUCTION FROM A PERMAFROST SEQUENCE (NORTH SIBERIAN LOWLAND, SE TAYMYR PENINSULA) - A MULTIDISCIPLINARY CASE STUDY

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A Late Quaternary permafrost profile from the Labaz Lake area (TaymyrPeninsula, Central Siberia) was investigated using analyses of diatoms, pollen, sedimentology and geochemistry. An interruption of the sedimentation during the last glacial period (Sartan) and a new start of lacustrine sedimentation in the Boreal could be inferred. At that time shallow-lake conditions prevailed and a connection to the Labaz lake is probable. Evidence from diatom data (assemblage composition, diatom concentration, proportions of life form groups and pH-preference groupings) enabled us to assess the environmental development of the study site during the Holocene in connection with pollen and geochemical data in more detail. The most favourable climatic conditions and comparatively higher lake level stands occurred during the Atlantic. Already towards the end of this period, a gradual transition to a wetland took place. Within the Subboreal, a short episode with mild climate conditions occurred. At that time the last trees grew in the Labaz Lake area and somewhat higher water level stands are likely. The Subatlantic climate deterioration lead to a further drying-up of the wetland along with a lowering of water-pH and permafrost aggradation, i.e. the transition from a locality with low-centred to one with high-centred polygons. The process of the formation of high-centred polygons is still underway.

PERMAFROST SCIENCE AND SECONDARY EDUCATION: DIRECT INVOLVEMENT OF TEACHERS AND STUDENTS IN FIELD RESEARCH

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A review of recent literature indicates that the subject of permafrost is virtually absent from secondary education curricula in North America and elsewhere. This situation is particularly distressing in the context of the large population increases and accompanying development that have occurred in the northern sections of North America and other high-latitude regions in recent decades. Because permafrost has a profound influence on the lives and finances of northern residents, inclusion of this subject in school curricula could advance the ideals of sound land-use planning, good engineering practice, and an informed citizenry, as well as providing some inoculation against ill-informed public and private expenditures.

This poster details the planning, execution, and synthesis of an educational program focused on providing field and laboratory experience in permafrost science for secondary-school teachers and students. The program was funded by the U.S. National Science Foundation's (NSF) Teachers in the Arctic/Antarctic Program (TEA). TEA is sponsored jointly by NSF's Office of Polar Programs and Directorate for Education and Human Resources. The Antarctic portion has been conducted for several years, but 1997 was the first year that the Arctic was included.

The University of Delaware research group received supplementary funding from NSF in 1997 to enable participation by a science teacher and a high-school student in a permafrost-related project in northern Alaska. The subproject involved three distinct phases: (a) an introductory week prior to the field season; (b) four weeks of field research; and (c) laboratory analysis of field data and creation of map products. During the introductory week at the university, our experimental design, goals, and equipment were discussed, and basic thermal and physical processes were reviewed. Both university and high-school personnel contributed to the field work, which included active-layer probing, data entry, operation of data loggers, and soils analysis. The analytic phase included processing of climatic and active-layer data, construction and interpretation of graphs and maps, and development of a web-page to describe the project and its results on the Internet.

Permafrost is a fundamental part of life in the north, yet little opportunity currently exists for northern residents to receive scientific instruction about its characteristics and effects. Now that it has been extended to the Arctic, the TEA program can deliver direct educational opportunities to inhabitants of the high latitudes on scientific subjects that influence their lives on a daily basis. During our field research at Barrow we visited the local high school, and found both students and faculty eager to learn more about permafrost and its influence.

The TEA program provides excellent opportunities for interactions and exchange of information between university scientists, secondary educators, and local residents. Because participants are drawn from contrasting environments, the program also functions as a type of cultural exchange fostering mutual understanding.

DEFORMATION OF ROADBEDS ON PERMAFROST AND ITS PREVENTION

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Deformation of roadbeds on permafrost soils is connected mostly with permafrost degradation in the roadbed base. The main factors, causing thawing of permafrost in the base of an embankment, usually are higher amounts of absorbed solar radiation, infiltration of warm summer precipitation through the body of embankment, increasing snow cover on the lower part of the embankment, warming effects from surface and underground water on the slope.

We have developed several methods of strengthening roadbed bases on very icy permafrost soils. These are based on adjustment of the ratio of cooling and warming factors in order to reduce the average annual temperatures of the substrate and to preserve it in a permanently frozen state, or based on preventative removal of very icy masses from permafrost and filling the cavities formed with a high bearing-capacity soil. Other proactive alternatives include:

- Strengthening of roadbed base by means of snow cleaning and painting, using a sun-precipitation protective shed, or by means of cooling pipes;
- Strengthening of roadbed base at sections with a cross-gradient using an impervious membrane liner or thermosyphons;
- Strengthening of roadbed base by substitution of thaw stable material;

To test the efficiency of these methods under operational conditions, we are undertaking pilot-experimental research on Siberian railways. In particular, on the Berkakit Tommot Yakutsk Railway, we are experimenting with a sun-precipitation protective shed. The study site is on a terrace of the Lena River, and is underlain by lacustrine and deltaic sandy-loam soils with ice seams and veins to depths of 10-15 m. The previous design was to maintain permafrost by means of thermopiles, installed to 2 m depth beside the slope embankment, and with insulation in the base.

To investigate the effects of a shed, numerical modeling of the temperature regime was conducted for a roadbed and its base consisting of very icy permafrost soils with temperatures of -0.5°C. The mean annual air temperature was -8.5°C and the annual amplitude was 27.2°C. In this numerical modeling we neglected the influence of precipitation and only the solar radiation effect was investigated. Numerical simulations show that the protective shed has a positive effect due to its shading which guarantees that the roadbase remains frozen.

A design for a cylindrical shed for a single track railroad has been developed. Arches are mounted on concrete foundations installed on the embankment with metal flooring as a barrier element. The cost of the railroad with shed is 100 rubles per linear metre lower than using thermopiles (1991 prices). The obvious technical advantage is that the whole of the embankment is protected by the shed whereas thermopiles have a radius of activity of only 1.5 m and do not influence all of the embankment base. Experimental work is beginning on Transbaikal Railroad.

We are ready to cooperate with companies and experts in practical application of the inventions and in optimization of the strengthening techniques for roadbed bases on very icy soils in various regions of Russia and other countries.

MULTI-LEVEL PERMAFROST OF THE ARCTIC COASTAL ACCUMULATIVE PLAINS-SEQUENCE OF SEA LEVEL OSCILLATIONS

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A two-layered structure of permafrost is typical of marine sediments of the western sector of subarctic Eurasia, particularly for north-western Siberia. The upper "modern" (Late Holocene) layer is 50-200 m thick, while the lower "relic" (Late Pleistocene) permafrost lies in the depth range 200-500 m. Ice-bonded permafrost is separated by intermediate thawed layers (taliks) with a thickness of 50-100 m. The cryolithosphere sequence often displays the intercalation of several frozen and thawed layers, usually considered a result of multi-annual oscillations of climate during the Late Pleistocene and Holocene.

During the Late Pleistocene, permafrost within the modern cryolithozone was characterized by a more continuous distribution, lower temperatures, and greater thickness. Appearance of the intermediate thawed layer is associated with Holocene climatic optimum (6-8 to 4 ka B.P.), when average annual air temperatures were thought to be 3-5°C higher than at present (-6 to -10°C). Under such conditions and taking into account the thermal influence of vegetation and snow cover, average annual surface ground temperatures probably did not exceed 1-2°C.

Our calculations showed that at the above surface temperatures, the depth of thawing in permafrost during Holocene climatic optimum could not exceed 60-100 m. However, the base of the intermediate thawed layer is usually deeper than this, situated below 150-200 m.

There are additional reasons to question climate as the only reason of such vertical heterogeneity of permafrost. The most striking are Pre-Holocene massive ice layers and lenses up to 40 m thick, more than 500 m long, with a volume exceeding several million cubic meters. The age of sediments unconformably overlying the massive ice is 30-40 ka B.P. Hence the ice itself is older. The top of the massive ice lies at depths ranging from 2-3 to 20-30 m (rarely down to 50-100 m) from the surface. Surface temperatures above the freezing point initiate gradual thawing of the ice.

A computer model was used to investigate the dynamics of the cryolithosphere temperature field due to pressure and salinity in the north-western Siberia during the Late Pleistocene and Holocene transgressions and regressions. The model is based on the notion of both repeated alternation of transgressions and regressions of the Arctic Ocean in the Kara Sea and shelf during the Late Pleistocene-Holocene, and time correspondence between cold and regressive epochs. These transgressive/regressive sequences formed a series of marine terraces descending towards sea.

On the basis of paleocryological data and computer modelling, we reconstruct the multi-level structure of cryolithosphere. The latter results from changing load upon permafrost sediment layers and depends upon salinization caused by transgressions of the Arctic Ocean. A spatial-temporal model of sedimentary basin evolution during the last 150 thousand years has been established. The model takes into account bottom temperatures, depths, sediment thickness, and salinity of pore waters.

The performed calculations revealed the following patterns.

A cryogenic succession of layers "thawed layer - permafrost layer - thawed base" appears in cases where salinity decreases with depth. A succession "permafrost layer - thawed layer - permafrost layer - thawed base" appears in cases where salinity increases with depth. A cryogenic succession of layers does not appear in non-saline permafrost soils. They remain frozen below the sea floor.

It was revealed that cryogenic levels resulted from the delayed reaction of sediments to changing environmental conditions, mainly during the first 5-7 thousand years of each transgressive and regressive period. After that time, the thermal state of sediment approaches an equilibrium.

The relationship between the formation of multi-level permafrost - transformation of gas hydrates and change of their thermal state, was also examined.

ACKNOWLEDGMENTS

The work was supported by the Russian Foundation for Basic Research (grants 96-05-64008 and 96-05-65854).

BOUNDARIES OF THE CRYOLITHOZONE IN NORTHERN EURASIA AS A DEBATABLE PROBLEM OF PLEISTOCENE PALEOCRYOLOGY

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Eopleistocene - Early Pleistocene

A cryolithozone appeared at the end of Eopleistocene - beginning of Early Pleistocene in the mountains and coastal lowlands of Northern Yakutiya. The data on syngenetic ice wedges within lacustrine-bog deposits of Bol'shoi Lyakhovskii Island (New Siberian Islands) are especially important, though these objects still need complete description and detailed publication. The wedge-shaped deformations described in the Oler Formation (the Lower Kolyma River region) are unanimously referred to as pseudomorphs of ice wedges. Our guarded attitude towards this point of view results from the following reasons. Firstly, due to the wide range of reconstructions of paleovegetation made by palynologists which range from hypoarctic tundra and forest tundra of modern type to southern taiga or close to treeless vegetation with presence of broad-leaved species. Secondly, due to a discrepancy between distinct climatic rhythms in the sequence and occasional distribution of most ground structures within the Oler Formation. Further, due to the discrepancy between assumptions of frequent climatic oscillations and conditions of syncryogenesis, etc. As a whole, the question of an ice-ground complex older than the Middle Pleistocene in the North-Eastern coastal lowlands remains open. Most likely permafrost was not severe. Its boundary did not cross 65°N, since thermophilic plant forms of Central Yakutiya undoubtedly indicate absence of permafrost. A much lower elevation of the Himalayas and Tibet was the probable reason for penetration of warm air masses into the northern regions of Eastern Eurasia. The deepest (though not the most extensive) among Pleistocene polar marine transgressions occurred in Western Eurasia in Eopleistocene - Early Pleistocene. Climate in the middle latitudes was temperate and slightly warmer than at present. Reliable traces of permafrost are absent.

Middle Pleistocene

The first decisive evidence that low temperature permafrost existed in Central Yakutia dates back to the second half of the Middle Pleistocene. It is based on syngenetic ice wedges, like those of the upper loamy unit of the Mamontova Gora reference section situated on the 50-m high terrace of the Aldan River. Climatic conditions were colder and more humid than the modern ones. However, due to the above reasons, climatic conditions in the southern Transbaikalia and middle Cisbaikalia were warmer, and the broad-leaved forest sub-zone existing since the Neogene was preserved. We suggest that the cryolithozone boundary should be plotted from northern Transbaikalia to the Lower Yenisei region (on the north-west) and the Sea of Okhotsk coast (on the north-east). The Middle Pleistocene was the epoch of the maximum polar transgression on the Western Eurasian plains. To the south the vast shallow moderately cold ice rafting sea basin was replaced by limno-alluvial loess plains. No reliable cryogenic deformations of this epoch have been reported. Only a submarine cryolithozone could have probably existed to the north of polar circle.

Late Pleistocene

This was the epoch of a clear transition to more continental climate, and in its second half - to colder and drier one, i.e., to the final stage of the Late Cenozoic climatic trend. The Zyryanka epoch in Central Yakutia is thought to be treeless and the coldest one throughout the whole Pleistocene. Many scientists suggest that the glaciation in Siberia was also the greatest. However, patches of broad-leaved forests were preserved in Transbaikalia and Cisbaikalia, thus giving evidence for climatic conditions still warmer than at present. At the same time, permafrost islands could have already appeared in the "golets" mountain zone of southern Transbaikalia. The permafrost boundary shifted to southern Mongolia (i.e., southward from its present location) during the cold and dry Sartan epoch, when broad-leaved biocoenoses completely degraded. The question of Late Pleistocene permafrost in Western Eurasia is still rather complicated. Soil wedges in cover deposits of watershed areas (often thought to be of eolian genesis) are usually referred to as former ice wedges. Ice wedges of considerably greater size must have been more abundant in inundated valley floors, i.e., on the 1st river terrace of Late Pleistocene age. However, practically no wedge-shaped forms have been found in the central parts of plains. The above mentioned facts call attention to the new migratory-autogeocoenotic concept in biogeography concerning (a) wide distribution of refugia for broad-leaved species on the East European Plain (up to 60-61°N) and (b) low migration abilities of these species determining the difference in location of their modern and pre-Holocene boundaries in the order of several hundreds kilometers. The existing distance between the permafrost and biogeographic boundaries should be also taken into account. Based of these facts, it is possible to establish the limit of the Late Pleistocene cryolithozone in the Northern European Russia (from 64°N on the west to 60°N on the east) and Western Siberia (56°N and 52°N correspondingly).

THE CRYOSTRATIGRAPHY OF UNCONSOLIDATED MATERIAL OVERLYING AURIFEROUS CREEK GRAVEL, KLONDIKE AREA, YUKON TERRITORY, CANADA

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Three distinct units have been recognized in frozen, unconsolidated materials which unconformably overlie Late Tertiary and Early Pleistocene auriferous gravels in unglaciated valley-bottoms of the Klondike area, Yukon Territory (Figure 1). The lowermost unit, up to 10 m thick, consists of grassy loess with abundant mammal bones near its base, which accumulated in valley bottoms during the Late Pleistocene (Fraser and Burn, 1997). Epigenetic ice wedges are found in some sections, within the uppermost 3 m of the unit. Cold, dry conditions prevailed during the time of deposition of this unit, correlative with the McConnell glaciation in central Yukon.

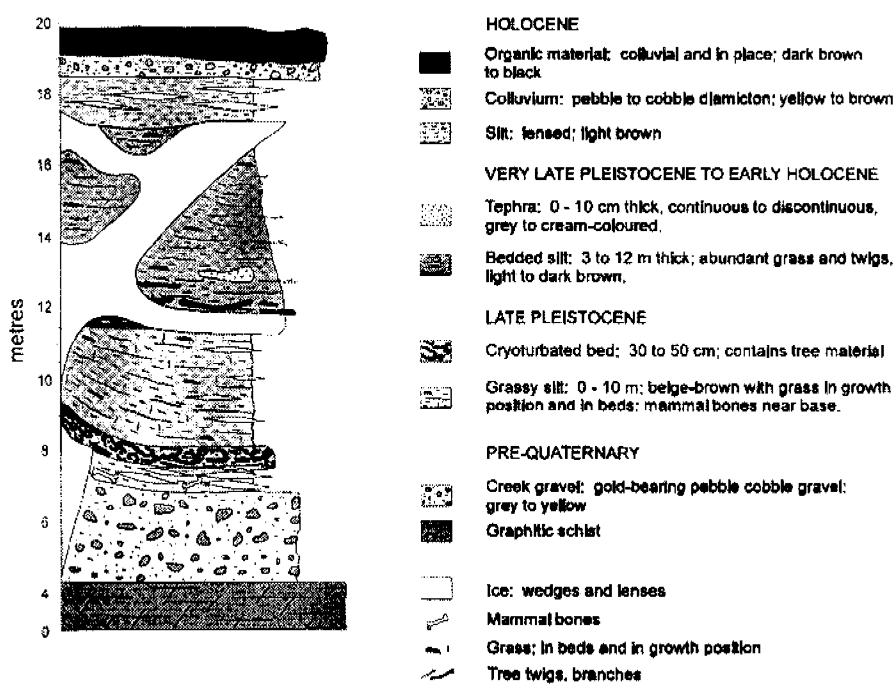

Figure 1. Stratigraphy of complete valley-bottom section exposed at Last Chance Creek, Yukon Territory, August, 1997.

The middle unit (unit 6, French and Pollard, 1986) is up to 12 m thick and consists of bedded Late Pleistocene silt, a colluvial deposit derived from loess, which was moved downslope during the very Late Pleistocene and Early Holocene as the climate became wetter. The unit contains organic material, mostly twigs and grass. Large ice wedges dominate the unit and commonly penetrate the underlying sediment. Syngenetic wedges are found where material has accumulated, whereas anti-syngenetic wedges have been observed on valley sides. In comparison with the relative absence of ice wedges from the underlying unit, the size and morphology of these wedges suggest development under wetter conditions. The base of the unit is a thaw unconformity represented by the truncation of small ice wedges and the appearance of twigs and branches. Wood collected from the base of this unit has been dated at 11 620 +/- 90 age years BP (TO-6869)..

The uppermost unit is Holocene organic material, up to 3 m thick. This unit has an unconformable lower contact, marked again by the truncation and erosion of large ice wedges. The unit represents accumulation during further warming of climate. Deformed ice wedges indicate long-term slope movement, particularly creep.

Sediments within the three units contain, on average, 70% ice by volume. The greatest amount of ice is found within the second unit, where ice wedges occupy up to 50% of exposed sections. Co-isotope relations indicate that most ice present in the three units is derived from surface water. Intrusive ice is found locally, either in the basal unit in dykes penetrating upwards from the gravels, or as pool ice in the Holocene unit.

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OCCURRENCE OF CRYOGENIC PHENOMENA IN SEISMIC STRUCTURES OF THE BAIKAL RIFT ZONE

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According to its permafrost features, the Baikal rift zone is a part of the southern geocryological zone and is characterised by a deep active layer (up to 3-4 m), predominantly island permafrost (with a temperature warmer than -1°C), and widely developed cryogenic processes. The combination of a frozen state and high seismicity (intensities of 7 to 8 or more), creates a dynamic local setting, and specific features of frozen ground and cryogenic processes in the region. Some geocryological manifestations observed on the surface and in the upper horizons of the ground are directly connected with large earthquakes.

During large earthquakes, with an intensity of 7 to 8 or more, which occur in frozen ground of the Baikal seismic zone, the release of stress is expressed as both ruptures and plastic residual deformations; on the surface it is accompanied by cryogenic formation and structural cryoturbation of the upper horizons of the active layer. Morphologically expressed or microscopic deformations, resulting from large and moderate earthquakes in unconsolidated materials (seismic dislocations), favour the variation of heat and mass exchange and, therefore, the degradation of permafrost, increases in active layer depth, and activation of many cryogenic and exogenous processes even at a low background intensity (beginning from 5-6).

The morphological structure and location of cryogenic formations within a seismic structure usually differ from analogous cryogenic formations which develop outside the effect of seismic structure and in non-seismic regions. In general they are of local distribution and, clustering and tending to a seismic structure, have a linear extension along it.

During seismic wave propagation in the Baikal rift zone, distinct resonance and cumulative phenomena result from the rise of amplitudes of low oscillation frequencies at sites of rapidly changed thawing and frozen grounds about 10 to 15 m in thickness. Thus, a shaking increment of 1 to 3 and development of morpho- and lithodynamical effects may occur at local sites even at a background earthquake with an intensity of 4 to 5. Depending on the season, the same ground has a different seismic resistance even if the energy release of earthquakes is the same, and earthquakes manifest different types of cryoturbations.

In seismically active regions, which are a part of the southern geocryological zone, permafrost and deep seasonal frost action, and associated long-term development of cryogenic processes significantly enlarge the surface deformations caused by an earthquake in unconsolidated soils. Cryogenic phenomena act as an indicator of long-term ground motions and relief structures; they retain and develop the traces of neotectonic disturbances, and mainly reflect the situation which results from an earthquake. They may provide certain data on specific manifestation and intensity of a seismic effect on a frozen ground, and be the so-called temporal bench mark. Cryogenic actions seem to inherit the latest neotectonic formations.

The interpretation of similar cryogenic phenomena in seismic areas of active permafrost may be used to locate and date seismic structures, especially of paleoseismic dislocations. It may provide certain data on specific manifestations, intensity and regime of a seismic event, and on a scale of its effect on the grounds. It may also become important to the seismic microzoning of different sites.

FRACTAL SIMULATION OF THE STRESS-STRAIN CURVE OF FROZEN SOIL

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The stress-strain relationship of frozen soil is important to indicate the strength of frozen soils in use. According to traditional mechanics, the stress-strain relationship in geomaterials is a smooth curve. However, some studies have shown that the real stress-strain curves of geomaterials, such as concrete, rock and frozen soil, are step-like and that they have fractal characteristics. Therefore, the traditional mathematical and mechanical methods used to describe the stress-strain curves of frozen soil are not accurate. Mandelbrot's fractal geometry theory is a new mathematical branch whose primary object is to describe natural structures that are irregular, rough or fragmented. It can also describe the degree of variation of a curve, a surface or a volume by using a fractal dimension. Therefore, fractal geometry theory can be used to analyze the stress-strain curve of frozen soil more accurately and in greater detail.

In this paper, a fractal method to simulate the stress-strain curve of frozen soil is presented, based on the fact that the stress-strain curve of frozen soil has fractal properties. First, a linear hyperbolic iterated function system (LHIFS), in which the perpendicular contraction factors are regarded as parameters, is established. Second, a method to calculate the best point which makes the attractor of the LHIFS an optimal approximation of the stress-strain curve of frozen soil is presented. Then, a method for calculating the fractal dimension of a stress-strain curve is obtained. Finally, a stress-strain relationship of clayey soil from the Qidong mine shaft, China, from uniaxial testing at -7°C is investigated.

Several conclusions can be drawn from this paper:

1) The fractal simulated method presented in this paper can be used to simulate stress-strain curves of geomaterial that have fractal features. Since the fractal features have been considered, this simulated method will describe the stress-strain curve of geomaterial more accurately than traditional mathematics and mechanics.

2) Since the method to calculate the fractal dimension is based on the optimal point, the calculated result is a good approximation.

3) The method presented in this paper provides a theoretical foundation for analyzing the stress-strain relationship of frozen soil using fractal geometry theories, and presents a new general method for simulating the stress-strain curve of frozen soil and calculating its fractal dimension by using a computer.

Fractal theory is a new effective method to solve complicated problems. Applications for the research of fractal theories in frozen soil are only at the initial stage. What a fractal dimension tells us about the mechanical properties of frozen soil, what are the physical implications of a fractal stress-strain curve, etc., are still open questions.

PERMAFROST HISTORY DURING THE MIDDLE AND UPPER PLEISTOCENE, MOSCOW-OKA REGION OF THE RUSSIAN PLAIN.

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Upper and Middle Pleistocene (~10 ka to 400 ka) deposits in the Moscow-Oka region of the Russian Plain are comprised of loess, till, glaciolacustrine and glaciofluvial sediments, with pedogenic and cryogenic overprinting.

Detailed studies of sections near the towns of Chekalin, and Gololobovo reveal four cryoturbated horizons during the last glacial cycle, and three during the penultimate glacial cycle. The oldest cryogenic horizon at these sites is a highly disturbed, 70 to 80 cm thick cryoturbated zone within the Kamenka Soil Complex (~380ka). Large solifluction lobes (~1.4 m x 0.75 m) are preserved approximately 3 m above the Kamenka Soil Complex. The latter stages of the Middle Pleistocene are marked by ice-wedge pseudomorphs (~1 m x 0.5 m) preserved beneath a Middle Pleistocene till. The Upper/Middle Pleistocene boundary is denoted by the Mezin Soil Complex that developed during the Eemian Interglacial (~125ka). The lower portion of this soil complex exhibits ice-wedge pseudomorphs (≤ 70 cm x 40 cm); immediately above, strongly cryoturbated A and B soil horizons suggest that a 70 cm thick active layer developed during the initiation of the last glacial cycle. Weak cryogenic overprinting characterizes the loess between the Mezin Soil Complex and the Bryansk Soil (24-32 ka). The last glacial maximum (~21 ka), however, exhibits large composite ground wedges, (≤ 1.9 m in height) overprinting a weakly developed soil.

FROST HEAVING NEAR ULAANBAATAR, MONGOLIA

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The Selbe-gol river begins in the Khentei highland foothills and joins the Tul river near Ulaanbaatar. This river valley is covered with alluvial deposits as deep as several dozen meters. The river bottom is broad and characterized by discontinuous island permafrost. The temperature of the permafrost ranges from -0.8 to -2.0° C. The base of the permafrost is at depths of 7 to 15 m. The ice content is low. The depth of seasonally frozen ground is 2.8-4.5 m. The city is expanding into areas underlain by permafrost.

The geocryology sector of the Institute of Geography and Geocryology was organized in 1963. At the time, Russian scientists began to support the study of geocryology in Mongolia. From 1963 to 1965, I.S. Cornilova, under the direction of Dr. V.F. Zhucov, collaborated with N. Lhagdandorrzh, building experimental stations in the Selbe-gol river's flood-plain in order to study frost heaving. In those three years, they obtained the first reliable data about frost heaving (Cornilova and Lhagdandorzh, 1965). This article contains some of the previously unpublished data collected during these experiments.

Station #1 was placed in placed in a portion of the flood-plain where there was vegetation. The ground consisted of boulders, debris, and sandy clay, and ice lenses were observed. Station #2 was located in a portion of the flood plain with dense vegetation and hedges. The surface included blocks, boulders, debris, and clay. The intensity of heaving of light loamy sand was 7-13 mm/year at station #1, and 22-25 mm/year on loamy soils at station #2. According to A. Anand's (1973) observations, the flood plain was characterized by frost heaving from 22 mm to 32.5 mm during an 18 day period (12-30, November, 1970). It follows that frost heaving occurred at 1.6 mm/day and reached 110 mm during the course of the whole season. The results of these experiments are similar to those of Russian researchers from the Angara river. For example, the frost heaving mean on the Angara river was 10-400 mm in one season (Voiloshnikov,1966). This may be explained by differing soils and moisture levels of deposits in the Selbe-gol and Angara rivers.

If frost heave was uniform, there would be no problem for buildings and roads. Problems arise only when thawing occurs and the ground's stability decreases. Weight is concentrated on the ground under a building's foundation and the ground stress under thawing soil varies greatly because the ice content is not uniform, and thawing affects different portions of the soil differently. Wall cracking is not a rare phenomenon in Mongolia, and frost heaving is rarely blamed. In 1958, the walls of a new wool factory in Khatgal began to crack after only one year of exposure.The building was repaired and given a stronger foundation by stopping soil stress. An engineering investigation showed the importance of permafrost in the damage (30% ice was found in the soil). The permafrost was as thick as 25-40 m in some spots. Its temperature was -0.5 to -2°C. The permafrost table was at a depth of 3.6 m on the territory's southern part and 2.8 m on the northern part. Similarly, N. Sharkhuu observed that a school in the region had cracks of 5-20cm with marked deformation. In particular, the school's stove had sunk by 20-30cm.

Overall, the intensity of frost heaving in Mongolia is moderate compared to that in other regions in the cryolithozone.

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DYNAMICS OF THE COASTAL ZONE OF THE GULF OF ANADYR, BERING SEA, DUE TO TIDAL ACTIVITY

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Long-term studies at five experimental sites in the Gulf of Anadyr and the Gulf of the Cross (Cape Nizky, Cape Dionissy, Cape Rogozhny, Cape Nezametny, Cape Kengynin) have shown that the main processes responsible for the coastal relief are destructive and constructive activity of waves and tides and thermal denudation processes on adjacent coastal land. The role of tides can be significant.

The climate of Chukotka coastal regions is severe, with long and cold winters, cool and rainy summers. The mean wind velocity is 6 m/s. The predominant direction of the winds is north-easterly in winters and south-westerly in summers. Significant pressure gradients, which have different directions from season to season, cause extremely irregular distribution of precipitation throughout the year, much of it being in the form of drizzling rains.

The northern part of the Bering Sea is covered with ice for 8-9 months a year. During summers, maximum air temperature is 12°C, water temperature is 7-9°C, and water temperature at the sea bottom is -1.7°C.

Involved in intense development of coasts are primarily lowlands of the Anadyr depression covered with unconsolidated Quaternary sediments of various facies. In addition to unsorted massive boulder loams, usually overlying dark, high plasticity clays with rare pebbles and shell fragments, there are also well-sorted sands and interbedded sands and pebbly gravels. The height of the coastal slope can vary from 10 to 40 m.

Permafrost and related cryogenic and postcryogenic processes and phenomena are widely developed on the coasts of the Gulf of Anadyr. Both ice wedges and injection ice of varying thickness are found in the permafrost. Blocks of glacial ice are common in glacial sediments. The volumetric ice content of sediments varies: some coastal sequences contain up to 4-5 horizons with polygenetic ice; their ice content is usually high.

The entire coast of the Gulf of Anadyr is influenced by high and low tides which also play a significant role in in seashore processes, in particular seashore profile, as water depth in the coastal zone changes due to the reverse character of the tides.

In evaluating geological-geomorphological role of the high tides, not only their velocity but also their level is important. Tidal amplification occurs in shallow and narrow embayments, such as the wedge-shaped Gulf of Anadyr and Gulf of the Cross. The tidal range is only 0.5-1 m on the northern coast of the Bering Sea, but reaches 2-2.5 m in the Anadyr Gulf and 5 m in the Gulf of the Cross. Thus, the tidal range always exceeds that of the waves which is below 1.5 m in the Anadyr Gulf.

It has been found that reworking of ice-containing coasts proceeds in a quite different way in the tidal zone as compared with the Arctic shoreline. This latter environment is dominated by thermal abrasion, i.e., destruction of coast under the influence of waves to form wave-cut niches which promote fast sea progression. The Anadyr Gulf coast is dominated by thermal denudation, i.e., thawing of the frozen coastal slope under the influence of solar radiation and warm air masses. Steady thermal denudation is favored to a large extent by the tides through complete and continuous removal of the thawed material from the coastal slope, which in turn facilitates fast thawing and denudation of the lower part of the slope and theoretically unlimited regression of its upper part.

However, the rate of coastal destruction is generally lower in the tidal seas (and increases with the tidal range) because the most active part of the coastal zone - the surf belt - migrates from maximum to minimum water levels along the coastal profile.

Our long-term observations (1971-1990) at experimental sites have shown that the mean rate of reworking of frozen coasts varies within 1 and 5 m/a in the tidal zone, averaging 2-4 m/a. Coasts with higher ice content (Cape Rogozhny, Cape Kengynin) are characterized by maximum regression rates.

PERMAFROST AND ACTIVE LAYER TRENDS ALONG A NORTH-SOUTH TRANSECT OF ALASKA

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A continuous program (since 1977) for investigating the effects of climate and environmental conditions on the active layer and permafrost has produced information on the variability of permafrost and active layer conditions, evidence for a recent warming of permafrost on a North-South transect of Alaska and observations of thawing discontinuous permafrost and thermokarst formation. The data show that permafrost temperatures along a transect from Prudhoe Bay to Glenallen and at Healy generally warmed in the late 1980's or early 1990's. This trend was not followed at Eagle, about 330 km east of the transect. The magnitude of the warming in continuous permafrost at sites close to the Arctic Ocean was about 4 °C at the permafrost table and about half that at sites farther inland. In the discontinuous permafrost, estimates of the magnitude of the warming at the permafrost table ranged from more than 0.5°C to 1.5°C. Modeling indicates that, in the discontinuous permafrost, the observed warming was part of a warming trend that began in the late 1960's with a total magnitude of about 2 °C. Warming rates near the permafrost table were about 0.05 to 0.2 °C yr^{-1}. No reliable trends in the depth of the base of ice-bearing permafrost nor in the depth of the 0°C isotherm could be detected. Active layer thicknesses at Franklin Bluffs and Deadhorse are near averages for the decade but at West Dock are near minimum for the decade. The correlation between active layer thicknesses and air temperatures was poor, bringing into question the paradigm that active layer thicknesses will increase with increasing air temperatures. Moss and peat layers are critical to the survival of permafrost in marginal areas. Thermal offset allowed mean annual temperatures at the permafrost table to remain below 0 °C with ground surface temperatures up to 2.5 °C. The observed warming has probably caused discontinuous permafrost in marginal areas to begin thawing. Thawing permafrost and recent thermokarst have been observed at several sites. Thawing rates at the permafrost table at two sites were about 0.1 m yr^{-1} indicating time scales on the order of a century to thaw the top 10 m of ice-rich permafrost. Calculated thawing rates at the permafrost base are an order of magnitude smaller. Calculations using calibrated numerical models showed that the observed warming is part of a warming trend that began in the late 1960's. In the discontinuous permafrost, increased snow depths were primarily responsible for the recent observed warming rather than warmer air temperatures. For any future warming, the greatest impacts of thawing permafrost will occur in areas of warm ice-rich discontinuous permafrost.

SUITABILITY OF CENTRAL ALASKA FOR EARLY DETECTION OF CLIMATE WARMING

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Considerable effort has been devoted to detecting early signs of upcoming climate warming in deep permafrost temperatures and predicting its consequences for nature and infrastructure in central Alaska (e.g., Lachenbruch *et al.* 1982; Osterkamp and Romanovsky, 1996). However, I would like to show that central Alaska is not a good location to identify early warnings of climate warming because it lies in the dynamic air mass boundary zone (Arctic Front, winter position), where mean winter air temperatures are dictated by the relative importance of temporal contributions of shifting air masses. These air masses are the relatively cold continental Arctic and warm maritime Polar that pass over Alaska (Bowling, 1984; Shaw, 1988, 1991), as the Arctic Front fluctuates latitudinally (Barry, 1967).

In central Alaska the mean winter air temperatures, which have a dominant effect on the annually averaged air temperature (Bowling, 1984) and soil heat flow (Putkonen, 1997), are dictated more by large-scale climate dynamics than by gradual changes in local air mass characteristics (Hartmann, 1994, p. 333). Hence, I hypothesize that observed changes in air temperatures and permafrost temperatures are more likely to reflect changes in circulation patterns than changes in the temperature of any air mass.

Daily air temperature data for the 1931-1995 period were obtained from the University of Alaska experimental station (146 m altitude) near Fairbanks (Climatedata, 1996). The two air masses that fluctuate over Alaska in winter carry an identifiable and distinct chemical signature that is related to their respective source areas (Shaw, 1988, 1991).

When the air temperature is at least 15°C colder than the mean seasonal air temperature, central Alaska is bathed by continental Arctic air (Shaw, 1988, 1991). This relation permits the number and duration of cold air advections in the November-March period to be correlated with the mean winter air temperature ($r^2 = 0.67$). Three mechanisms can be invoked to explain the strong correlation: (1) mean winter air temperatures in central Alaska are determined by air mass fluctuations, (2) a common external factor affects both the number of advections and mean winter air temperature, or (3) pure coincidence. The first mechanism seems most likely, because of the proximity of the Arctic Front and associated atmospheric circulation, and agreement with other studies (van Loon and Rogers, 1978; Walsh and Chapman, 1990) which concluded that recent temperature changes in the Arctic are induced by circulation.

Because of the large temperature difference of these air masses, I argue that the interannual standard deviation of surface air temperature is larger at the air mass boundary zone between continental Arctic and maritime Polar air than within either of these air masses. This is verified in the recent Atmosphere-Ocean Model control run [interannual standard deviation of air temperature, control DJF65-74 (http://www.giss.nasa.gov/data/caom/): Russell *et al.*, 1995], where globally strongest interannual variation generally follows the Arctic Front around the globe, being absent only in the Hudson Bay-Greenland region. Therefore, although the broad Arctic has been suggested as the site of largest anthropogenic temperature increase, attention should be paid to regional differences in the interannual variation and early detection of climatic change in the area attempted where the signal/noise ratio is the largest, e.g., well within air masses and away from boundary areas.

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KINETIC NATURE OF SOFT-FROZEN SOIL STRENGTH

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Two problems arise during determination of the long-term strength of soft-frozen soils (frozen peat, saline soils, ice-rich soils, etc.). The first problem is to determine the time before failure, because deformation of soft-frozen soil samples is plastic. The second problem is to obtain a parametric equation that allows the prediction of the soil strength during the period of structure operation.

We propose to solve these problems in the following manner:
(1) to determine the time before failure (t_f) of soft-frozen soil samples using experimental log plots of creep rate versus time. The t_f must correspond to the minimum rate in this plot.
(2) to express the time dependence of the long-term strength of soft-frozen soil samples under various tests by the equation:

$$\sigma_k = \frac{\sigma_{ok}}{\left(t_f / t_0\right)^{\beta_\theta}} \qquad (1)$$

where σ_{ok} (MPa) and β_θ are the parameters determined from the experimental dependence lg σ_k versus lg t_f at each of the constant temperatures; t_f is the time before failure under each of the fixed loads; t_0 is the period of free atomic oscillation, equal to 10^{-13} s.

The value of σ_k is calculated as a stress at the surface of solid components of the soil. These components are represented by ice and soil particles. We can determine the area of the surface only roughly, assuming that it is proportional to the volumetric content of solid components (K):

$$K_\theta = \rho_d\left[1 / \rho_s + \left(W - W_{un}\right) / \rho_i\right] \qquad (2)$$

where ρ_d, ρ_s, and ρ_i are the densities of a dry soil, soil particles, and ice, (g/cm^3); W is the overall moisture content, W_{un} is the unfrozen moisture content, (fractions of a unit).

Then the stress at the surface of solid components is equal to $\sigma_k = \sigma/K_\theta$, where ($\sigma$) is the stress at a geometric area of the sample section.

The presence of a point of convergence, equal to 10^{-13} s, shows that the soft-frozen soil failure has the thermal fluctuation nature.

The equation for the durability of solid materials, obtained by S.N. Zhurkov , is of the form:

$$t_f = t_0 \exp\frac{U_0 - \gamma\sigma}{KT} \qquad (3)$$

where t_f is the time before failure, t_0 is the period of free atomic oscillation, equal to 10^{-13} s; U_0 is the initial activation energy; γ is the coefficient of stress concentration; σ is stress; K is the Boltzmann constant, T is temperature (K).

A comparison of Equation (1) and Equation (2) allows the calculation of the activation energy for soft-frozen soils:

$$U_\sigma = \frac{2.3RT}{\beta_\theta}\left(\lg\sigma_{ok} - \lg\sigma_k\right)K_\theta \tag{4}$$

where $U_\sigma = U_0 - \gamma\sigma$; $R = kN_A$ (kcal/mol grad) is the universal gas constant; N_A is the Avogadro number.

The results of this investigation show that failure of soft-frozen soils has a thermal fluctuation nature.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project no. 96-05-6577A.

ROLE OF UNFROZEN WATER IN THE ACTIVE LAYER AND PERMAFROST

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Our recent results of *in situ* investigations of unfrozen water based on numerical analysis of the seasonal dynamics of the active layer and near-surface permafrost temperatures in Alaska, show that a layer with surprisingly large unfrozen water content exists during the freeze-up and following cooling of the active layer near the depth where freeze-up occurs. The curves of unfrozen water content as a function of temperature for this layer vary from site to site and at some sites show unexpectedly large values of unfrozen water at low temperatures (Osterkamp and Romanovsky, 1997).

Other evidence of the presence of a significant amount of unfrozen water in the permafrost was obtained from interpretation of the permafrost temperature profiles measured between 1981 and 1995 in thawing permafrost at a farm field on the University of Alaska, Fairbanks campus. This field was cleared of forest in 1940 and since then the permafrost table has lowered by more than 10 meters. Temperatures within the degrading permafrost have not reached 0°C but remain between -0.18°C and -0.2°C (precision better than 0.01 K) increasing very slowly (0.002 K per year). The length of the time required for the permafrost temperatures to reach 0°C can be estimated using the time constant, τ, for the response of a slab (degrading permafrost) to a step change in surface boundary conditions which is

$$\tau=\frac{X^2}{4D} \qquad (1)$$

where X is the permafrost thickness (about 40 m at this site) and D is the average thermal diffusivity of frozen silt (about $1.1\times10^{-6}\ m^2\ s^{-1}$). For these values, (1) yields $\tau \approx 12$ years. However, the temperature in permafrost is still increasing after 57 years of warming. This fact and the form of the temperature profiles in the upper part of permafrost can be explained only by the presence of significant amounts of unfrozen water in the degrading permafrost. Two major factors are responsible for the strong curvatures in this part of the temperature profiles and both of them are related to the presence of unfrozen water: first, the energy dissipation due to the increase of the unfrozen water content with increasing temperatures and second, the increase of the thermal conductivity with depth due to the increase of the ice portion in the total moisture content as a result of lower temperatures.

Using a numerical modeling technique, the daily permafrost temperature dynamics between two measurements made in the autumns of 1995 and 1996 were reconstructed for the Bonanza Creek site near Fairbanks, Alaska. It was found that a thermal model which does not account for unfrozen water can not reproduce correctly the temperature profile for 1996 when the measured 1995 temperature profile was used as an initial condition and the measured daily permafrost surface temperature was applied as a boundary condition. At the same time, very good agreement was found when unfrozen water dynamics was included in the model. The same conclusion was reported by Burn (1992) on the basis of a sensitivity analysis of the permafrost temperature dynamics in warm permafrost near Mayo, Yukon Territory, Canada.

Unfrozen water in the thawing, freezing and frozen active layer and near-surface permafrost (down to several meters) increases the amount of heat passing through the ground surface in the annual cycle. It also protects the ground from rapid cooling in the early winter after freeze-up occurs and, as a result, prolongs an increased heat flux out of the ground. This enlarged heat flux increases the warming influence of snow during this period. Depending on the presence or absence of unfrozen water in the freezing active layer and near-surface permafrost with the all other conditions the same, the ground surface temperature can differ significantly during the month of freeze-up and ensuing active layer cooling.

Unfrozen water dynamics in the soil after freeze-up and prior to thawing of the active layer play a major role in determining the physical conditions for microbial activity in the Arctic soil during winter.

The physical, chemical and mechanical properties of frozen ground and permafrost become strongly dependent on temperature when unfrozen water is present. This makes it important to know the unfrozen water dynamics in the active layer and near-surface permafrost for engineering purposes. The presence of a significant amount of unfrozen water can also lead to corrosion of pipelines buried in permafrost.

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PROPERTIES OF FROZEN GROUND AFFECTING FOUNDATIONS IN SOUTHERN ZABAIKALIE

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Southern Zabaikalie is characterized by complex regional physico-geographical, engineering-geocryological and hydro-geological conditions. The mean annual air temperature ranges from -0.2°C to -4.8°C and there is little precipitation. Seasonally frozen ground, and warm island and discontinuous permafrost exist. The depth of seasonal freezing is from 1.5 - 5 m. Where present, permafrost thickness ranges from tens of cm to 100 m with mean annual ground temperatures of 0°C to -2°C. To ensure that foundations remain stable in this region, it is necessary that local variability in frozen ground characteristics is properly assessed.

Heterogeneous conditions in the region are promoted by high insolation (dominated by direct beam radiation), combined with terrain that varies from fairly mountainous ridges to valley bottoms. In general, foundations are based on sedimentary rocks of Jurassic-Cretaceous age, including siltstones, sandstones and mudstones. These may be overlain by surficial deposits of Quaternary age. Regional permafrost conditions are also affected by seismic activity. Variability in the cryotexture of permafrost to depths of 50 m was established from 659 boreholes and 10 pits.

One of the main indicators of the characteristics of frost heave for buildings is the degree of heave under natural conditions. However, the degree of heave can change from weak to medium- and even high- during long-term maintenance of structures. Heaving in fine sediments is caused by both segregation and injection. The latter occurs in a closed system as the active layer freezes and also affects coarse sediments.

It is concluded that detrimental factors for building construction and maintenance for terrain subject to frost heave are (1) cryogenic pressures in water within the active layer, (2) blockage of downslope drainage of the active layer by foundations, (3) terrain changing from potentially flooded to flooded. For thawing permafrost, the main problems are derived from leakage of water supply and sewer systems, and from disorganized surface drainage during rain-storms.

ANALYSIS OF SOME PERMAFROST FEATURES THROUGH CRYOSTRATIGRAPHY AND GROUND PENETRATING RADAR (G.P.R.) INVESTIGATIONS ON AN EMERGING COAST, NASTAPOCA RIVER, SUBARCTIC QUÉBEC

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Ground penetrating radar (G.P.R.), a recent geophysical method similar to seismic reflection and sonar, was used to characterize permafrost cryostratigraphy in coastal and marine sediments. The nature and properties of these fine materials have allowed abundant ice to accumulate in the ground and different geomorphological processes to occur. This study was concentrated on cryogenic mounds, permafrost plateaus and polygon fields in the coastal zones located on both sides of the Nastapoca river. The abundance of permafrost and high concentrations of ice in the coastal zone are in part attributable to the harsher climatic conditions associated with the presence of the Hudson Bay.

G.P.R. profiling was undertaken at several sites in order to define the lateral and vertical distribution of ground ice. For this purpose, an analysis of the electromagnetic signatures from different permafrost features was conducted. Topographic corrections were applied to the profiles as well as spatial and temporal filters and gains in order to obtain a better resolution of the electromagnetic signatures. Boreholes, down to 3 m in depth, located on the same transects as the G.P.R. profiles allowed validation of the G.P.R. data. The cores obtained were logged for estimated ice content, ice characteristics and distribution, and soil type. This cryostratigraphic analysis of the permafrost features gave information on type, quantity and distribution of ground ice as well as on the nature of sediments. These elements are important in the delineation and mapping of permafrost and geomorphological features.

The major reflectors on the ground penetrating radar profiles are associated with different permafrost and stratigraphic features such as the permafrost table, the thaw front, ice-rich layers and stratigraphic boundaries. Some periglacial and permafrost elements can also be observed through the G.P.R. signatures. These include expansion cracks, ice-rich mounds and particularly the underground structure of frost boils. This study permitted correlations to be made between cryostratigraphy and G.P.R. signal for the purpose of describing the internal structures of permafrost features.

RESPONSE OF THE CRYOLITHOZONE IN YAKUTIA TO CLIMATE CHANGE

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The problems of the sensitivity of the thermal regime of frozen ground in Yakutia to the fluctuations (yearly and long-term) of such climate elements as air temperature t_a and its components, average summer (Ω_s) and winter (Ω_w) temperatures, snow cover thickness and density, are considered. The regional characteristics of the air thermal regime are analyzed on the basis of the data of meteorological observations and the results of the global atmospheric circulation simulation at doubled CO_2 concentration (GFDL, GISS, NGAR, OSU, UKMO). The latter allowed the estimation of the spatial distribution of future air temperature increases.

It is shown that within the regional mainland t_a varies from -4.4 to -18.0°C, whereas Ω_s ranges from 5,000 to 46,000 degree-hours. At doubling atmospheric CO_2 concentration, these characteristics will fluctuate in the range of -1.3 to -13.5°C and 10,000-64,000 degree-hours, respectively. It is noteworthy that the future climate have a changed degree of continentality compared to the present-day`s, with some increase in the central and eastern, considerable decrease in the northern, and slight decrease in the western and, partially, southern regions. t_a and Ω_s will increase by an average of 3.7°C, 4.5°C, 6.0°C, 3.1°C and 14,500, 15,000, 5,000, and 18,000 degree-hours, respectively.

A numerical simulation of ground temperatures in Yakutia for equilibrium values has shown that the average annual temperature of rocks now varies from 1.8 to -14°C. In the future its range will be 5 to -9.3°C. At the same time the average rock temperature increase will be 5.1°C in the north, 3.2°C in the south, 5.7°C in the east, and 4.2°C in Central Yakutia.

The concept of the coefficient (K) of permafrost sensitivity to climate warming is introduced. Numerically it expresses the value of the soil temperature increase per degree of increase of the air temperature. The calculations show that K averages is 0.85 for the north, 1.03 for the south, 1.14 for the central area, and 1.27 for the east of the region studied. The latter means that the sensitivity to climate warming is lowest in Yakutian Arctic and highest in its eastern and central areas.

In our opinion, the southern border of permafrost distribution in Eastern Siberia should be considered to be the -2.5°C mean annual air isotherm, and of the continuous permafrost, about -7.5°C. The equilibrium model of the soil temperature regime predicts the movement of the borders further northward: to -7.0°C and -13°C, respectively. However, as this model does not take into account the actual time of the system operation, it is able to reveal only some of various patterns of the temperature regime formation in the soils of the region; hence, it does not give an idea what actually will happen with the actual soil temperature increase in the region when the climate is warmer. The calculations have been done for climate conditions in Yakutsk for the period up to the year 2060.

Three options have been considered.

Option 1. The air thermal characteristics change linearly. As a result of this change in upper boundary conditions, the inertia of the thermal field of perennially frozen ground decreases it by 27-33%.

Option 2. Yearly fluctuations of air thermal characteristics, snow thickness and density, are imposed upon linearity. The calculations show that yearly fluctuations of these elements also decrease the cryolithozone response to climate warming.

Option 3 should be considered summarizing, as it takes into account the increasing trend of air temperature due to CO_2 doubling and natural historic fluctuations of the climate elements: air temperature characteristics taken through the harmonic analysis of the Yakutsk example, in particular, show climate warming for 1995-2020 and its sharp cooling by the middle of the next century. The conditions of this option reduce the soil temperature increase acquired by equilibrium models by the total of 54%. Extrapolating the results to the entire territory of Yakutia, we arrive at the following scenario: the coefficients of permafrost sensitivity to climate warming and of the average annual soil temperature increase by 2060 will be, respectively, 0.39 and 2.3°C in the north; 0.47 and 1.5°C in the south; 0.58 and 2.6°C in the east; and 0.52 and 1.9°C in Central Yakutia.

Finally, taking into account the delayed response of the climate system to CO_2 concentration increase, the authors conclude that the soil warming will hardly exceed 0.5-1.5°C by the end of the calculation period. The « climate optimum » predicted for 1995-2020, when yearly air temperatures can exceed long-term annual by 2-3.5°C, can be more dangerous for permafrost in the region.

CLIMATE WARMING AND MONITORING OF THERMAL STATE OF SOILS IN CENTRAL YAKUTIA

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Studies of the thermal state changeability in upper layers of permafrost are becoming urgent in connection with global climate warming expected in the next century.

To determine the evolution of the thermal state of soils under the influence of climate change, the authors have been undertaking monitoring in Central Yakutia since 1981. The region is characterized by a strongly continental climate with low winter temperatures and high annual air temperature amplitudes.

The investigation area occupies the right and left banks of the Lena River at the latitude of Yakutsk. Experiments are made by complex methods: landscape, climate, thermophysical and hydrothermal. Remote and *in situ* studies of natural complexes, their systematization and cartographic summary have been made. Landscape studies of the natural complexes of the area allowed the definition of 8 terrain types, including over 100 types of urotshistshes (smaller terrain units) and facies.

Monitoring sites cover practically all terrain types typical for Central Yakutia. Observations were made in all dominating and most characteristic urotshistshes and facies. Within each observation site, boreholes were drilled to 10-20 m depth and prospecting digs were made with sample selection, determination of soil lithological composition, cryogenic structure and thermophysical properties. The boreholes are equipped with stationary thermistor sensors for scheduled thermal observations. The objects of research are the soils in the layer of annual temperature fluctuations. Heat exchange between the surface and atmosphere (meteorological elements, vegetation and soil cover), soil composition, physical and thermophysical properties and heat regime are all studied.

The current changes of the main climate parameters (air temperature, precipitation, snow cover) in Central Yakutia (on the data of over 30 meteorological stations) were analyzed. In the past century at Yakutsk, the average annual air temperature has increased by 0.8°C. The most significant changes have been observed for the last 30 years, mainly because of warm winters. For 1965-1994, the air temperature trend has been + 0.073°C/year, whereas in 1981-1994, it was +0.097°C/year. The analysis of the nearest meteorological stations data does not show any correlation with the urban effects. The same period is characterized by some increase in snow cover. Annual and summer precipitation were within normal limits.

Our investigations allowed quantitative estimation of the spatial changeability of main parameters of the soil thermal state: seasonal active layer thickness (ξ)and average annual temperature at this depth (t_ξ). For each landscape the main parameters controlling the soil thermal state were defined. Depending on the landscape conditions, ξ varies from 0.5 to 5m, whereas t_ξ is from 0.5 to -6.5°C.

The effect of climate change on the soil thermal state was analyzed using data from Chabyda station, 20 km to the southwest of Yakutsk. The station territory comprises slope and small valley terrain types, the former being the warmest, the latter the coldest. For that reason the monitoring observations of these two terrain types should give the idea of entire range of the soil temperature fluctuations and the active layer thickness both in time and in space. Yearly fluctuation t_ξ is chiefly determined by the winter fluctuations of air temperature and the height of snow cover, ξ by summer precipitation and summer air temperatures. The highest yearly changes of t_ξ (to 3-3.5°C) were registered in the small valley, of ξ in the slope (to 0.8-1.0 m). Due to short-term climate fluctuations, a considerable soil temperature increase occurred from 1986-1987 to 1990-1991. In the following years, the soil temperature decreased slightly.

Our studies show an ambiguous soil response to climate effects. The increasing trends of soil temperature and the increase of active layer thickness have not been observed during 15 years of research, on the background of general increase of the average annual air temperature.

The aim of further investigation is to arrange monitoring sites in different terrain surroundings, and to evaluate climate effects on the soil thermal state for a longer period.

A COMPARISON OF DECADAL AND MILLENNIAL VELOCITIES OF ROCK GLACIERS IN THE SELWYN MOUNTAINS, CANADA.

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Surface velocities derived from surveys in 1983 and 1995 are compared with velocities derived using lichenometric ages and rock glacier length on nine rock glaciers in the Selwyn Mountains of the Yukon and Northwest Territories. During the last glacial maximum, the Selwyn Mountains were covered by a northern extension of the Cordilleran Ice Sheet and the region has been deglaciated throughout the Holocene. Today it is an alpine environment characterized by sporadic permafrost. In 1983, we established survey arrays on 22 rock glaciers in the Frances Lake area of the Selwyn Mountains. In 1995, we successfully re-surveyed 15 of the 22 rock glaciers, obtaining a 12-year record of rock glacier surface movement (Sloan and Dyke, 1998; in preparation). Nine of these rock glaciers were lichenometrically dated in an earlier study (Dyke, 1990). This data set is unusual in that it comprises velocities from a group of rock glaciers rather than from an individual rock glacier. The mean surveyed velocity for the nine rock glaciers was 0.20 ± 0.11 m/yr., and the mean lichen-based velocity for the same nine rock glaciers is 0.20 ± 0.13 mm/yr. No significant difference between the two sets of velocities was found at the 0.05 level of significance. Uncertainties in the measurements require that prudence be used in drawing conclusions, however the decadal and millennial velocities are of the same order of magnitude even when the errors are accounted for. Whalley *et al.* (1995) found that centennial-scale rates of one rock glacier in Iceland were one order of magnitude greater than decadal velocities in a similar comparison of age/length-based velocities and surveyed velocities. By comparison, the difference observed between decadal and millennial scales on these rock glaciers is small. The Glockturn rock glacier in Austria is estimated to have flowed at ca. 0.10 to 0.15 m/yr. during the last 7,000 to 10,000 years (Gerhold, 1970, in Barsch, 1996), a velocity that is of the same order of magnitude as those presented here. Two conclusions can be drawn: (1) the millennial-scale velocities are of the same order of magnitude as the surveyed decadal-scale velocities for these nine rock glaciers in the Selwyn Mountains, and (2) either method can be used to determine long-term rock glacier velocities with some confidence.

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STONE-BANKED TERRACES IN RISCOS RINK, JAMES ROSS ISLAND, ANTARCTIC PENINSULA REGION

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James Ross Island is located in the Antarctic Peninsula Region at a latitude of 63°S. Ice-free areas occur in the northwest part of the island where many kinds of periglacial landforms develop. The island is mainly composed of Cretaceous sedimentary rocks and thick volcanoclastic deposits of Late Miocene to Holocene age. Riscos Rink is a lava plateau at an altitude of 400 m a.s.l. Stone-banked terraces occupy the southwest-facing slope of 4° which is 1100 m long. There is a small ice cap about 1.5 km in diameter at the upper end of the slope. In the summer period the ice cap supplies melt water downslope to the stone-banked terraces. Larger terraces are observed on the lower part of the slope. The fronts of the stone-banked terraces are lobate and stony. Most of the superficial materials at the terrace front range from 10 to 20 cm in maximum dimension, but some are as large as 50 cm. Fine material is absent. The fronts slope at angles of 8° to 17° and have a maximum height of 5 m. The lower ends of the fronts of stone-banked terraces mostly cease on the blocks of bedrock. The terrace treads have a maximum length of 40 m and a maximum width of 60 m. The tread near the front is nearly horizontal at angles of 0 to 1°. Immediately behind the front slope the long axes of stones are rotated to an orientation paralleling the front. Sorted polygons are currently active on the treads. Frost-heave phenomena are frequently observed in the centers of sorted circles. The treads become gradually steeper up to 2 to 3°, where sorted stripes are present.

The stone-banked terrace, which was chosen for excavation, was about 1.25 m high and 15 m long. On the upper part of the front of the terrace, the surface layer of stones was dry and more than 50 cm deep. It thins toward the lower part of the front. Within this layer, stones become progressively smaller with depth but interstitial fine material is absent. Tabular stones tend to lie parallel to the surface. A sand layer was detected beneath the stone layer. At the lower part of the front, fine material is overlain by a sand layer 8 cm thick. The stones on the tread of the stone-banked terrace are smaller than those on the front. The surface stone layer on the tread, which overlays fine material, is 15 to 12 cm thick but becomes thinner upperslope. The depth of the frost table at the tread is about 50 cm in early February.

The authors measured air temperatures in Riscos Rink at two-hour intervals from the end of January 1995. Mean annual air temperature in 1996 was -6.8°C. The warmest month in 1996 was February with mean monthly temperature of 0.6°C. July in 1995 and June in 1996 were the coldest months with mean monthly temperatures of -21.4 and -15.4°C respectively. The highest and lowest air temperatures in 1996 were recorded as 15.7 and -30.1°C, respectively. The calculated freezing index amounts to about 2740°C days, and thawing index about 240°C days in 1996. Air temperatures crossed the freezing point on 149 days in 1996. These conditions favour the development of certain kinds of periglacial landforms such as patterned ground, and solifluction lobes, because these landforms are closely related to the freeze-thaw activities. Snowmeters, placed at the bottom of the front of the stone-banked terraces, show one-year snow accumulation reaches a depth of 80 cm. However, snow hardly accumulates more than few decimeters on the treads because of strong winds.

Stone-banked terraces are defined as terrace- or garland-like accumulations of stones and boulders overlying a relatively stone-free moving subsoil (Lundqvist, 1949; Benedict, 1966; Embleton and King, 1968). The above-mentioned characteristics are in agreement with the observation of stone-banked terraces in Riscos Rink. However, they differ from general description on several points: notably the gentle slope where stone-banked terraces develop in Riscos Rink, and the angles of the fronts of stone-banked terraces. There are possibly some difference regarding their developmental processes. One of the reason why stone-banked terraces, not turf-banked terraces, occur on the gentle slope in Riscos Rink, is due to the absence of turf-like vegetation on James Ross Island.

SOME GEOTECHNICAL INFLUENCES ON THAWING ALPINE PERMAFROST

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The importance of Alpine permafrost as a natural hazard is increasing due to climate change. Granular soil particles of various shapes and sizes, bound together in a cohesive fashion within the permafrost by interstitial ice and associated suctions at just $<0°C$ form a matrix of interlocking frictional cohesionless particles as the ice changes state. Within the thawing zone, instability is most likely due to water flow combined with the elevated pore pressures which accompany the thawing process, both of which may trigger sliding.

When temperatures rise, the active layer will extend deeper into the permafrost, allowing increasingly larger volumes of material potentially to form debris slides. Within this active zone, the frictional material response will be governed by *in-situ* effective stresses s' from inter-particle contact. If the pore pressures rise, either due to large quantities of water or the thawing processes, then s' drops. This can be catastrophic since stability depends on s' (and inter-particle friction f'); the maximum shear stress $= s' \tan f'$.

Creeping rock glaciers (with end and side slopes of 45° due to the soil-ice-interaction) offer ideal conditions to study these phenomena. The natural slope of loose unfrozen material is 40° dry and 20° if water flows steadily in fully saturated conditions parallel to the slope. This may cause instability at rock glacier boundaries when there is minimal water flow, but significant instability if large volumes of water are released suddenly.

The stress distribution within creeping permafrost varies with time. Intense loading in the form of compression, shear or crushing will occur in the ice and at particle boundaries, especially along the shear zones, causing ongoing strain and movement within the matrix. Hence, creeping materials generate less shearing resistance than those loaded monotonically to failure. During primary creep, the rate of strain gradually reduces until a secondary phase is reached, with constant strain rate. Deformation continues until the internal ice crystal-particle structure is so aligned, that resistance is further reduced. The strain rate accelerates towards failure (tertiary phase; Vyalov *et al.*, 1965) and the structure will fail at significantly lower loads than expected.

The perennially frozen, creeping mass exists as an ice-water-air-soil mixture, with different percentages of each component. The macroscopic behaviour (i.e. the permafrost deformations) will be controlled by near-microscopic particle-ice interactions, and these require further clarification. The important physical properties (strength and stiffness) of permafrost may be determined from laboratory triaxial testing of cylindrical samples under temperature controlled conditions. Influencing parameters are: temperature, relative percentages of ice and soil, soil particle size and shape, unfrozen water content, confining stress and strain rate.

The colder the temperature, the stiffer and stronger the matrix will be. Additionally, the temperature must be $<-5°C$ before the interstitial water is frozen, due to the Gibbs free energy around the particles which causes capillary forces.

The relative percentages of ice and soil, together with the particle sizes, control the ultimate strength of the frozen matrix. Three phases are observed (Ting *et al.*, 1983). For ice-rich material, strength increases 26 % c.f. massive ice. With increasing sand %, the particles contact each other and the structural effect of embedding relatively hard particles in ice strengthens the matrix. For dense packings (57 %; ice-poor), particle interlocking causes dilation (volume increase) prior to failure, generating further strength.

Shearing action in the pore ice causes both crushing and shear within the crystals, which is dependent on the confining stress level and relative density of the soil particles. The strain rate will also affect the failure stress strongly; faster straining allows higher strengths to develop.

For a better understanding of the thermo-mechanical behaviour of a rock glacier, new investigations must be carried out. When testing in the laboratory, conditions appropriate to those measured in the field should be applied, and original soil samples should be used. For example, the greatest shear strain rate (0.015 strain/year), deduced from deformations in the Murtèl-Corvatsch rock glacier, was in a layer containing 50 % silty sand and 50 % ice at approximately 30 m depth and -1°C (Hoelzle *et al.*, 1998). These will form control conditions for laboratory tests to determine strength and stiffness of typical Alpine permafrost relating to time and temperature.

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THAW-CONSOLIDATION BEHAVIOUR OF SOME BRITISH SOILS.

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Fossil periglacial solifluction features cover most of Britain, particularly the Midlands and the South, causing serious and continuing earthwork and construction problems. Although the engineering significance of the presence of periglacial solifluction deposits is widely appreciated, the mechanics of emplacement of these deposits in Britain has received surprisingly little attention. Research on the engineering aspects of fossil periglacial solifluction has been conducted at the University of Warwick for several years. Recently attention has also been directed towards the scientific understanding of the mechanisms involved. To this end, a "Permode" has been constructed, based on the design of the originators at the University of Alberta in Edmonton, Canada. The Permode is an oedometer equipped with freezing and thaw capabilities and associated pore water pressure devices. The apparatus in use at the University of Warwick takes samples 100 mm in diameter and about 100 mm long. The samples are subjected to axial (vertical) loading and pore pressure measurements can be made at top and/or bottom of the sample. The top loading cap and lower platen each contain a convoluted channel through which the freezing liquid is circulated. Thermocouples situated at various positions along the length of the apparatus monitor the temperature profile through the sample.

Initially the permode is being used to investigate the pore pressure response of soils when subjected to cycles of freezing and thawing under undrained conditions. Since the applied stress on the sample is known, the effective stress can be calculated. This "residual stress" has considerable implications for the stability of slopes under periglacial conditions.

Further testing will investigate the response of soils when subjected to cycles of freezing and thawing with drainage permitted. The results will be compared with the thaw-consolidation theory developed by Morgenstern and Nixon (1971).

Testing at present is being carried out on some British soils (e.g., London clay, Lias clay), taken from sites where shear surfaces developed under periglacial conditions have been recognised.

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PRESENT STATE OF MEASUREMENTS OF CRYOGENIC PROCESSES IN THE LAGUNITA DEL PLATA, MENDOZA, ARGENTINA, REPORT NO. 2

D. Trombotto, E. Buk, J. Corvalán and J. Hernández

In March 1996, a new expedition was undertaken to the Lagunita del Plata (33°S, 69°W), Cordòn del Plata, Cordillera Frontal, Mendoza, Argentina. The estimated mean annual temperature in this peOriglacial area of the Andes Centrales is -2°C and the annual precipitation is 600 mm.

From 4500 m on upwards the region presents « approximately continuous » permafrost (denomination introduced by Garleff and Stingl, 1986). Supersaturated mountain permafrost (Haeberli, 1985) however is present at altitudes of 3700 - 3800 m a.s.l. in the distal tongues of active rock glaciers.

At 4500 m a.s.l. and close to perennial snow patches, permafrost is found at a depth of 90 cm (Trombotto, 1991). Dry permafrost appears at 4400 m a.s.l., at a depth of 90 cm.

The expedition had two objectives: (1) to verify the occurrence of island permafrost at 4000 m a.s.l. on an inactive cryoplanation surface and (2) to remeasure solifluction movements between 4000 and 4500 m a.s.l.

In order to collect more specific data on the subsoil of the cryoplanation surface and the occurrence of permafrost, two geoelectrical profiles with a length of 600 m (W) and 200 m (E) respectively were made, applying the Schlumberger method.

Four layers, each with different characteristics, but correlated in both profiles, were distinguished. Layer three was of special interest because on the E profile and at a depth between 11 and 50 m it resulted in an apparent resistivity of 260 Ωm with considerably dispersed values. The value in the W profile, a layer saturated with water, was 55 Ωm. This layer coincided with the one detected by seismics in 1987 with values around 1200 m/m.

Applying the Terzaghi-Barsch formula, the minimum depth of the permafrost table was found at a depth of 10 m, coinciding with the values above. This layer was interpreted to contain degraded permafrost, denominated « humid island permafrost » by the authors, because it is affected by meltwater from the south slope bordering the cryoplanation surface.

It is deduced that outside the environment of the rock glaciers of the Cordòn del Plata and at up to 4000 m a.s.l., island permafrost is still found. Therefore the occurrence of permafrost from 4300 m a.s.l. on upwards and close to snow patches corresponds to the lower limit of the discontinuous type. On the other hand continuous permafrost may only be expected approaching a height of 5000 m a.s.l. where cryoplanation is active.

For solifluction measurements, two cases were taken into account: (1) movements of the points within the geodesic triangulation network and (2) 7 points on solifluction lobes. Data were obtained from measurements in 1983, 1987 and 1996. The lobes are located in greywacke, the first four between 3985 and 3991 m a.s.l. and the other three between 4011 and 4014 m a.s.l.

In the first case, maximum speeds (6.5 cm/a) on terracettes or « balconies » on cryogenic sedimentary slopes on south-exposed slopes were registered between 1983 and 1987 between 4371 and 4491 m. The maximum value during the second period however was reduced to 3 cm/a.

In the second case, on the solifluction lobes, this phenomenon is repeated. Between 1983 and 1987 maximum speeds oscillated between 2 and 5 cm/a, while between 1987 and 1996 the maximum value was of 1 cm/a only. In both periods, vertical movements of the measurement marks were registered. Upward movements, particularly in the first period, may be caused by extrusion. The downward movement may be explained by the frontal position of the marks or possibly also by the removal of the sediments caused by slopewash.

Analysis of variations in the physical dimensions of perennial snow patches on the south face and the lake on the cryoplanation surface, showed that these changes could be correlated with extraordinary meteorological events such as the El Niño phenomena of 1982-1983 (very strong), 1987 (moderate) and 1991-1992 (moderate).

During the first four years, two El Niño phenomena were registered, and it is assumed that these affected cryodynamics and reactivated processes. In the following period of measurements however, only little noticeable changes were registered although this period lasted much longer. This may be explained by the occurrence of only one El Niño phenomenon of little local impact.

The long warm and dry period strongly influenced the area reducing its snow-covered surface, reinforcing the action of meltwater and even lowering the water-level of the lake, but this influence was interrupted by extraordinary events like years of particularly heavy snowfall and cool summers which also have to be considered for the measurements as they trigger or increased cryogenic processes.

The above mentioned data need to be confirmed in the future by more information and more frequent measurements.

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SEASONALLY AND PERENNIALLY FROZEN GROUND AROUND ULAANBAATAR, MONGOLIA

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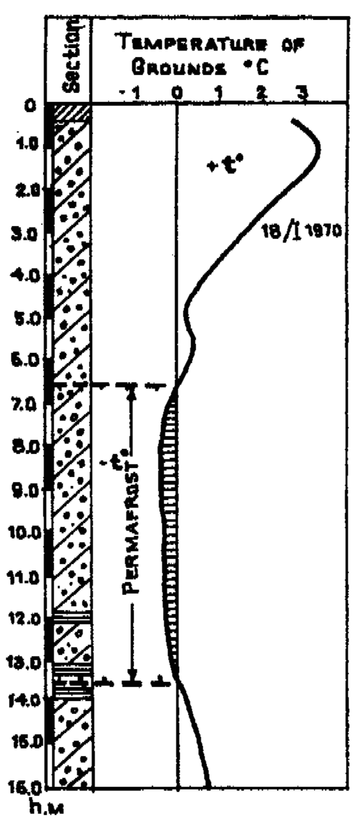
The landscape around Ulaanbaatar is mountainous and the territory lies at an altitude of 1300-2258 meters above sea level. The mean annual air temperature is -3.1°C and the mean temperature in January is -26.5°C and in July it is 18°C in the valley bottom. The altitudinal lapse rate is 0.6-0.8 °C/100 m. Annual precipitation is 250 mm in the valley of Tuul River and 433 mm at high elevation (H=2250) of the river catchment area. Stable snow cover forms in the first 10 days of November and melts at the beginning of April. Mean snow cover depth is 5-7 cm with densities of 0.2-0.21 g/cm^3.

There are many icings, frost heaved areas, cracks and kurums around Ulaanbaatar. The depth of seasonal freezing in alluvial sandy loam with pebbles and gravels is from 2.6 to 4.5 m. Small islands of permafrost occur in the territory of the city. In particular, they develop in higher moisture content loamy sediments, in the valleys of the Selbe and Uliastai Rivers, and near Nogoon nuur Lake (Figures 1 and 2). Permafrost thickness ranges from 7 to 15 m and its mean annual temperature is -0.2 to -0.3 °C. Shops and buildings constructed in 1960 near Nogoon Nuur have been destroyed by the influence of permafrost.



TEMPERATURE OF GROUNDS (BORE HOLE 15)

depth	temperature of grounds °C
0.5	2.81
0.75	3.10
1.00	3.34
1.25	3.30
1.50	3.22
1.75	2.92
2.00	2.57
2.25	2.19
2.50	2.00
3.00	1.19
3.50	1.11
4.00	0.79
4.50	0.30
5.00	0.26
5.50	0.48
7.00	-0.20
10.0	-0.15
11.25	-0.2
12.5	-0.12
13.25	-0.1
14.25	0.29
15.0	0.38
16.0	0.70

***Figure 1.** Temperature grounds of the Nogoon Nuur area (Bore hole #15)*

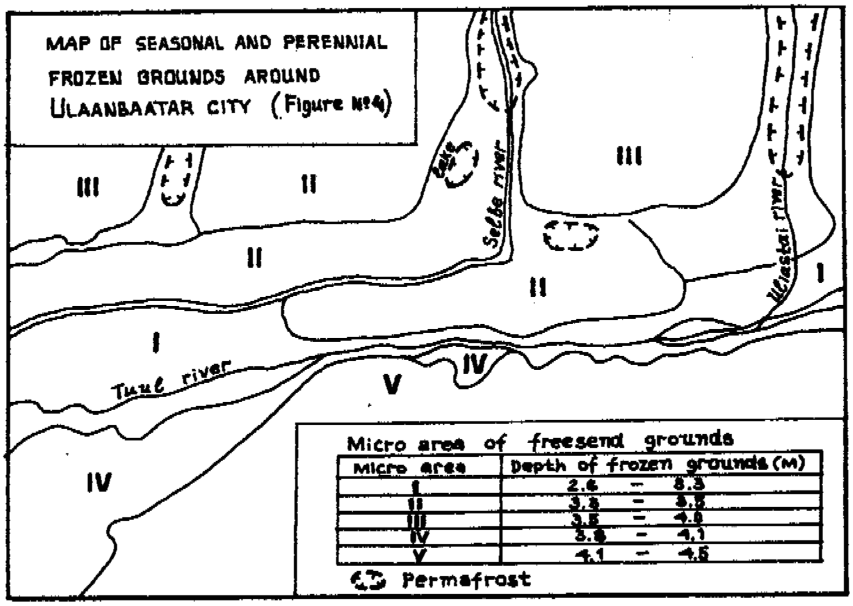


Figure 2. Map of seasonal and perennial frozen grounds around Ulaanbaatar city

The biggest icing, Arshaant Khalia, located in northern part of the city, is 0.5-1.0 m deep and occupies 1000-3000 m^2.

Seasonal ground freezing near Ulaanbaatar reaches 2.6-2.4 m. A map of seasonal freezing of grounds in the area of Ulaanbaatar city at a scale of 1: 25 000 was completed in 1995 for use in building construction and siting of water supply pipelines (Figure 2).

During the last 70 years the air temperature in Ulaanbaatar has increased by 0.7°C and ground temperatures have increased by 0.1-0.3°C. Calculations show that this warming leads to a decrease in the depth of seasonal freezing of ground by 0.1-0.3 m.

CAINOZOIC PERMAFROST RECORD

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Permafrost develops during cooling phases, controlled by orbital forcing. High latitude permafrost is related to the assembly of continental masses in polar positions such as Antarctica during the Paleogene. Probably, as with glaciation, it is also controlled by the obliquity of the Earth. Permafrost development in middle latitudes corresponds with low summer insolation controlled by precession, increasing continentality and albedo related with glacio-eustatic lowering, and after a reduction of the greenhouse effect at the end of interglacial. The distribution of permafrost during the middle Cainozoic is uncertain. Climatic cooling started at the end of the Eocene in the southern Hemisphere, and led to an Oligo-Miocene Glaciation on the Antarctic continent. Sea ice evidence is known on the Arctic shelf at that time and local mountain glaciation is described in Alaska from the early Miocene. But traces of iceberg rafting are known on northern Atlantic shelves only from about 11 Ma onwards (Bleil, 1989). The glaciation of Greenland commenced about 9.5 Ma ago. There is evidence of valley glaciers in Scandinavia and in western Cordillera from 2.6-3 Ma and of an ice cap from 2.3-2.2 Ma (N. America, Alps, Scandinavia). A Scandinavian ice cap reached North Sea shelf only around 1 Ma. Ice rafting events suggest indirectly that permafrost existed in the regions surrounding the Arctic Ocean, before the opening of the Fram Strait, 5 Ma ago. Lower Pliocene evidence of permafrost in the Kolyma-Indigirka is given by Gylichinsky et al (1988) and Middle Pliocene extension is suggested by Western Siberian basin palaeo-temperatures (Galushkin, 1997). Extended marine regressions at 11, 5.2 and 2.6 Ma left wide areas of the Arctic shelf exposed and a climate cyclicity suggests the discrete formation of some permafrost at least since the Middle Miocene, probably continuous in the Kolyma and the Western Siberia at least since the Plaisancian (3.5 Ma). The first large extension to the South occurred early, in parallel with the largest ice sheets evidence at 2.2 Ma. No evidence of large glaciations are known between 2.2 and 1.2 Ma nor from sediments nor from OI record. From isotopic curves, notable cold phases started around 600 ka. From the core site located at 21°N in Guinea Gulf, intense glacial stages were only found after 480 ka (OI stage 12). Except for the Pliocene event, most of the classical permafrost features are younger than 600 ka, occurring after the 400 ka crisis. This is also valid for Europe and for southern Siberia. The autocyclic limitation of ice sheet volume by sea water thermal budget limits the Quaternary glaciation and the permafrost extent in the present-day landmass configuration.

Some authors have claimed that permafrost developed early in the Quaternary, for example in the Tiglian stage, 1.8 Ma, especially in sites located in tectonic basins reactivated since the Neogene. Old Quaternary "cryoturbations", ice wedge casts described in such location in Western Europe correspond to extension fissures, karstic slumps or other type of non-periglacial deformations. Pseudo-periglacial involutions correspond to load casts of co-seismic origin or in other cases, to water escape and loading of glacio-tectonic origin. The specific location in cluster of co-seismic features, and their restrictions to sedimentary basins or thick saprolites, allow their differentiation from other processes. Their stratigraphic occurrence fits with those of glacio-isostatic readjustments. Periglacial cryoturbation is related to water available for ice segregation, differential frost heave and is rather regular within a topographical unit, but is not necessarily related to permafrost. Opposite, co-seismic loading, pseudo-pingos related with compression shear or extension fissures are rather irregular in the topography, associated with reverse microfaults, concave failures, overconsolidation, water escape and dewatering structures. The study of real ice wedge casts in Europe allows an understanding of the law of their recurrence throughout the Last Glacial, alternating with loessic sedimentation. Their development is correlated (1) not with orbital forcing, but more probably to winds related with the cyclic thickening /thinning of ice sheets (Heinrich and Dansgeard-Oechger events), (2) not with the extension of continuous permafrost, but well with the ice content in the upper permafrost layer and a low snow precipitation. Using these interpretations of periglacial features for palaeopermafrost reconstruction, data fit with the late Neogene global change.

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RESPONSE OF THE THERMAL REGIME OF SOILS TO RECENT CLIMATIC CHANGES IN YAKUTIA

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In Yakutia, continuous monitoring of the temperature of soils has been carried out since 1931. However, because of frequent relocations of weather stations, representative data are available from only 30 stations for the period of 1965-1987 (Figure 1).

This paper presents the analysis of linear trends of the mean annual temperature of soils at 1.6 m depth ($t_{cp1.6}$). Shown in Figure 2 are the most characteristic mean annual temperature dynamics of soils at 1.6 m depth and their linear trends.

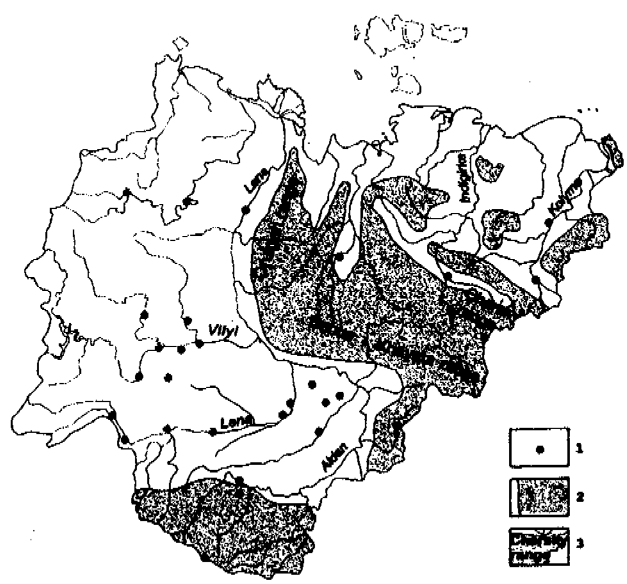

Figure 1. *Locations of weather stations which record soil temperatures.*
1: weather station; 2: mountainous areas and their boundaries; 3: names of mountain ranges.

They allow three regions to be distinguished: (1) the northern plain areas with a decreasing trend; (2) the south-western, central and north-eastern areas with an increasing trend; and (3) the southern, south-eastern and central-eastern mountainous areas with either a steady trend or a trend with opposite signs.

1. The first region covers the tundra and northern taiga in north-eastern Yakutia where $t_{cp1.6}$ shows no marked rise but has a tendency to decrease by 0.03-0.04°C/yr (Sukhana, Jarjan stations). Over the period of record, the freezing index (Σ_{-tB}) increased by 14-16 °C-days/yr at relatively steady thickness of the snow cover (h_{CH}) averaging 0.2-0.3 m. This is indicative of the predominant influence of cold, dry, arctic and occluded, western air mass transfers over the region.

2. The second region covers the areas between the Vilyui, Lena, Indigirka and Kolyma rivers. The highest $t_{cp1.6}$ increasing trend of 0.04-0.08 °C/yr is recorded by the stations located in the

Vilyui valley and the middle reaches of the Aldan. Elsewhere, $t_{cp1.6}$ has an increasing trend of 0.03-0.04 °C/yr.

In the south-western and central areas, Σ_{-tB} decreased by approximately 6.8-9.1 °C- days/yr, with h_{CH} increasing by 0.0023-0.0068 m/yr and the total annual precipitation (S_{OC}) remaining relatively stable over the period of record. However, a marked increase of S_{OC} by 0.0023-0.0045 m/yr was observed at the Verkhnevilyuisk, Vilyuisk, Nyuya and Olekminsk weather stations. It means that the increased advection of air masses in winters over the area south of the Vilyui River hampers the influence of the Asian anticyclone.

The observed increase of $t_{cp1.6}$ in the north-eastern plains of the northern taiga and in the intermontane depressions is also attributed to the increased advection from the Pacific, with Σ_{-tB} decreasing by 12-14 °C-days/yr, S_{OC} increasing by 0.0012-0.0014 m/yr and h_{CH} remaining relatively stable.

3. In the mountains, a marked decreasing trend of 0.02-0.07°C is found in deeply incised river valleys in the north-east and south-east where the effect of the Asian anticyclone is exacerbated by winter orographic inversions. The effect of the inversions becomes significantly less at the elevation of 860 m. For instance, the Nagorny station records show a relatively steady temperature dynamics of the soils.

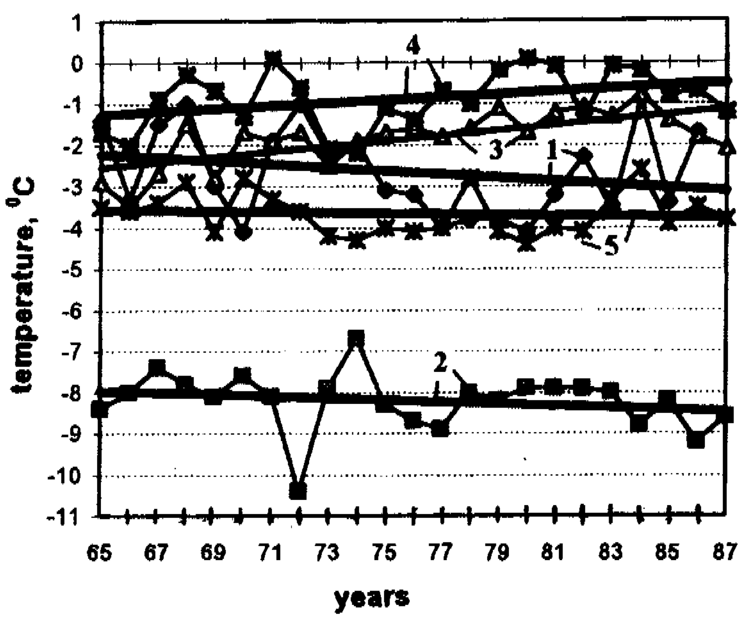

Figure 2. Mean annual temperature dynamics of soils at 1.6 m depth and linear trends at weather stations in Yakutia. 1: Jarjan; 2: Predporozhnaya; 3: Verkhnevilyuisk; 4: Yakutsk; 5: Nagorny.

Southern Yakutia, which lies at a crossroads of the north-western, southern and eastern air mass transfers, is characterized by maximum precipitation and maximum snow accumulation (Kazurova, 1961). This type of climate dominates at the Gorelyi weather station located at the upper boundary of the mountain taiga (951 m elevation). This upper boundary of the mountain taiga is known to be a natural limit to the orographic inversion effect. Above it is an altitudinal belt of maximum snowfalls. It is this belt that is characterized by favourable conditions for the formation of the thermal regime of soils in the mountains. According to the Gorelyi station record, a $t_{cp1.6}$ increasing trend is 0.09°C/yr.

Thus, milder winter climates in Yakutia, which cause an increase in the mean annual temperature of soils, arise from the increased advection of both transcontinental, Atlantic and Pacific air masses. Where this effect is weaker, no temperature increase is observed in the soils.

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APPLICATION OF GEOPHYSICAL INVESTIGATIONS INCLUDING SEISMICS AND GROUND PENETRATING RADAR FOR MONITORING ACTIVE LAYER DEVELOPMENT IN ALPINE PERMAFROST

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Geophysical investigations including refraction seismics and ground penetrating radar (GPR) were carried out on an active rock glacier in the Central Alpine cirque Äusseres Hochebenkar (Ötztaler Alpen). The purpose of the investigations was to test these geophysical methods, which have the advantage of providing a relatively fast and destruction free examination of the subsurface, under site specific conditions in the cirque. Both methods applied had to be optimized for operational use in a monitoring project investigating the relationship between changes of environmental factors and the internal structure of alpine permafrost.

Two profiles across the rock glacier were measured by both methods to correlate the results. Seismic equipment was a BISON 5000, GPR system a pulseEKKO 100 (antennas: 25, 50 MHz). An additional measurement outside the rock glacier was made to investigate the surrounding geological conditions. The GPR results are encouraging for further deep sounding. Internal structures of the rock glacier to a depth of 50 meter could be detected (25 MHz) although measurement conditions for GPR were rough. More detailed near-surface information was obtained by 50 MHz profiling.

Coupling of the geophones and handling of the radar antennas with a length of 2 and 4 m were time consuming. Damage to the fibre optic cable and other GPR equipment could be prevented by working with at least four persons. This number will have to be reduced. Seismic waves were stimulated by using a sledge hammer. The quality of the signal was good, but needed extensive stacking operation.

The correspondence between seismic data and the GPR is very good. A slightly undulating internal permafrost layer could be detected at about 10 m depth. Further strong reflectors are correlated with the base of the rock glacier, which is slightly convex, at depths varying from 25 to about 50 m. Other structures are interpreted as density contrasts representing ice content variations within the rock-ice mixture of the rock glacier.

An additional GPR profile included a part of the steep northern flank of the rock glacier. This part shows three main reflectors associated with the base, the permafrost table and another strong density contrast. The new data on the structural conditions from the flank to the main part of the rock glacier contributes to a better understanding of the nature of this rock glacier.

The investigation of Äusseres Hochebenkar by GPR and shallow refraction seismic techniques was successful. Personnel and time expenses were reasonable in comparison with the amount of data portraying the subsurface that was obtained. Further measurements are highly recommended and promise a more detailed picture of the structures and processes within this rock glacier.

ON THE DIFFERENCE BETWEEN GROUND ICE RESISTIVITIES IN CENTRAL YAKUTIA AND THE SUBARCTIC LOWLANDS

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The resistivities of ice complexes and frozen sediments were determined by direct current soundings. The geometry of ice wedge patterns in Central Yakutia is close to that in Subarctic Lowlands. The distance between the axes of ice wedges is 12-15 m, the wedges are up to 5-7 m wide, their extension to depth is up to ~50 m in Subarctic Lowlands and ~60, perhaps ~70 m in Central Yakutia (Vturin, 1975; Ivanov, 1984). In both cases, the ice is fresh. However, ice complex resistivities in Central Yakutia and the Subarctic Lowlands differ by almost by two orders of magnitude: median values are ~20 000 and ~1 300 000 Ωm, respectively. The resistivity of the adjoining loams also differ with median values of ~1200 and ~100 000 Ωm, respectively. To estimate the causes of these differences, as a first step, the simplest geometry of the ice complex, formed by square lattice of vertical ice sheets (Figure 1) with thickness (d_0) and distance between their axes (D_0+d_0), can be examined. Taking into account the anisotropy of the ice complex, we must consider the mean value of its square resistivity $\rho_m = \sqrt{\rho_\parallel \times \rho_\perp}$, where ($\rho_\parallel$) and ($\rho_\perp$) are resistivities of the ice complex parallel and normal to the direction of the ice bodies. The conductance of the ice complex volume D_0^2h, where (h) is the extension of ice bodies to depth, in the first direction is $1/R_\parallel = D_0^2/\rho_\parallel \times h = [D_0^2-(D_0-d_0)^2]/\rho_i \times h + (D_0-d_0)^2/\rho_1 \times h$, where ($\rho_i$) and ($\rho_1$) are the resistivities of the ice and adjoining frozen loams.

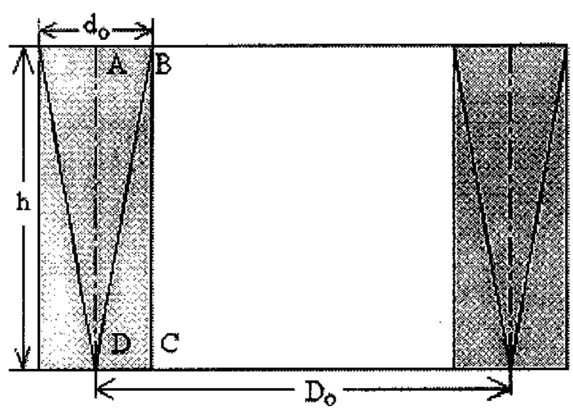

Figure 1. Models of ice complex, elementary cells (cross-section): 1) vertical sheets (ABCD - half of the sheet); 2) vertical triangular wedges (ABD - half of the wedge).

Neglecting the term $\sim 1/\rho_i$, we have $\rho_\parallel \approx \rho_1/(1-d_0/D_0)^2$. Resistance of the same volume of the ice complex in the normal to ice bodies direction is $R_\perp = \rho_\perp \times D_0/D_0 \times h = \rho_i \times d_0/D_0 \times h + 1/[d_0 \times h/\rho_i \times (D_0-d_0) + (D_0-d_0) \times h/\rho_1 \times (D_0-d_0)]$. Neglecting the terms $\sim 1/\rho_i$ and ρ_1/ρ_i, we have $\rho_\perp \approx \rho_i \times d_0/D_0$.

It is clear that the resistivity of a half of the ice wedge (ABD on Figure 1) is half the resistivity of half of the ice sheet (ABCD on Figure 1). So the triangular form of the ice wedges can be taken into account by using the average values for ice wedge thickness and distances between them. Neglecting as before the term $\sim\rho_l/\rho_i$ we have $1/(\rho_{\parallel\Delta} \times h/D_0^2) \approx 1/\rho_1 \times h/(D_0-d_0/2)^2$ and $\rho_{\parallel\Delta} \approx \rho_1/(1-d_0/2D_0)^2$; $\rho_{\perp\Delta} \times D_0/h \times D_0 \approx \rho_i \times d_0/2h \times D_0$ and $\rho_{\perp\Delta} \approx \rho_i \times d_0/2D_0$.

So,

$$\rho_{m\Delta} \approx \sqrt{\rho_{\|\Delta} \times \rho_{\perp\Delta}} = \sqrt{\rho_i \times \rho_1 \times d_0/2D_0 \times (1-d_0/2D_0)^2} \quad (1)$$

and the resistivity of the ice is

$$\rho_i \approx [\rho^2_{m\Delta} \times 2D_0 \times (1-d_0/2D_0)^2]/\rho_1 \times d_0 \quad (2)$$

Resistivities of the ice complexes in Central Yakutia and Subarctic Lowlands, (ρ_{my}) and (ρ_{ms}), differ by a factor of 60 - 70, while resistivities of adjoining loams, (ρ_{ly}) and (ρ_{ls}), differ by factor of 80 to 90. From (1), it follows that under otherwise equal conditions - the same resistivity of the ice and d_0/D_0 - $\rho_{ms}/\rho_{my} = \sqrt{\rho_{ls}/\rho_{ly}} \approx 8$ or ~8 times less than in reality. So the comparatively high conductivity of adjoining loams explains only a small part of the relatively low resistivity of the ice complex in Central Yakutia. In the case of the resistivity of the ground ice in the Subarctic Lowlands, according to (2), for maximum and minimum values d_0/D_0=0.5 and d_0/D_0=0.25 will be $\rho_{is} \approx 4 \times 10^7$-$10^8$ Ωm. In Central Yakutia under similar conditions, the resistivity of the ice in wedges is 0.8×10^6-2×10^6 Ωm. So in general $\rho_{is}/\rho_{iy} = 50$. Therefore, it appears that the low resistivity values in the adjoining loams and other sediments in Central Yakutia are due to the relatively high conductivity of all kinds of ground ice in this area.

Conductivity of the ice depends mainly on the proton content and an addition of a small quantity of acid; supplying protons increases the ice conductivity by orders of magnitude. Central Yakutia has relatively saline soils because evaporation exceeds precipitation. A general increase of solutes in sediments is also observed and this can explain the relatively high conductivity of ground ice.

In conclusion, the ground ice in Central Yakutia has a relatively high conductivity, generally 50 times greater than in the Subarctic Lowlands. This can be explained by a relatively high, but still very small, content of different acids in it.

MAP OF POTENTIAL ENVIRONMENTAL DAMAGE DUE TO OIL SPILLS IN THE PERMAFROST REGION OF RUSSIA

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Potential environmental damage caused by oil spills is mapped for the permafrost regions of Russia. A portion of the map of potential environmental damage due to oil spills in the permafrost region of Russia. Environmental damage is evaluated according to three components: 1) natural resources damage; 2) ecosystem damage; and 3) socio-economic damage.

Natural resources damage is estimated according to the amount of fines calculated per ton of oil spilled in water bodies, on soils or evaporated into the atmosphere (volatile oil hydrocarbons) (Table 1). Ecosystem damage is estimated according to the rate of decomposition of oil in soils, the period of time required for natural restoration of land plant communities, and benthic fauna biodiversity (Table 2). Socio-economic damage is estimated according to location of residence of ethnic minorities of the North life style (Table 3). The map, covering the area from the western border of Russia to longitude 110° east (Lake Baikal), is presented (Figure 1).

Table 1. Ecosystem damage classification

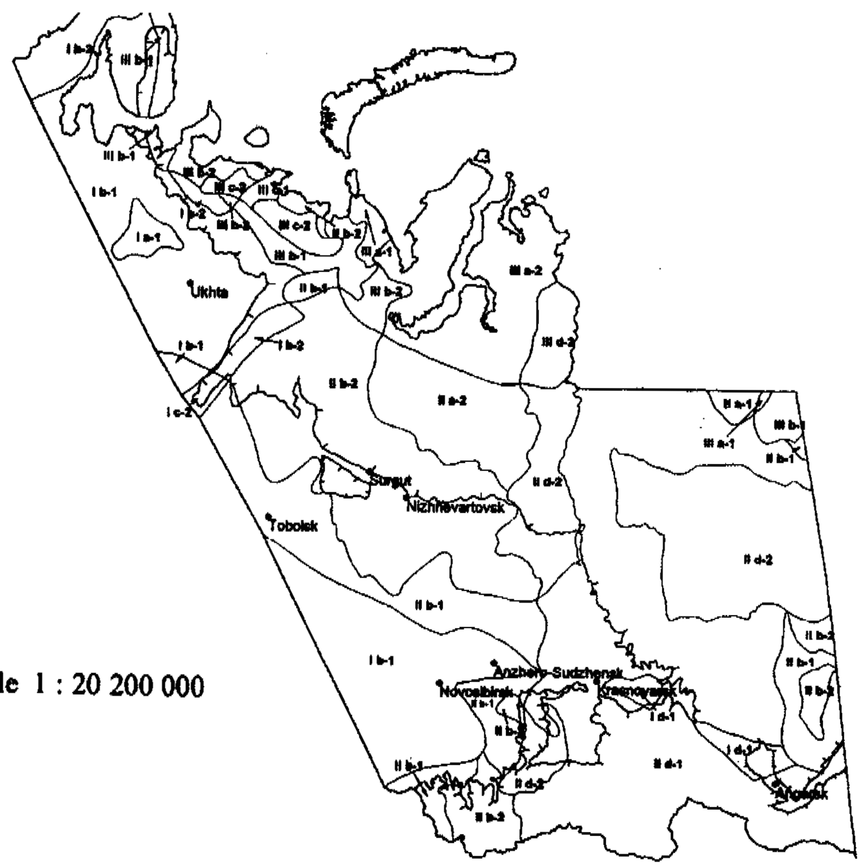
Symbol on the map	Ecosystem sensitivity estimation	Biodiversity of benthic freshwater community	Rate of decomposition of oil in soils	Tune to naturally restore terrestrial plant community after an oil spill
I	low sensitivity	200 - 300 species	Low	10-30 years
II	sensitive	200 – 300 species	Very low	10-30 years
III	very sensitive	100-200 species	Accumulation of toxic substances of oil	>30 years

Table 2. Natural resources damage classification

Symbol on the map	Water body damage (* 1000 roubles)	Soil damage (* 1000 roubles)	Atmosphere damage (roubles)
a	1100 to 1190	135 to 610	310 to 500
b	1100 to 1390	135 to 610	310 to 500
c	1100 to 1390	135 to 1220	310 to 500
d	1100 to 1490	310 to 1220	310 to 500

Table 3. Socio-economic damage classification

Symbol on the map	Ethnic minorities of the North
1	Absence
2	Presence



Scale 1 : 20 200 000

Figure 1. Ecological damage map of the cryolithozone of Russia.

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INFLUENCE OF CLIMATIC FACTORS ON THE THERMAL REGIME OF THE ACTIVE LAYER AND PERMAFROST AT BARROW, ALASKA

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Climatic warming predicted by GCMs is greater in the Arctic than elsewhere. Consequently, investigations on the potential response of the active layer and permafrost to the predicted warming become one of the key issues in Arctic system studies. A finite difference model for one-dimensional heat flow with phase change was used to investigate the impact of changes in air temperature, seasonal snow cover, and soil moisture conditions on mean annual ground and permafrost surface temperatures, and active layer thickness at Barrow, Alaska. The modeling results were validated against the field measurements and agree well. Results show that the effective depth hoar fraction of the seasonal snow cover ranged from 0.11 to 0.35, with an average of 0.18. The effective thickness of the depth hoar layer varied from 2.7 cm to 4.8 cm, with an average value of 3.7 cm. The calculated mean annual ground and permafrost surface temperatures were about -8.3°C and -8.8°C, respectively. The calculated active layer thickness were about 0.44 cm. These results are very representative for the present-day thermal conditions of the active layer and shallow permafrost at Barrow, Alaska.

Results from sensitivity analyses indicate that among the variable climate factors, change in air temperature is the most important single factor controlling the change in soil temperatures. Changes in winter air temperature, or in the freezing index, have a substantial impact on mean annual air, ground surface, and permafrost surface temperatures, but very limited effect on active layer thickness. Changes in summer air temperature or thawing index have a minimal effect on mean annual air, ground surface, and permafrost surface temperatures, but a significant impact on active layer thickness. Changes of soil water content for the top 0.1 m peat layer by 20% to -60% from its average value would change mean annual ground surface and permafrost surface temperatures by -1.5°C and -1.2°C, respectively, while active layer thickness decreases about 0.21 m or 44%. If soil water content for the top two layers (0.1 m of peat layer and 0.4 m of mineral soil) were to change by 20% to -60%, then mean annual ground and permafrost surface temperatures would decrease about -1.6°C and -0.9°C, respectively, while active layer thickness could decrease about 0.15 m or 33%. Thermal offset values decrease with a decrease in soil water content due to the decrease of active layer thickness. The existence of thin depth hoar layer within the seasonal snow cover is crucial to its insulating effect, while snow thickness becomes a secondary factor. For example, changes in depth hoar fraction or depth hoar thickness alone would change mean annual ground and permafrost surface temperatures by 2.7°C and 4.3°C, respectively. For a constant depth hoar layer thickness (5 cm in this example), change in snow thickness can only vary mean annual ground and permafrost surface temperatures by 1.6°C. For a constant depth hoar fraction, changes in snow thickness by ±50% can result in changes of mean annual ground and permafrost surface temperatures by 4.1°C and active layer thickness by 0.07 m.

Reports of the International Permafrost Association

The following series of reports presents results of IPA activities over the past five years and suggests directions for the next five-year period. Included is a summary report from the Secretary General. Working groups were asked to respond as appropriate to the 1993 and 1995 Council resolutions. These resolutions are presented here as a reminder of the guidance provided by the IPA Council at previous meetings. The Yellowknife conference provides the opportunity for working groups to meet and recommend to Council plans for their new or continuing activities. The Council and Executive Committee express their appreciation to all members of working groups and to their chairs and secretaries for their conscientious efforts and for preparation of these reports.

GLOBAL CHANGE AND PERMAFROST RESOLUTION

Approved 8 July 1993 at the IPA Council Meeting, Beijing, China

WHEREAS the importance of permafrost is reflected in both international governmental and non-governmental reports and science plans (Intergovernmental Panel on Climate Change (IPCC); IGBP core projects: International Global Atmospheric Chemistry Project (IGAC); Land-Ocean Interactions in the Coastal Zone Project (LOICZ); Biospheric Aspects of the Hydrological Cycle Project (BAHC); and Global Change and Terrestrial Ecosystems Project (GCTE));

WHEREAS the distribution and properties of permafrost are of increasing interest to those concerned with assessing the influence of global climate change on high latitudes and high altitudes;

WHEREAS permafrost is sensitive to climate and contains a memory of past climate changes;

WHEREAS the IPA is concerned with the advancement of knowledge on the formation and degradation of permafrost at regional and global scales;

Be it RESOLVED that the IPA, consisting of 20 adhering national bodies, representing many earth science and engineering disciplines, seek a more active role in the IGBP core projects by communicating IPA interests and activities to relevant IGBP programs, IPCC assessments, and other programs;

FURTHERMORE the IPA notify other national and international scientific and engineering organizations of its present working groups' plans and activities including the availability in early 1994 of the IPA 1:10,000,000 map of permafrost and ground ice of the Northern Hemisphere;

Finally, be it RESOLVED that relevant IPA working groups give particular attention to global climate change and prepare status and trend reports for the Seventh International Conference on Permafrost, to be held in Canada in August 1998.

DATA, MONITORING, AND COORDINATION RESOLUTIONS

Approved 5 August 1995 at the IPA Council Meeting, Berlin, Germany

Data Resolution 1

Acknowledging the importance of permafrost data for scientific and engineering study of current environments, together with the detection and prediction of future environmental change and its impacts;

The Council of the IPA requests member countries to:

1. encourage active participation in the Global Geocryological Database project (GGD);
2. seek financial support for associated national and international activities; and
3. facilitate open access to data holdings;

in support of these objectives.

Data Resolution 2

Noting increasing recognition of the need for cryosphere information within international science programs such as:

- Global Climate Observing System (GCOS) and Global Terrestrial Observing System (GTOS);
- Intergovernmental Panel on Climate Change (IPCC) assessments;
- International Geosphere Biosphere Program (IGBP);
- International Tundra Experiment (ITEX); and
- other similar, current and future endeavors:

The IPA pledges its support for such initiatives and, through the activities of its working groups, seeks to play an active role in their planning and coordination.

Data Resolution 3

Recognizing the grave risks of irrecoverable losses of permafrost data and related information as a result of the conclusion, change of direction, or termination of projects, organizations or individual careers:

The IPA strongly encourages national and international efforts to prevent such losses; and offers to provide expert advice to ensure the continuing survival and accessibility of orphaned data and information.

Monitoring Resolution

Considering the importance of documenting and understanding long-term change in permafrost terrain, and noting the efforts of the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS) to provide a framework for monitoring the permafrost thermal state and the permafrost active layer as key environmental variables, the IPA recommends:

1) the establishment of an international network for long-term monitoring of the thermal state of the permafrost and active layer in both hemispheres; and 2) the standardization of methods for measurement and site selection, to be finalized at the upcoming December 1995 workshop in Hanover, New Hampshire, USA.

Meetings Resolution

In order to involve maximum engineering and scientific participation in the international permafrost conferences held once every five years, all members and working groups are urged to encourage societies and professional organizations to coordinate the scheduling of their meetings, workshops and field trips within the 12-month period prior to and following the permafrost conferences. Following the June 1998 conference in Yellowknife, Canada, the next conference is provisionally scheduled for summer 2003 in Europe.

DATA AND INFORMATION WORKING GROUP REPORT

Past Activities and Future Directions

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Membership: R.G. Barry, Chair (USA); J.A. Heginbottom, Secretary (Canada); H.J. Åkerman (Sweden); M.J. Clark (United Kingdom); Zhang Xian-Chen (China); E.S. Melnikov (Russia). *Ex-Officio:* F.E. Nelson, WG Global Change and Permafrost; R.O. van Everdingen, WG Terminology; N.N. Romanovskii and J. Brown, IPA Executive Committee.

Corresponding members: J. Branson (UK), C. Hanson (USA), M.O. Leibman (Russia), O. Gregersen (Norway) and M. Thorley (SCAR-COMNAP).

INTRODUCTION

The Working Group on Permafrost Data and Information was established at the 5th International Conference on Permafrost in Trondheim, Norway in 1988, following a well-attended informal workshop on Permafrost Data and Information organized by R.G. Barry on behalf of the World Data Center-A for Glaciology (Brennan and Barry, 1989) and the presentation of a related conference paper (Barry, 1988). M.J. Clark was approved as the initial Chairman of the Working Group and R.G. Barry as its Secretary.

The Working Group purpose was stated as follows: "to improve and standardize the collection, archiving, documentation and dissemination of permafrost data" (Brennan and Barry, 1989, p.123).

RECORD OF ACTIVITIES

The group sought to encourage the submission of data set descriptions (metadata), initially to the Arctic Environmental Data Directory (AEDD) as a component of the Global Change Master Directory (GCMD), and of data sets to the WDC-A for Glaciology. The importance of maximizing communication within the permafrost community on data standards was recognized and the WG began to explore the possibilities of putting appropriate data sets and related informatics, including a permafrost glossary, on CD-ROM media.

The strategy that evolved was based on related, coordinated initiatives of WG members, staff at theWDC-A for Glaciology, the editors of the IPA Circum-Arctic Map of Permafrost and the Terminology WG chair. The initial steps included:

(1) development of a prototype inventory of data on permafrost, the active layer and related climate/terrain variables; and

(2) an assessment of the availability of permafrost data in the community.

These two steps were accomplished by the WDC-A for Glaciology mailing a questionnaire on data holdings to 310 members of the IPA community. Responses from individuals representing 17 countries ultimately led to the submission of metadata descriptions for 250 datasets. These initial activities were reported, together with preliminary thoughts on a permafrost data and information system, at the

Sixth International Conference in Beijing in August 1993 (Barry and Brennan, 1993) and at the WG organized workshop on permafrost data issues. The discussions led to the formulation of a Global Geocryological Database (GGD) project, conceived as a data system for permafrost science and engineering. Workshops organized by the WG were held at the GeoData Institute, University of Southampton, UK (30 June-1 July 1994) and at the Norwegian Geotechnical Institute, Oslo, Norway (3-5 November 1994). These resulted in a GGD brochure that specified the objectives of the GGD project. These were:

(1) to advance scientific understanding of permafrost;

(2) to improve the basis of engineering design in cold regions;

(3) to aid in understanding and predicting global and regional climate change;

(4) to offer a basis for detecting environmental change, particularly through establishing and managing long-term monitoring programs;

(5) to enhance the basis for developing environmental scenarios and assessing environmental impact.

It was proposed that data sets should be organized into standard file structures and accessioned by one of several National Geocryological Database regional nodes in Boulder, Lanzhou (WDC-D for Glaciology), Moscow and Southampton. Working links were also proposed with: the UNEP Global Resources Information Database (GRID), Arendal, Norway; the World Glacier Monitoring Service (WGMS), Zurich; the International Arctic Science Committee (IASC), Olso, Norway; and other groups. These workshops and a successor at the Alfred Wegener Institute, Potsdam, Germany (1-3 August 1995) developed relative priorities for data on key permafrost variables according to five areas of application (see *Frozen Ground* News Bulletin Number 18, 1995, p.13). An initial emphasis of the Global Geocryological Database (GGD) project was to retrieve data that were in some sense at risk of being lost and/or unavailable to the community at large. Under a U.S. National Science Foundation grant to R.G. Barry and C. Hanson, a "Pilot GGD" was developed with an emphasis on Russian permafrost data and information as discussed at the Oslo workshop (Barry *et al.*, 1995). The Oslo and Potsdam workshops began to formulate the procedural and technical aspects of the GGD activity, with draft statements of a protocol for data management, acquisition and dissemination and data/metadata formats. Another outcome of the Potsdam meeting was the decision to develop an IPA Web page at the GeoData Institute, University of Southampton: <http://www.geodata.soton.ac.uk/ipa>. The Web site, designed by Julia Branson, provides the opportunity to present current status reports on the activities of this and other working groups.

The Pilot GGD project focused on:

(1) an inventory of maps of permafrost published in the USSR;

(2) a list of organizations and individuals involved in Russian permafrost data collection and research;

(3) borehole logs used in compiling the Russian sector of the IPA permafrost map; and

(4) selected historical soil temperatures from stations across the Russia.

Several small coordination meetings were held in Moscow, St. Petersburg and Boulder in 1995 and 1996. Following the Potsdam Workshop in 1995 it was decided that although the process of data collection for the GGD was in its infancy, it was important to design a means of disseminating sample data and related information products to permafrost specialists so as to demonstrate the value of the GGD initiative specifically, and IPA information strategies generally. The chosen vehicle was a CD-ROM. A major workshop was held in December 1996 at WDC-A for Glaciology, with representatives from Canada, Russia, USA and the U.K. present, to address the proposed North American data sets to be included on a CD, the overall content and strategy for producing the CD, and Working Group plans for the Yellowknife Conference.

A CD-based presentation focusing on the Circumpolar Active Layer Permafrost System (CAPS) was approved and was to be the first-ever compilation of permafrost and related data/metadata with a truly global perspective. Spearheaded by a Compilation and Editorial Team within the Data and Information Working Group, CAPS is the culmination of five years of work identifying and organizing selected sets of basic permafrost data and making them available to the international science and engineering communities, together with educators and policy-makers. CAPS also presents major information products from other IPA Working Groups and supporting organizations, notably permafrost maps, literature and map bibliographies, multi-lingual permafrost and ground-ice glossary, and selective imagery.

The CAPS CD ROM will be released at the Yellowknife and will be available on the IPA Web page with links to other data and bibliographic resources (IPA, 1998).

RATIONALE FOR THE FUTURE

The GGD and future versions of CAPS are envisaged as contributions to a dynamic permafrost data and information service which will evolve with the needs of its users. These initiatives are widely supported by the international permafrost community with the aim of enhancing the GGD priority themes:

(1) Cold Regions Process Understanding;

(2) Environmental Change Detection;

(3) Model Validation;

(4) Engineering Design;

(5) Environmental Impact Assessment.

Permafrost scientists and engineers have reached a consensus on the data and information priorities that should be employed in acquiring, managing and disseminating permafrost information. These priorities are reflected in the compilation of the IPA's growing interest in monitoring programs such as CALM and PACE, in the GGD itself, and in the sample data sets selected for publication in CAPS. In particular, it is anticipated that the CAPS data will make a significant contribution to the issue of global climatic change. Knowledge of the environment in the past (for example, in Palaeo-Periglacial Phenomena data sets), together with understanding of recent fluctuations (CALM sites), provides a quantitative basis for an understanding of environmental change. Such data are expected to assist climatic modelers to achieve an enhanced understanding of the importance of permafrost and associated properties within the global thermal regime. By developing and communicating a firm appreciation of the role of polar and mountain permafrost in relation to environmental change, CAPS will underpin an informed process of policy-making through the IPCC and other governmental and non-governmental agencies.

The GGD metadata and archives with its approximate 200 entries representing all cold regions of the Earth, and CAP represent major advances in international cooperation, and lay a firm foundation for strengthening the data and information services available to permafrost specialists. The future now appears to offer the prospect of consolidating such core activities while developing new capabilities in support of the IPA mission. A continued major effort is required to reinforce the GGD as the primary global archive of permafrost and associated datasets as the core activity, including increased representation of Southern Hemisphere in the GGD. The GGD archive remains small in relation to the total volume of data already created and the rate at which new data are being acquired or lost. The IPA Council at Berlin adopted a resolution urging member countries to support the GGD initiative, and this must be seen as fundamental to the data strategy of the Association.

A continued focus on mapping, with the potential to release a fully interactive GIS version of the circum-arctic permafrost map, will be a high priority. This will require a substantial data management exercise, and would also offer an opportunity to consider the value of CAPS version 2.0 incorporating new and revised data.

A concentrated effort will be directed to designing and producing version 2.0. While this would at one level offer an opportunity to continue to build the GGD with the addition of further data sets, the real potential lies in the prospect of enhanced functionality. The expectations of the professional community are high, and we recognise the importance of providing comprehensive free text Boolean search facilities, and of offering GIS-type access to user-customized maps. Our aim must be to provide cross-platform support for such capability, and wherever possible to provide it on a stand-alone basis rather than assuming user access to support software. If the hypermedia functionality of the product is also enhanced, it will be able to serve two groups simultaneously - the data-oriented specialist and the information-oriented general user. The data and information priority has come a long way since our first meeting in Trondheim 10 years ago: then the aim was to compile data, now the focus is on empowering the user to create value from data!

A review of the opportunity to supplement the IPA archive with audio-visual products is timely. With the current strong trend towards multi-media presentation, we find ourselves well able to provide permafrost data, text, maps, and images, but completely unable to offer film, video and audio records. This imbalance must be addressed urgently so as to develop a strategy for IPA audio-visual "rescue" as well as commissioning new product, particularly personal video profiles of key figures in the profession.

There is a strong case for a new emphasis on communication, centrally but not exclusively focused on the IPA Web Site and on support for the regular publication of information through *Frozen Ground* (though whether such publications should be paper or electronic is open to debate). Communication is a core rather than a peripheral mission, and is critical to the IPA itself, not just to the Data and Information Working Group. Proactive communication of the significance of permafrost to related disciplines and professions must be seen as a central mission. Even more fundamental is the formulation and communication of policy on such major issues as environmental change and environmental impact. If the IPA is ready to move into the policy field, then its Data and Information infrastructure is ready to provide underpinning information and assist in communication.

It is not unreasonable to claim that there has been a revolution in permafrost data availability over the last decade. Ten years ago, a meeting of concerned professionals at Trondheim recognised a developing information crisis - no policy, no standards, no access and almost no genuinely international products. Today we have a rapidly growing global archive and data access system securely based within the World Data Center system. There is an agreed data priority matrix, an agreed basic data model, a professional data quality assurance protocol and the beginnings of an effective data dissemination strategy. Paper and electronic publication systems are in place and developing steadily. Major international co-operation has resulted in the Circum-Arctic Map of Permafrost and Ground Ice and the Circumpolar Active Layer Permafrost System CD, which combine to offer for the first time a hemispheric or global view of the status of permafrost. The contrast across ten years could hardly be more dramatic.

All of this represents a major achievement in its own right, but the real success story lies behind these impressive symptoms of success. Perhaps for the first time, permafrost scientists and engineers are breaking with tradition and sharing their data. In so doing, they are triggering all of the advantages that derive from access to spatial and temporal comparison and analysis. Concerns remain, of course, and rigorous promotion of personal rights must continue, but if the IPA itself represents a pioneering vision to pull together the disparate interests that focus on the world of permafrost, then its data strategy represents the personal commitment of a steadily-expanding community of outward-looking individuals who recognise that the power of cooperation and continuity underpin the power of information.

In order to institutionalize the process described, the Working Group on Data and Information will propose to the IPA Council that a permanent Committee on Data, Information, and Communication be established within the IPA.

SELECTED WORKING GROUP AND RELATED PUBLICATIONS

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SECRETARY GENERAL'S REPORT

The IPA from 1994 to 1998 and Beyond

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INTRODUCTION

The stated objectives of the International Permafrost Association are to foster the dissemination of knowledge concerning permafrost and to promote cooperation among persons and national or international organizations engaged in scientific and engineering work on permafrost. The IPA is an Affiliated Organization of the International Union of Geological Sciences. The four-member Executive Committee and eight working groups under the direction of the Council undertake activities to promote and accomplish these objectives on topics related to the theoretical, basic and applied frozen ground research including permafrost, seasonal frost, artificial freezing, and periglacial phenomena.

This report summarizes activities of the International Permafrost Association since the 6th International Conference on Permafrost (ICOP) in Beijing in July 1993 and suggests some future directions. Reports of individual working groups in this volume and in *Frozen Ground* provide details of the activities listed below.

MEMBERSHIP

Membership increased to 22 Adhering Bodies with the addition of Mongolia and Kazakhstan in 1995.

The Executive Committee consists of President Cheng Guodong (China), Vice Presidents H.M. French (Canada) and N.N. Romanovskii (Russia), and Secretary General J. Brown (USA).

Council Members as of June 1998 and by Adhering Body:

Argentina (D. Trombotto); Belgium (A. Pissart); Canada (D. Hayley); China (Zhu Yuanlin); Denmark (S. Bertelsen); Finland (M. Seppala); France (J. Aguirre-Puente); Germany (L. King); Italy (F. Dramis); Japan (M. Fukuda); Kazakhstan (A.P. Gorbunov); Monogloia (D. Tumurbaatar); The Netherlands (J. Vanderberghe); Norway (K. Flaate); Poland (K. Pekala); Russia (V.P. Melnikov); Southern Africa (I. Meiklejohn); Spain (D.E. Palacios); Sweden (H.J. Åkerman); Switzerland (D. Vonder Mühll); United Kingdom (C. Harris); United States of America (B. Hallet).

FINANCIAL

The Association depends on annual contributions from Adhering Bodies (Members). Funds are spent primarily on working group activities and Council and Executive Committee meetings. Based on total revenues, US$15,000 was reserved from the 1995-97 income to support Members and other travel to the 7th ICOP in Yellowknife and for participation in the Council meetings. Member contributions range from $250 to $2000 with total income by year as follows:

1993: $10,450 from 13 members

1994: $11,000 from 16 members

1995: $13,500 from 16 members

1996: $10,750 from 14 members

1997: $13,000 from 16 members

1998: $7,500 from 6 members (as of May 15, 1998)

During the five-year period all activities of the Secretary General and some Executive Committee and working group activities were supported by a U.S. National Science Foundation grant to the American Geophysical Union (AGU). This included support to publish and distribute *Frozen Ground*, to prepare both the printed and digital versions of the permafrost map and to support several international workshops and publications. CRREL provided editorial assistance for the production of *Frozen Ground*.

MEETINGS AND CONFERENCES

IPA organized numerous meetings and co-sponsored sessions and conferences (see *Frozen Ground* or working group reports in this volume for details).

1994

June 30-July 8, Data planning meeting in Southampton, UK; Executive Committee in Arundel, UK; and Polar Libraries Colloquy, Cambridge, UK.

July 26-August 9, Lower Kolyma Cryosol Meeting and field trip.

September 4-9, Symposium on Periglacial Slope Deposits and Processes, Reims, France, and field excursions in northern and southwestern France.

November 3-5, Data Rescue Workshop, Oslo, Norway.

November 13-18, Cryosol meeting on Permafrost-Affected Soils, Seattle, WA.

December 5-9, AGU International Session on Frozen Ground and Changing Climate, San Francisco, CA, with Global Change and Permafrost Working Group meeting.

1995

April 7-11, 6th International Tundra Experiment Workshop (ITEX), Ottawa, Canada, with Global Change and Permafrost Working Group meeting.

April 24, Cryosol Working Group meeting, Pushchino, Russia.

August 1-3, Global Geocryological Database workshop, Potsdam, Germany.

August 4-5, Council and Executive Committee meetings in Berlin, Germany, as part of the INQUA Congress; Special session on Cenozoic Ground Ice Stratigraphy.

December 9-11, International Frozen Ground Workshop, Ability to Detect Change, Hanover, NH, and AGU related session on Frozen Ground Processes, San Francisco, CA.

1996

July 7-16, High Arctic Field Trip and Symposium, Canadian Arctic.

July 15-16, Data review meeting, Boulder, CO.

August 5-10, Session at the International Geographical Congress, Hague, The Netherlands.

August 18-30, Executive Committee meeting in Lanzhou, China and Almaty, Kazakhstan.

December 12-13, Global Geocryological Data workshop, Boulder, CO.

1997

April 21-25, Symposium on Cryogenic Processes and Phenomena, and Executive Committee meeting Pushchino, Russia.

August 5-8, Second International Conference on Cryopedology, Syktyvkar, Russia, and field trip to Vorkuta.

August 22-28, Mountain Working Group field excursion through Alps and special sessions in Bormio.

August 28-September 3, Executive Committee and Symposium on Periglacial Geomorphology as part of the International Conference of Geomorphology, Bologna, Italy.

December 16-17, Periglacial Processes and Environments workshop, Cardiff, UK.

PUBLICATIONS AND REPORTS

Frozen Ground: nine issues were published and distributed to over 2000 readers in 30 countries. The USA Cold Regions Research and Engineering Laboratory, Hanover, NH, designed and prepared camera copy of all 296 pages.

Maps: Circum-arctic map of permafrost and ground ice conditions was prepared and published by the U.S. Geological Survey. The digital version was initially prepared by GRID Arendal and subsequently revised by the Secretary General with the assistance of CRREL and the USGS (Woods Hole).

CD-ROM: The CD Circumpolar Active-Layer Permafrost System (CAPS) was produced for this conference by the U.S. National Snow and Ice Data Center, Boulder, CO. The cumulative bibliography (1973 -1997) including the past five years is to be found on the CD.

Glossary: The Terminology Working Group produced the 12 language glossary of approximately 700 terms.

Data reports: Two issues of Glaciological Data were published by the World Data Center A for Glaciology, Boulder, CO, on permafrost and climate change (GD 27) and data rescue (GD 28).

IPCC: Permafrost sections were contributed to the Cryosphere Chapter 7 of the Intergovernmental Panel on Climate Change Second Assessment Report.

WMO: several reports to the Global Climate Observing System and its terrestrial components.

WCRP: several chapters on cryosphere research.

IUGS: Annual reports are submitted to the International Union of Geological Sciences.

In addition several journals are closely associated with the IPA: the Wiley journal *Permafrost and Periglacial Processes,* the Chinese journals *Cryosphere* (English) and *Journal of Glaciology and Geocryology,* and the new Russian journal *Earth Cryosphere* which appeared in 1997 with four issues.

RESOLUTIONS

The 1993 Council resolution on global change (reproduced at the beginning of thie section of the Volume) called for increased IPA involvement in IGBP, IPCC and a synthesis reports for the Yellowknife conference. Representatives of IPA participated in the preparation of the IPCC Assessment Report with the full permafrost text reported in *Frozen Ground* Number 15. Individual papers and plenary sessions at Yellowknife are addressing global change issues.

The 1995 Council meetings resulted in five resolutions (see above); three related to data, one to monitoring and one on coordination of meetings. The first two on data have met with considerable success with the preparation and production of the CD and coordination with international programs and organizations. The third resolution to prevent loss of data has met with only limited success. The monitoring resolution has resulted in the development of the Circumpolar Active Layer Monitoring (CALM) network and in part the EC project Permafrost and Climate in Europe (PACE). The fifth resolution on coordination of international conferences has had virtually no success with the number of related frozen ground and engineering meetings continuing to increase. This trend presumably affects publication and participation in the IPA ICOP.

LIAISON

A number of activities and meetings are ongoing with the following international organizations and programs:

International Geographical Union (IGU), Commission on Climatic Change and Periglacial Environments (formerly the Commission on Frost Action Environments)

International Associations of Geomorphologists (IAG)

International Quaternary Association (INQUA)

International Commission on Snow and Ice (ICSI)

World Meteorological Organization (WMO): Global Climate Observing System (GCOS)/ Global Terrestrial Observing System (GTOS)/ Terrestrial Global Observation Panel for Climate (TOPC)

World Climate Research Program (WCRP) cryosphere initiatives

IUGS Commission on Geological Sciences for Environmental Planning: Cogeoenvironment

International Symposium on Ground Freezing (ISGF)

International Society of Soil Mechanics and Foundation Engineering (ISSMFE)

International Society of Soil Science (ISSS)

Polar Libraries Colloquy (PLC)

International Arctic Science Committee (IASC)

UNEP GRID and the Arctic Data Directory (ADD)

Northern Research Basin Symposium (NRBS)

International Geosphere-Biosphere Program-Northern Eurasian Studies (IGBP-NES)

FUTURE DIRECTIONS

Organizational

Proposed changes in the IPA Constitution would increase membership on the Executive Committee, with these members having specific or shared responsibilities such as coordination of international and working groups activities, regional and national programs such as mapping and monitoring, and future meetings. With fewer responsibilities, the position of Secretary General would be changed to Secretary with responsibilities for correspondence and the collection of annual contributions.

Working Groups and Other Committees

Current rules limit working groups to a maximum of two, five year terms. The terms for working groups on data, terminology and mountain permafrost have expired and new groups are required to perform ongoing or new activities. A permanent committee on data and information has been proposed. Other existing working groups will continue, or as is the case of the engineering working groups, would be reorganized into a proposed single group. New working groups are being proposed: one for Southern Hemisphere Permafrost and Processes and a second on Subsea-Coastal Land Interactions. In all cases, membership on the working groups should be open to active participants irrespective of national membership, and all groups would have specific goals. In addition to data, another function requiring a sustained commitment of all members is that of long-term observational programs. During the Yellowknife meeting, plans for a Permafrost Monitoring Service will be given serious consideration. Such a proposed service would work closely with the WMO GCOS/GTOS program. Other groups or task forces also may be anticipated and approved at the Council meetings in Yellowknife.

Funding

Annual contributions alone are not sufficient to continue the current levels of activity within IPA. Additional regional and national sources of funding should be developed by members of the Executive Committee and others. There is a consensus to continue publication of at least an annual issue of *Frozen Ground* and to maintain and frequently update the IPA Web site. At least half of the annual income from Members' income should be committed to these tasks. The balance would support the Executive Committee and some working group requirements.

In closing this report, I personally thank all of you who have contributed to the many successful IPA activities over this five-year period. To those authors who could not attend the conference, our thanks for contributing your results and papers. On behalf of the IPA, I extend our collective appreciation to the Canadian organizers for hosting this conference and wish all delegates success in the conference, field excursions and meetings of the IPA Council and working groups.

SELECTED IPA PUBLICATIONS

Brown, J. (1997). Disturbance and recovery of permafrost terrain. In Crawford, R.M.M. (ed.) *Disturbance and Recovery in Arctic Lands: An Ecological Perspective*. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 167-178.

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MOUNTAIN PERMAFROST WORKING GROUP REPORT

Mapping, Modelling and Monitoring of Mountain Permafrost: A Review of Ongoing Programs

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Membership: W. Haeberli; Chair (Switzerland); F. Dramis, Secretary (Italy); Cheng Guodong (China); A.P. Gorbunov (Kazakhstan); S.A. Harris (Canada); J.L. Sollid (Norway); D. Trombotto (Argentina).

INTRODUCTION

For its second 5-year period of activity, the Working Group on Mountain Permafrost of the International Permafrost Association (IPA) during the Sixth International Conference on Permafrost held in Beijing, China, 1993, envisaged international coordination and cooperation with regard to mapping, modelling and monitoring of mountain permafrost in order to reach a more complete view in space and time of present conditions and potential future developments (Haeberli, 1994). High priority was given to the development of the monitoring component as part of the newly established Global Geocryological Database (GGD; Barry and Brennan, 1993; Barry *et al.*, 1995) and the formation of Global Climate Observing Systems (Townshend *et al.*, 1995; Cihlar *et al.*, 1997). The schedule for the corresponding steps to be undertaken comprised:

(1) the development and circulation of a questionnaire (see Appendix) about existing programs in 1994;

(2) the compilation of an inventory/overview on the basis of the results from the questionnaire in 1995; and

(3) the delivery of actual data into GGD during 1996/97.

The present review represents the result of step (2). It briefly introduces the basic concepts used, comments on the programs in the participating countries, makes reference to selected publications, and points to the first trends becoming visible from the data bases. These activities complement the stated purpose of the Working Group on Mountain Permafrost which is to "improve the exchange of information on, describe the state of knowledge about, and stimulate research activities concerning permafrost at high altitudes and in rugged topography, especially at low latitudes".

The new PACE project which aims at establishing an important baseline for monitoring mountain permafrost along a north-south transect in Europe is also briefly described. A selective collection of rock glacier inventories and related research activities at different levels of detail concerning study locations in Antarctica, Argentina, Austria, Bolivia, Chile, Greenland, Italy, Kazakhstan, Norway, Romania, Spain and Switzerland can be found on the IPA/CAPS CD.

This product contains (1) metadata documenting investigators, research activities and research sites, (2) data samples: rock glacier inventories, averaged values from inventories, rock-glacier flow velocities, detailed maps, photos, BTS-measurements, etc. Dramis *et al.* (1997) present a collection of observational material from the Alps. The CAPS CD also contains the metadata and first 5-year data from the Circumpolar Active Layer Monitoring (CALM) network. CALM complements the monitoring programs described in this report. Since our work began the IPA circum-arctic permafrost map has been published and illustrates at a scale of 1:10,000,000 the major location of mountain permafrost occurrence in the Northern Hemisphere (Brown *et al.*, 1997).

CONCEPT

Changes in - often relatively warm/thin - mountain permafrost are assumed to take place along vertical profiles with depth at individual points in the form of:

(1) changes in active layer thickness, thaw settlement, frost heave in supersaturated material at the permafrost table as an immediate response (time scale: year(s));

(2) disturbance of temperature profiles within the permafrost, i.e., between the permafrost table and the permafrost base, as an intermediate response (time scale: years to decades and centuries);

(3) displacements of the permafrost base as a definitive response (time scale: decades to centuries or even millennia).

As a consequence of, and interacting with such changes, 3-dimensional dynamics of complex landscapes may induce:

(4) modification of permafrost distribution patterns, involving

(5) adjustment of geomorphic, hydrological and glaciological processes such as permafrost creep, frost heave, thaw settlement, thermokarst, erosion and slope instability on thaw-destabilized slopes, runoff variations in time, drainage pattern evolution, snow cover metamorphism, and avalanche formation.

Potential parameters and techniques considered for long-term monitoring programs can be listed as follows:

Depth to the permafrost table	(shallow) borehole temperatures geophysical surface soundings
Vertical temperature profile	(deep) borehole temperatures heat conduction theory (supersaturated permafrost)
Permafrost base displacements	difficult; precise borehole temperatures
Permafrost distribution patterns	BTS method (thick winter snow cover) geophysical soundings shallow drilling with soil temperature measurements
Thaw settlement and frost heave	geodesy and precision photogrammetry analysis of vector and strain-rate field

Landscape phenomena	aerial photography (small-scale infrared): - vegetation cover on rock glaciers (flow activity), scree slopes (rockfall activity) and debris flow traces (frequency of occurrence) - size and water level of thermokarst lakes - extent of perennial ice patches - drainage patterns
Hydrological processes	discharge measurement (winter maintenance!) snow monitoring (extension to permafrost sites)

Monitoring and modelling efforts are closely interrelated: results from long-term monitoring - as they become available - can be used to calibrate models of transient response at individual points (for instance, heat conduction, melting and thaw settlement in material with variable ice content, etc.). Calculations for individual points can later be combined with spatial simulations of surface permafrost conditions in order to simulate typical transient effects at depth for extended areas. In a further step, such model simulations must be tested and further developed by applying appropriate sounding methods at characteristic sites indicated by model simulations. They could then hint at especially sensitive areas and help in assessing how representative are results from long-term monitoring at a restricted number of sites. In fact, our state of knowledge and preparedness with regard to assessing, and hopefully mitigating, potential effects of realistic warming scenarios, essentially depends on the establishment of adequate long-term monitoring programs.

PROGRAMS IN INDIVIDUAL COUNTRIES

Argentina

The program is part of a larger plan to study present and past geocryologic features in the provinces of Mendoza and San Juan. Present conditions are being studied in two different periglacial areas: two basins with permafrost in rock glaciers (El Salto rock glacier and Morenas Coloradas rock glacier) and another one with seasonally frozen ground and permafrost in the region of the cryoplanation surface of the Pampa de los Avestruces. Data are being collected at locations between southern latitudes 30°-34°, longitudes 69°-70° and elevations up to 5,500 m a.s.l. by continuous recording of standard air temperature, continuous ground temperature recording down to 5 m (thermocouple installations in holes made by inserting steel pipes in the thawed active layer or seasonally frozen ground). They also include snow precipitation, wind (foehn effects), relative moisture, radiation, as well as information on ground-ice, active layer thickness, and soil moisture content.

Rock glacier monitoring by D. Barsch (University of Heidelberg) also continues in the Andes of Mendoza. This long-term program includes photogrammetry and seismic measurements of the active layer thickness. The sites are Morenas Coloradas, El Salto (Mendoza) and Agua Negra (San Juan).

Austria

Based on several local and regional studies, the knowledge about the existence and spatial pattern of mountain permafrost in the Austrian Alps has greatly increased during the last two decades. In fact, it is now possible to summarize the main characteristics of the vertical and horizontal distribution in a monograph (Lieb, 1996). The mapping of mountain permafrost was based on various methods - BTS-measurements and mapping of rock glaciers were of greatest importance. Rock glaciers were mapped over the whole of the eastern Austrian Alps using aerial photographs. In this way an inventory containing different criteria such as the lower limits of all the rock glaciers was produced.

Special studies on mountain permafrost were carried out and are continuing at several test sites using geophysical and geodetic methods. The two most important study areas are the Hochebenkar, Oetztal Alps, Tyrol (Haeberli and Patzelt, 1983), where a good map of permafrost distribution and thickness of the active layer has been produced, and the inner Dösen Valley, Hohe Tauern, Carinthia (Lieb, 1996; Kaufmann, 1996). In the Dösen Valley, research projects on high mountain permafrost started in 1993 as multidisciplinary cooperation of the Department of Geography at the University of Graz, the Department of Applied Geodesy and Photogrammetry at the Graz University of Technology, the Department of Geophysics at the University of Leoben and the Institute of Applied Geophysics at the Joanneum Research Leoben. A map of permafrost distribution and first results of seismic and georadar measurements are already available.

A useful baseline now exists for long-term monitoring of mountain permafrost changes. In the case of Hochebenkar, a series of geodetic surveys allows the observation of the changes in the surface velocity of the rock glacier. In Dösen Valley, a series of maps, compiled by V. Kaufmann at Graz University of Technology, form the basis for a comparison with older aerial photographs and for high-precision photogrammetry to examine future variations in rock glacier permafrost. Borehole drilling and measurements have not been undertaken so far in Austria but are planned for the next few years.

Canada

Ground temperature cables and weather stations were first put in place in alpine permafrost at Plateau Mountain in 1974 (Harris and Brown, 1978), and since then, the network has been extended northwards along the mountains. Continuous temperature observations have been obtained and studies carried out on related features such as ice caves, patterned ground, block slopes, rock glaciers, etc. There is a close relationship between the elevation of the lower limit of continuous permafrost and the winter snow cover (Harris, 1986). At Plateau Mountain, the snow blows off the top, resulting in permafrost at a much lower elevation than at Sunshine Ski Area, with its 2 m snow cover (Harris, 1981). The latter is unusual, and is marked by the only major development of alpine meadows in this part of the Rocky Mountains (Harris, 1995).

The long-term air temperature records at the summit of Plateau Mountain (2,500 m a.s.l.) exhibit a 2°C decrease in mean annual air temperature between 1975 and 1985. This was followed by an increase in variability but no noticeable warming. Several cold air drainage events have occurred since 1985, but none were recorded in the previous decade. This cooling in air temperature between 1975 and 1985 was accompanied by an increase in the freezing index (sum of the negative daily temperatures in a year), while the thawing index remained fairly constant. Comparison with other stations suggests that permafrost in the entire range of mountains is experiencing relatively constant thermal conditions. This fact represents a sharp contrast to the rather dramatic mass losses of glaciers in the same region and during the same time interval (IAHS (ICSI)/UNEP/ UNESCO, 1994). The only exception is at Marmot Ski Area at Jasper, but even there, the mean annual air temperatures for 1991-1994 are similar to those from 1979-1985. The ground temperatures on top of the mountain continue to decrease, although the lower limit of permafrost has risen about 10-15 m. Part of this change may be due to interference in the ground temperature regime by the ski operation. Areas of moisture movement through the ground cause the biggest changes in ground thermal regime (Harris, 1992), and removal of snow by increased strength of westerly winds probably accounts for the continued ground cooling at individual sites.

Mountains also occur in many parts of the eastern Canadian Arctic but they have been little studied. Continuous cold permafrost (<-10°C) prevails in many of these areas and small glaciers are cold-based. Debris flow and slushflow activity in the Sawtooth Mountains on Ellesmere Island were recently examined (Lewkowicz and Hartshorn, 1998) and these sites were visited during the High Arctic Symposium and Field Trip in 1996 (see report by the Periglacial Processes and Environments Working Group).

China

Due to the pervasive influences of permafrost change on the environment and on civil engineering, efforts have been made by Lanzhou Institute of Glaciology and Geocryology to monitor permafrost changes during the past 30 years in the Qinghai-Tibet plateau and the Tianshan Mountains (Wang, 1993; Cheng *et al.*, 1993, in press; Jing *et al.*, 1993). Long-term observations include borehole temperature measuring, moisture dynamics of the active layer (neutron probe), permafrost creep (inclinometer system), movement of rock glaciers, block streams, solifluction and gelifluction, permafrost thaw settlement and frost heave along the highway, vegetation change and other permafrost-related data (DC electrical soundings, radar, remote sensing). Five *in situ* observation fields, more than 20 boreholes along the Qinghai-Tibet highway, and five boreholes near the Tianshan glaciological station, were chosen for the purpose of long-term permafrost monitoring.

In the past 20 or 30 years, permafrost degradation on the Qinghai-Tibet plateau occurred to varying degrees in several districts of different frozen ground types. The evidence includes increases in ground temperatures, contraction of permafrost areas, a decrease in permafrost thickness, disappearance of permafrost, enlarging taliks, etc. Mean annual ground temperatures showed increases of 0.1 to 0.3°C on average in the plateau and permafrost degradation is especially strong in regions near the permafrost lower limits and in regions with little ice in the sediments. In regions where the deposits are rich in ice, the ground temperatures increased more slowly or even remained unchanged. For example, the borehole JXG near the northern lower limits showed a rise of the permafrost base by some 35 cm per year and the ground temperature at depths between 10 and 20 m rose by 0.5° to 0.8°C during the past 20 years. On the other hand, borehole temperatures in the Fenghuoshan where the sediments are rich in ice, have risen only by 0.1 to 0.2°C. Based on the data available, ground temperatures below a depth of 30 m generally increased slowly or even show no obvious change.

The five boreholes used for temperature measurement in the Tianshan have been measured for three years now and do not show obvious changes, probably because of the relatively short record.

France

A great number of resistivity soundings were carried out on active and relict rock glaciers as well as on other permafrost bodies, especially in the Southern Alps (Evin and Assier, 1983; Evin *et al.*, 1991; Fabre and Evin, 1990). Attempts are also being made to monitor the long-term evolution of selected rock glaciers (Francou and Reynaud, 1992).

Germany

Germany has a very limited permafrost area, restricted to the highest regions of the German Alps (Zugspitz-Area, around 2,900 m a.s.l.). Permafrost has been detected occasionally in the course of railway construction work (cf., Ulrich and King, 1993). A 6 m borehole has been drilled in the course of a new cable car construction at the top of the Zugspitze. The site is disturbed by the construction activity. It will be measured regularly in the future. It is planned to drill a 30-60 m deep borehole on Zugspitze at an undisturbed site for long-term monitoring within a project supported by the Ministry of Research and Development.

Mountain permafrost research in Germany focuses on discontinuous mountain permafrost in the Swiss Alps and long-term monitoring is mainly done by the Universities of Giessen and Heidelberg. Long-term observations include shallow borehole temperature measurements, photogrammetry and geodetic surveys of permafrost creep at selected rock glaciers as well as a systematic inventory of geophysical data (refraction seismics, DC resistivity soundings, BTS mapping). An important rock glacier site is Macun (Upper Engadin, Swiss Alps), studied mainly by Barsch and Hell (1976). This rock glacier will be resurveyed at intervals of two to five years; the last surveys were undertaken in 1989, 1992 and 1994. The results show a decrease in flow velocity during the last 25 years. Other rock glacier monitoring sites are located at Albana and Val Sassa and regular surveys at longer intervals are planned there.

Another important research area with geophysical data inventory is the Zermatt area (King, 1990, 1996). Geophysical research and data collection started there in 1983 and continues in order to supply field data for checking results from modelling permafrost distribution patterns. The models will be developed in cooperation with Swiss colleagues.

Rock glacier monitoring also continues in the Andes of Mendoza (cf., text for Argentina).

Italy

Several hundred BTS and shallow ground temperature measurements (STG) were done in the Valtellina area in combination with detailed geomorphological surveys including ^{14}C-dating of buried soils and peats for chronological analysis of the glacial and periglacial evolution of the area. The BTS and STG measurements showed a good correlation not only among themselves but also with the thickness of the active layer as evaluated by means of geoelectric prospecting (Calderoni *et al.*, 1993; Guglielmin and Tellini, 1993; Guglielmin *et al.*, 1994). More than 60 vertical DC resistivity soundings have been carried out on rock glaciers (both active and inactive) and other landforms which - according to measurements of BTS, STG and spring water temperatures - were hypothesized to be characterized by the presence of permafrost. Vertical electric soundings also allowed the identification of different internal structures in relation to the age of the investigated phenomena. Detailed phytosociological surveys carried out in the same area, allowed correlations to be made between vegetation, duration and thickness of snow cover, and the depth of the permafrost table. In addition, mapping of permafrost using satellite remote sensing techniques, furnished relevant and accurate results (Antoninetti *et al.*, 1993). This method will contribute to future monitoring of permafrost variations.

A complete automatic meteorological station was installed in September 1993; the results of the first two years of observations are presently under examination. The meteorological station automatically records wind direction and speed, air temperature, snow cover temperature at different heights, snow cover thickness, rainfall, and incident and reflected solar radiation. Furthermore, it is also capable of measuring soil temperature at different depths (0, 30, 50, 150 and 300 cm) at two different points in the La Foppa I rock glacier and in a nearby tardiglacial moraine in Val Vallaccia overridden by the same rock glacier.

Relict permafrost has been recently found at elevations between 2400 and 2700 m a.s.l. on the Maiella Mountain (Central Apennines) by means of BTS measurements in rock glaciers and surrounding terrain.

Japan

Mountain permafrost was found in the early 1970's in two volcanic regions, Daisetsu Mountains (around 2,000 m a.s.l.) in northern Japan and Mt. Fuji (the summit, 3,776 m a.s.l.) in central Japan, by means of shallow drilling and ground temperature measurements (Fujii and Higuchi, 1978). In the Daisetsu Mountains, this pioneering work was followed by a wide range of studies including the analysis of core materials, long-term monitoring of ground temperature, simulation of permafrost degradation since the Last Glacial period and photogrammetry of palsa formation (Sone *et al.*, 1988). This volcanic permafrost is of special interest in view of the high geothermal activity. Both, climatic change and volcanic activity control the permafrost development. In fact, permafrost in Mt. Fuji is quite young, considered to have grown after an eruption which took place several centuries ago. The sporadic distribution of permafrost on non-volcanic high mountains in central Japan (the Japanese Alps, around 3,000 m a.s.l.) is indicated by a certain number of rock glaciers, which may be active or inactive, and by mountain hut construction encountering frozen ground. Preliminary BTS and seismic measurements suggested that permafrost underlies at least one rock glacier. A permafrost monitoring program has just started at three localities in the Japanese Alps. This program includes long-term monitoring of ground temperature, electrical resistivity measurements, and geodetic and photogrammetric surveys. Automatic recording of freeze-thaw processes (rock weathering, soil heaving and solifluction) also continues near the lower limit of permafrost (Matsuoka, 1994).

Kazakhstan and Central Asia

The focus here has been on monitoring thermal conditions within permafrost and the study of the rock glacier activity and solifluction processes. Most of these geocryological studies have been carried out in the catchment of the Bolshoy Almatinka river near Almaty (Zailysky Alatau Range, Northern Tien Shan). This territory has been proposed as a test region for monitoring cryogenic phenomena. In addition to monitoring activities, maps at scales of 1:1,000,000 and 1:500,000 have been compiled showing permafrost distribution within the whole of the Tien Shan and Pamir mountain chains. According to these maps, the areas of continuous, discontinuous and island permafrost have been determined as 83,000, 76,000 and 110,000 km^2 for the investigated region.

A special geocryological map of the Almatinka test region has been compiled at a scale of 1:25,000. In this region, 10 active rock glaciers are being geodetically observed. Solifluction processes and the development of icings are also documented. Two boreholes are being monitored with respect to permafrost temperature. The first borehole in the Northern Tien Shan of Kazakhstan is at 43°05'N/76°52'E and at an altitude of 3,350 m a.s.l. At this site, permafrost thickness was about 40 m in 1975. Since then, the temperature at 15 m depth increased from -0.6°C to -0.2°C in 1993. The second borehole in the Inner Tien Shan of Kirghizstan is at 41°51'N/78°12'E and at about 4,100 m a.s.l. At this site, permafrost thickness is estimated at 100 to 300 m and the temperatures at 25-20 m depth have increased by an average of 0.1°C between 1987 and 1992.

Some of the research material of the last years has been summarized by Gorbunov *et al.* (1995), Gorbunov *et al.* (in press), and Gorbunov and Seversky (in preparation).

Norway

There is no borehole monitoring in mountain permafrost in Norway at present. One 10 m borehole was measured in the Jotunheimen, southern Norway, from 1982 to 1986 (Ødegard *et al.*, 1992), but the cable was then damaged and the borehole closed. At this site at an altitude of 1,851 m a.s.l, mean annual ground temperature was estimated to be -2.1°C to -2.3°C at the top of the permafrost. There are plans to reactivate this borehole as well as to drill some new holes at other sites in the same area for long-term monitoring of ground temperature. On Svalbard there are a few 10-15 m boreholes with automatic logging of ground temperatures, related to construction at Longyearbyen and Sveagruva. The measurements at Sveagruva are conducted by the Norwegian Geotechnical Institute (NGI). There are plans to drill deep boreholes on Svalbard for long-term ground temperature monitoring.

In 1995 a program to monitor shallow ground temperatures related to different geomorphological features (solifluction, ploughing blocks, nivation), was initiated at Finse in southern Norway. The site has a mean annual air temperature of -2° to -3°C and is marginal to mountain permafrost. This monitoring program is part of the PhD work of Ivar Berthling, University of Oslo, Department of Physical Geography, and focuses on solifluction and ploughing block dynamics.

New field data on mountain permafrost distribution have been collected from the mountain massifs of Jotunheimen and Dovrefjell in southern Norway. DC resistivity soundings and measurements of the bottom temperature of winter snow cover (BTS) confirm extensive permafrost occurrence at high altitude (Ødegard *et al.*, 1996). At Dovrefjell the permafrost limit occurs at about 1,450 m a.s.l.

(Ødegard, 1993). From resistivity soundings the permafrost thickness has been estimated at some 40 to 60 m at 1620 m a.s.l in a flat area near Snøhetta in Dovrefjell. The BTS data correlate well; measurements in 1992 and 1993 along the same profile showed a good replication of BTS-measurements.

Preliminary results from a site further east, Tron (1,666 m a.s.l.), indicate permafrost above 1,600 m a.s.l. So far, however, the data is too limited to establish an east-west gradient of permafrost distribution in southern Norway.

Based on a calculation of areas with mean annual air temperatures <-4°C, the area of discontinuous mountain permafrost in southern Norway is estimated at about 4,000 km^2. This value is corrected for the area covered by glaciers (about 1,600 km^2) and low altitude valleys within the mountain massifs. More BTS and resistivity soundings will allow further interpretation of the data in Geographical Information Systems (cf. Hoelzle *et al*, 1993), making possible more detailed knowledge of permafrost distribution patterns.

Switzerland

The area underlain by permafrost in the Swiss Alps is roughly estimated at about 2,000 km^2 (Keller *et al.*, in press) or somewhat more than the total glacierized area (about 1,300 km^2, IAHS (ICSI)/UNEP/UNESCO, 1989). During the past 25 years, attempts were made to establish systematic long-term observations on mountain permafrost in the Swiss Alps (Haeberli *et al.*, 1993). Emphasis is on discontinuous permafrost and the observations are made in a collaborative effort of VAW/ETH Zurich and the Universities of Bern, Fribourg, Lausanne and Zurich. Long-term observations include borehole temperature and deformation measurements (Hoelzle *et al.*, in press; Vonder Mühll *et al.*, in press), high-precision photogrammetry of permafrost creep (Kääb *et al.*, in press) and thaw settlement/frost heave on selected rock glaciers, systematic inventory of geophysical data (refraction seismics, DC resistivity soundings, gravimetry: Vonder Muehll, 1993), BTS-mapping (Hoelzle *et al.*, 1993), runoff measurements (Tenthorey, 1992), and periodically repeated analyses of infrared air photos with respect to vegetation cover, thermokarst phenomena, drainage patterns, debris flows, etc.

The two drill sites Murtèl-Corvatsch and Pontresina-Schafberg are of the greatest importance. The 60 m deep borehole on the Murtèl rock glacier was drilled in 1987. Core analyses and borehole geophysics showed that permafrost underneath the 3 m thick active layer is extremely supersaturated and the ice content amounts to almost 100% down to a depth of 28 m. Between 28 m and 58 m the pores of the coarse blocks are ice-filled (structured permafrost). Temperatures at 10 m increased from -2.3°C (1987) to -1.4°C (1994) but decreased intermittently due to thin snow cover in the winters of 1994/95 and 1995/96. Between the depths of 52 m and 58 m, seasonal temperature variations around 0°C are observed in a talik. Total permafrost thickness is estimated at about 100 m. The two drill holes at Pontresina-Schafberg reached depths of 65 m and 37 m and remained within permafrost. 10 m temperatures in 1994 were -0.5°C and -1.0°C. Parallel development of borehole temperature at both sites (Murtèl and Pontresina-Schafberg; Stucki, 1995) indicates that recent warming of permafrost temperature is not a local but a regional phenomenon. Monitoring of rock glacier flow by photogrammetric and geodetic methods extends back to 1932 (Messerli and Zurbuchen, 1968; Barsch and Hell, 1976) and is presently being carried out in cooperation with German colleagues (cf. text for Germany). The rock glaciers Gruben, Gufer, Réchy, Furggentälti, Murtèl, Muragl and Suvretta are being photogrammetrically monitored at intervals of about 5 years (Kääb *et al.*, in press).

The last decade has brought a strong increase of borehole temperatures in the permafrost of the Upper Engadin and accelerated thaw settlement on Gruben rock glacier. The energy flux involved in permafrost degradation is about one order of magnitude smaller than the energy flux reflected by glacier melt.

USA

Permafrost is present at higher elevations of the contiguous United States, in both the western and eastern mountain ranges (Péwé, 1983), throughout the mountains of Alaska and on isolated peaks in Hawaii. However, no coordinated, systematic studies are underway to map, monitor or model mountain permafrost. In Alaska, a long-term borehole monitoring program by Osterkamp and Romanovsky (1996) includes several boreholes in the Brooks Range and adjacent mountains where active rock glaciers have been studied (Ellis and Calkin, 1979). The borehole at Chandalar Shelf (3100 m a.s.l.) is 61 m deep and has been measured annually since 1985. The CAPS CD contains data from these locations. These sites are now part of the Circumpolar Active Layer Monitoring (CALM) network. A digital map of permafrost in Alaska is available at <http://agdc.usgs.gov/data/usgs/erosafo/permafrost/metadata/permafrost.html> at a scale of 1:2,500,000.

In the contiguous United States, several areas have a long history of observations. Niwot Ridge in the Front Range of the Rocky Mountains, is one site of the Long Term Ecological Research (LTER) program at which hydrologic and snowbed studies are active. Williams *et al.* (1996) report on a continuous climate record since 1951 at this site and show a decline in mean annual temperature, an increase in annual precipitation amount, and a decrease in mean daily solar radiation for the summer months. The changes in climate at Niwot Ridge are not synchronous with lowland warming in the Great Plains to the east and serve as a reminder that climate in alpine areas is driven by local conditions and may be out of phase with regional and global climate trends. Nel Caine and Hillary Hamann are working on snow hydrology and permafrost-related problems on and near Niwot Ridge.

The Galena rock glacier in Wyoming is the site of renewed intensive field investigations including a 13 m borehole in which temperatures and displacement will be measured. Future plans include extending the current borehole to bedrock and drilling additional boreholes at various locations on the rock glacier. A special issue of *Geografiska Annaler* is in preparation which reports results of the 1996 Chapman conference on geomorphic and climatic significance of rock glaciers including the Galena rock glacier.

Periglacial patterned ground has been investigated in the White Mountains of California since 1991 (Wilkerson 1995). Patterns range from large-scale sorted polygons, nets, and stripes, to small-scale hexagonal patterns located within active frost boils from 3900-4150 m a.s.l. Landforms near the summit of White Mountain Peak (4150 m a.s.l.) are highly active at all scales. At present, air and surface temperatures are recorded at 3800 m. A drill is available for boring to 30 m so that thermistors can be installed starting in summer 1998. Other sites in Wyoming and Utah have been the subject of recent investigations: Nicholas and Garcia (1997) on fossil rock glaciers in the La Sal Mountains; Konrad and Clark (1998) on the use of rock glaciers in the Sierra Nevada, California to reconstruct Neoglacial climate.

Periglacial investigations are now in progress in Hawaii. Hallet and Werner are conducting a coordinated and theoretical study of sorted stripes that are exceptionally well-developed on certain slopes above 4000 m on Mauna Kea. Continuous monitoring of surface heave, near-surface temperature, and moisture, and manipulative studies of sorted stripes are being employed to examine the evolution and recovery of altered plots in an effort to test their theoretical model (Werner and Hallet, 1993).

Other investigations are conducted outside the U.S., for example in the Himalayas where remote sensing techniques, digital elevation mapping and ground penetration radar are being used in the Nanga Parbat (8125 m) region to investigate frozen debris-covered slopes. Related studies focusing on mass movement will be reported in a 12-paper special issue of *Geomorphology* (J. Shroder, editor, in press).

THE PACE PROJECT IN EUROPE

A major new three-year research project with full title "Permafrost and Climate in Europe: Climate Change, Mountain Permafrost Degradation and Geotechnical Hazard" (acronym PACE) has been funded under the European Union Environment and Climate Program by the EU and the Swiss Government, and commenced in December 1997. The primary objectives are :

(1) to establish a framework for monitoring global climate warming by detecting changes in permafrost ground temperatures in the mountains of Europe;

(2) to develop methods of mapping and modelling the distribution of thermally sensitive mountain permafrost, and predicting climatically induced changes in this distribution; and

(3) to provide new, process-based methods for assessing environmental and geotechnical hazards associated with mountain permafrost degradation.

Thus, the PACE Project will establish a Europe-wide, long-term, mountain permafrost monitoring program based on a transect of instrumented boreholes from Janssonhaugen, Svalbard (Norway) in the north to Veleta Peak in the Sierra Nevada, Spain, in the south, including intermediate sites at Kebnekaise in northern Sweden, Juvasshytta in Jotunheimen, Norway, the Zermatt area and on Schilthorn in Switzerland, and the Stelvio Pass, Italy. The application of a range of geophysical techniques to the mapping and characterization of mountain permafrost will also be explored in order that rapid and reliable methods of detecting mountain permafrost may be developed. New approaches to numerical modelling of mountain permafrost distribution will be based on energy balance transfer functions and digital terrain models. Scaled centrifuge modelling of thaw-induced slope instability processes will be undertaken in order to investigate trigger mechanisms related to permafrost degradation. These related research activities will be integrated to provide improved methodologies for mountain slope hazard assessment associated with future climate change.

The PACE Project is co-ordinated by C. Harris at the University of Cardiff, United Kingdom and the Project Partners are Justus Liebig University, Giessen, Germany; The Third University of Rome, Italy; University Complutense, Madrid, Spain; The University of Oslo, Norway; Stockholm University, Sweden; the University of Zurich, Switzerland; The Federal Institute of Technology, Zurich, Switzerland; and TerraDat (UK) Ltd of Cardiff. Work on borehole drilling and instrumentation is led by L. King (Giessen), geophysical exploration by D. Vonder Mühll (ETH Zurich) and Terradat UK, geomorphological and related mapping of permafrost by F. Dramis (Rome) and J.L. Sollid (Oslo), numerical modelling by W. Haeberli and M. Hoelzle (Zurich), geotechnical centrifuge modelling by C. Harris (Cardiff) and M.C.R. Davies (Dundee) and hazard assessment by C. Harris (Cardiff).

The research undertaken by the PACE Project will develop a common European approach and provide an integrated interdisciplinary program of mountain permafrost research. Data will be contributed to the IPA Geocryological Database and the CALM project.

SUMMARY AND CONCLUSIONS

The first systematic overview of long-term monitoring programs related to mountain permafrost provides information from 11 countries. Additional information can be expected from Russia, Sweden and others. With respect to measured parameters, information is available or is planned (p) to be collected on borehole temperature in the Andes of Argentina (p), the Canadian Rockies since 1974, the European Alps since 1987, in Scandinavia for 1982-86 and (p), on Svalbard (p), in the Kazakh/Kirghiz/Chinese Tien Shan since 1975 and on the Qinghai-Tibet Plateau since 1962. In most of these regions, rock glacier flow is being monitored and maps/geophysical soundings exist at selected sites.

The most important signal becoming visible by now is from borehole temperatures and covers the past few years to decades. With the exception of the Canadian Rockies, where the seemingly constant thermal conditions in perennially frozen ground sharply contrast with the simultaneous mass losses of nearby glaciers as observed within the framework of worldwide glacier monitoring, warming of permafrost temperatures is pronounced in the European Alps (0.9°C during 1987-1994), the Kazakh/Kirghiz Tien Shan (0.4°C during 1975-1993 in Kazakhstan, 0.1°C during 1987-1992 in Kirghizstan) and in Qinghai-Tibet (0.1 to 0.8°C between the 1970's and the 1990's). Warming rates reported from these mountain permafrost sites vary over more than an order of magnitude (0.005 to 0.13°C per year) and average a few tenths of a degree C per decade or a few degrees C per century. Such values are roughly an order of magnitude higher than mean atmospheric warming during the past about 150 years or so. The longest and most detailed records relating to rock glacier flow are available in the European Alps. They indicate characteristic climate-induced thaw settlement at rates of about 0.01 to 0.1 m per year with flow velocities remaining fairly constant or decreasing slowly.

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APPENDIX: Questionnaire

Mapping, Modelling and Monitoring of Mountain Permafrost

Questionnaire of the IPA Working Group on Mountain Permafrost

Key to country names:

Argentina	RA
Austria	A
China	CN
France	F
Germany	D
Italy	I
Japan	J
Kazakhstan	K
Norway	N
Russia	R
Switzerland	CH
USA	US

1. Mapping

1.1. The following natural indicators are being used for large-scale mapping:

rock glaciers	RA, A, CN, F, D, I, J, K, N, R, CH, US
perennial snowbanks	RA, A, CN, F, D, J, K, N, R, CH, US
vegetation patterns	RA, A, CN, D, I, J, K, R, CH
summer/autumn temperature of springs	RA, A, F , D, I, K, CH
other (pingos, palsas, kurums, etc.)	RA, CN, D, K, I, J, N, R, US

1.2. The following types of geophysical soundings are being used for large-scale mapping:

BTS measurements	A, D, I, J, K, N, CH,
active layer temperature gradient	RA, D, I, J, K, N, CH
electrical resistivity	RA, A, CN, F, D, I, J, K, N, R, CH
seismics	RA, A, F, D, N, R, CH
gravimetry	CN, N, CH
radar	A, F, CN, R, CH
other	RA (magnetotellurics), CN, J, R

2. Modelling

2.1. CN, D, I, J, N, CH, US are using models for numerically simulating permafrost distribution in mountain areas

2.2. Types of models are:

I:	topography, radiation, landsat information
D:	air temperature, slope/aspect + PERMAKART*
CH	PERMAKART* and PERMAMAP** (air temperature, radiation, DTM)
N:	topography
CN:	heat conduction with phase change
J:	multipoint Adams-Bashforth method (MAB)
US:	Goodrich/Guymon model (finite difference/finite element with phase change)

* = Keller (1992) in PPP 3:2; ** = Hoelzle *et al.* (1993) in Beijing Proceedings

2.3. All participating countries are interested in a collaborative effort concerning selected study areas for intercomparison

2.4. Digital terrain information is available in: RA, A, CN, D, I, J, N, R, CH, US

2.5. The resolution of corresponding grids varies from 10 to 2,000 meters and is typically around 50 meters

2.6. The scale of the map basis in study areas without digital terrain information is typically 1:25,000

3. Monitoring

3.1. RA, A, CN, D, I, J, K, N, R, CH, US are carrying out a permafrost monitoring program

3.2. (-)

3.3. (-)

3.4. RA, CN, I, J, K, N, R, CH, US can observe/measure boreholes

3.5. Localities of borehole monitoring are Valtellina/Alps (I), Andes of Mendoza (RA), Northern Tienshan (K), Engadin/Alps (CH), Jotunheimen area (N), Tibetan Plateau (CN), various mountain ranges (R), Daisetsu Mountains (J), Galbreath Lake, Chandalar Shelf, Coldfoot (US)

In these cases, information is available on

borehole coordinates	RA, CN, I, J, K, N, R, CH, US
date and technique of drilling	RA, CN, I, J, K, R, CH, US
borehole depth	RA, CN, I, J, K, N, R, CH, US
borehole diameter	RA, CN, I, J, K, N, R, CH, US
approximate mean 10 m-temperature	RT, CN, K, N, CH, US
estimated permafrost depth	RA, CN, J, K, N, R, CH, US
measurement intervals	RA, CN, I, J, K, N, R, CH, US
sensors/data loggers used	RA, CN, I, J, K, N, CH, US
borehole accessibility (recalibration possibility)	RA, I, N, CH, US
lithology	RA, CN, J, K, N, R, CH, US
ice content	CN, J, K, R, CH
hydraulic permeability	CH
deformation	R, CH, US
core material	J, K, R, CH,
water in the borehole during drilling	CN, I, R, CH
surface topography	RA, CN, I, J, K, N, R, CH, US
snow conditions	RA, CN, I, J, K, N, R, CH, US
vegetation	RA, CN, I, J, K, N, R, CH, US
geomorphology	RA, CN, I, J, K, N, R, CH, US

3.6. RA, CN, I, J, K, N, R, CH, US carry out long-term airphoto and/or field observations

3.7. these observations concern

quantitative measurements on	
permafrost creep	RA, A, CN, D, I, J, K, N, R, CH
frost heave/thaw settlement	RA, CN, J, CH, US
qualitative observations on	
vegetation changes	RA, A, , CN, D, I, J, K, RCH, US

rock glacier activity	RA, A, CN, D, I, J, K, N, R, CH, US
snowbank size	RA, A, CN, D, J, R, CH, US
debris flows	RA, I, J, K, N, R, CH, US
rock falls	RA, D, I, J K, R, CH, US
drainage patterns	CN, R, CH
thermokarst	RA, J, K, R, CH,
solifluction	RA, I, J, K, N, R, CH, US
patterned ground	RA, CN, I, J, K, N, R, US
other	RA, CN, I, J, K, R, US

3.8. RA, D, N CH, US carry out long-term hydrological monitoring in permafrost areas

3.9. These measurements concern

runoff	RA, D, N, CH, US
climate data	RA, D, N, CH, US
repeated tracer experiments	D, N, CH, US

3.10. All participating countries would be interested in starting a program within an international coordinated monitoring network.

PERIGLACIAL PROCESSES AND ENVIRONMENTS WORKING GROUP REPORT

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INTRODUCTION

The purpose of the Periglacial Processes and Environments Working Group was: (1) to investigate the frequency and magnitude of periglacial processes, especially those occurring within the active layer; (2) to evaluate different methodologies and techniques for process measurements; and (3) to predict the effects of potential climate change on periglacial environments using contemporary data and the stratigraphic record. A further important role for the WG has been to foster links between the IPA and the International Geographical Union and the International Association of Geomorphologists.

Activities over the past five years have concentrated on organizing symposia, workshops and field meetings. The majority of these have been held jointly with the IGU Commission on Frost Action Environments and the recently designated Commission on Climate Change and Periglacial Processes (CCPP) as well as in collaboration with other international organisations. The close co-operation between this Working Group and the IGU Commissions is reflected in joint newsletters which have been produced regularly over the past 5 years and distributed internationally.

Meetings have focused on specific regions or topics, and have attracted a large number of participants from the majority of IPA adhering bodies. In addition, they have allowed a great deal of interaction with other WGs, notably those for Global Change and Permafrost and Mountain Permafrost.

MEETINGS

Field Excursion and Symposium on Periglacial Slope Processes and Environments, France (4-9 September 1994)

Organized by J.-P. Lautridou, J. C. Ozouf and J. P. Coutard (CNRS, Caen), this extremely successful five-day field excursion covered a transect from the Charentes-Perigord area to the Champagne region and thence to Lorraine and visited exposures of periglacial slope deposits, including grèzes litées, and areas of recent landslide activity. Half-day symposia were held at Reims and Nancy. Three field guides were produced to accompany the excursion (see *Frozen Ground* Number 16 for details). More than 35 delegates from 10 countries attended the meeting.

Ten papers appeared in a special issue of *Permafrost and Periglacial Processes* (Volume 6 No. 2, 1995).

Workshop on Frozen Ground, Hanover, New Hampshire, USA (9-11 December 1995)

Organized by Bernard Hallet and Patrick Black, the workshop "Our current understanding of processes and ability to detect change", was held in conjunction with the Mountain Permafrost and Global Change and Permafrost Working Groups at Dartmouth College and the Cold Regions Research and Engineering Laboratory. Some 50 delegates from 12 countries enjoyed a well-focused workshop with thematic sessions on soil freezing and frost heave, slope processes and frost sorting, soil hydrology, biochemistry and gas exchange, monitoring mountain permafrost, permafrost temperature data and permafrost landscape development. Six papers presented at the symposium were published in *Permafrost and Periglacial Processes* (Volume 7, No. 4, 1996).

Special Session H32G, Frozen Ground Processes AGU Fall Meeting, San Francisco, California, USA (13-14 December 1995)

The session was organized by Bernard Hallet and included twelve papers and fourteen poster presentations covering a wide range of topics including soil freezing processes, thermal monitoring, mountain permafrost, methane emissions, dating, soil water hydrology and periglacial geomorphology. Abstracts were available in *EOS, Transactions of the American Geophysical Union 1995 Fall Meeting*, **76**, No 46.

High Arctic Field Meeting and Symposium, Canada (July 7-16 1996)

Ten participants from seven countries attended this meeting on Ellesmere, Cornwallis and Axel Heiberg Islands in the Canadian Arctic. Organized by Antoni Lewkowicz, the logistical support and accommodation were provided by the Canadian Polar Continental Shelf Project, Department of National Defence, and the Atmospheric Environment Service. Four days were spent on Ellesmere Island, in the Eureka area, at Hot Weather Creek and in the Sawtooth Range. A field guide describing patterned ground, detachment slides, debris flows, slushflows, solifluction and aeolian activity at the sites visited was published (Lewkowicz, 1996). In the Resolute area, Kathy Young (York University) showed study sites where she is examining wetland nutrient flows over permafrost. Link Washburn (University of Washington) described his work on solifluction and patterned ground study sites. Eight presentations were given at a symposium at Eureka. These discussed chemical and physical weathering in periglacial areas, landsliding in permafrost, ice wedge and sand wedge casts, and periglacial conditions in southern Germany and the UK during the last glaciation.

International Geographical Union (IGU) Congress, The Hague, Netherlands (August 1996)

Within this large congress, a one-day session, Environmental Change under Periglacial Climatic Conditions, was organized by the newly formed IGU Commission on Climatic Change and Periglacial Environments. In a plenary session, a state-of-the-art report on present periglacial and frost action research was presented by Jef Vandenberghe.

The existing link with the IPA through the WG on Periglacial Processes and Environments was formalized in a signed agreement between IGU and IPA. The Chair of the IGU Commission (Jef Vandenberghe) is a member of the IPA WG, and the Chair of the WG (Antoni Lewkowicz) is a member of the IGU Commission. Charles Harris is the Secretary of both groups.

27th Arctic Workshop, University of Ottawa, Canada (February 27-March 2 1997)

This meeting was organized by Antoni Lewkowicz and involved more than 100 delegates, mostly from Canada and the USA, but also from Russia, Germany, UK, Estonia and Latvia. The meeting was wide-ranging, covering all aspects of the Arctic environment including permafrost. A Program and Abstracts Volume was published (Lewkowicz and Kokelj, 1997).

Members of both the Periglacial and Global Change WGs attended and detailed discussion of the CALM procedures were undertaken.

Periglacial Geomorphology Session 4th International Conference on Geomorphology (3 September 1997)

Organized by Francesco Dramis, the session's keynote presentations were given by W. Haeberli, C. Harris , Y. and A.C. Vasilichuk. Poster presentations followed the oral session. Abstracts were available in the Abstracts of the Fourth International Conference on Geomorphology, Bologna Supplemento III, Tomo 1, Supplimenti di Geografia Fisica e Dinamica Quaternaria, Torino 1997.

Workshop on Periglacial Processes and Environments, Cardiff UK (16-17 December 1997)

The workshop was organized by Charles Harris and Julian Murton on behalf of the IPA Periglacial Processes and Environments Working Group, the IGU Commission on Climate Change and Periglacial Environments and the Quaternary Research Association. The conference was attended by 50 delegates from 15 countries and a total of 24 papers were presented covering the following research themes: (1) cryostratigraphic methods and palaeoclimatic reconstruction; (2) monitoring of permafrost temperatures and periglacial processes; (3) dating of periglacial structures and sediments; and (4) physical modelling of periglacial processes. The meeting ended with a visit the Geotechnical Centrifuge Laboratory in the Cardiff University School of Engineering where physical modelling of cryogenic processes is underway. A selection of papers from the meeting will be published in a special issue of *Permafrost and Periglacial Processes.*

RELATED AND FUTURE ACTIVITIES

Handbook

Preparation of the handbook entitled "Recommended Methods for Measuring Periglacial Processes" has been initiated. The proposal to undertake this task was first put forward at the Beijing Conference. The impetus to standardize techniques is drawn from the need to be able compare circumpolar studies, particularly in the context of global change research. Standardization of methodology has been followed in CALM, in the International Tundra Experiment (ITEX) and in work on the Paleoclimates of Arctic Lakes (PALE). This task is also in keeping with the Monitoring Resolution of the IPA passed at the Berlin Meeting in 1995 (see the beginning of the IPA Reports section in this volume).

An outline of the handbook has been developed and several informal meetings have been held with members of the Global Change WG relating to active layer measurements and CALM. It is planned to make completion of this task the main aim of the Working Group over the next five-year period. The main topics to be covered are the following:

(1) Monitoring of ground thermal regime:
- (a) Active layer temperatures and depth
- (b) Stable permafrost
- (c) Permafrost growth

(2) Detection of Frozen Ground:
- (a) Ground penetrating radar
- (b) DC resistivity
- (c) Seismic techniques
- (d) Other methods

(3) Frost heave:
- (a) Frost heave of soil
- (b) Bedrock heave

(4) Cold climate weathering:

(a) Field
(b) Laboratory
(5) Thermal contraction cracking and ice wedge growth
(6) Processes of patterned ground formation
(a) Sorted circles
(b) Earth hummocks
(c) Mud boils
(d) Stripes
(7) Seasonal frost mound formation
(8) Frozen ground creep:
(a) Permafrost creep
(b) Rock glacier movement
(9) Solifluction
(10) Slopewash
(11) Retrogressive thaw slumping
(12) Rockfall and talus processes
(13) Physical modelling of periglacial processes
(14) Portable techniques for monitoring geotechnical properties relating to periglacial processes:
(a) Porewater pressures
(b) Active layer total and unfrozen moisture content
(15) Automated data acquisition
(16) Survey benchmark installation

The idea of this handbook is to standardize measurement techniques so that studies undertaken at different locations in the northern and southern polar areas and at high altitude produce comparable results. The aim is not to stifle creativity, but to recommend the best methods available at the present. New methods which may be developed in the future can then be compared with the old so that the data will remain comparable. The methods manual would be updated regularly at future International Permafrost Conferences.

The layout for each topic would be as follows:

(1) Topic title (process)
(a) Significance of process
(b) Brief literature review (summary of literature on process with principal references)
(2) Recommended measurement technique(s)
This section would review techniques and demonstrate why the recommended one(s) are the best. It would indicate which techniques are not recommended and give reasons. It would also deal with aspects such as spatial sampling and the minimum time necessary for acceptable results.
(3) References
(4) Appendix
Gives all the details necessary to employ the technique without previous experience.

A fundamental aim for this publication is that it should have the widest possible distribution. It should be made available especially to scientists who do not necessarily have funds for purchasing such a handbook from a traditional publishing house. Thus the aim would be to produce it cheaply, in a manner similar to the ITEX manual, so that it can be given away or sold for minimal cost (including packaging and mailing). For this reason, the WG would seek sponsorship from the IPA for the final production costs. In addition, it is planned that the material would be made available on the IPA website for those who have Internet access.

To undertake this task effectively, it is clear that the Periglacial WG needs to have an expanded membership. It will be proposed in Yellowknife that as the authors of the various sections of the Handbook agree to undertake this task, they be named as WG members.

Collaboration

The Periglacial WG will continue to collaborate closely with the IGU Commission on Climatic Change and Periglacial Environments and will support meetings organized by the latter. In addition, the WG will assist in the publication by the IGU Commission of an up-to-date review of recent developments in periglacial research. In order that these developments may be brought to the attention of the entire periglacial research community, a collection of state-of-the-art review papers for publication as a special issue of a regular journal is proposed. Collaboration with the International Association of Geomorphologists is also planned to continue over the next 5 years.

The Chairman and Secretary would like to thank all members who have participated in the activities of the Periglacial Processes and Environments Working Group over the past five years. The group has fostered publication of scientific papers and encouraged international collaboration in research, and hence helped fulfil the aims of the International Permafrost Association.

SELECTED WORKING GROUP AND RELATED PUBLICATIONS

Abstracts of the Fourth International Conference on Geomorphology, Bologna Supplemento III, Tomo 1, *Supplimenti di Geografia Fisica e Dinamica Quaternaria*, Torino 1997.

EOS, Transactions of the American Geophysical Union 1995 Fall Meeting, **76**, No. 46, 1995.

Lewkowicz, A.G. (1996). *Field Guide, High Arctic Symposium and Field Meeting, July 7-16, 1996*, Ottawa, Department of Geography, University of Ottawa, 64 pp.

Lewkowicz, A.G. and Kokelj, S.V. (eds.) (1997). *Program and Abstracts, 27th Arctic Workshop, Department of Geography, University of Ottawa, February 27-March 2, 1997*, Ottawa, Department of Geography, University of Ottawa, 250 pp.

Permafrost and Periglacial Processes, **6**, No.2. Special issues of the Grèzes Litées Symposium, France, 4-9 September 1994, Processus et depots periglaciaires de versant. Excursion: Grèzes litées. 206 pp., 1995.

Permafrost and Periglacial Processes, **7**, No. 4. Contributed papers from the IPA sponsored Workshop on Frozen Ground: Our Current Understanding of Processes and Ability to Monitor Change; Hanover, New Hampshire, December 9-11, 1995, pp. 299-360, 1996.

ENGINEERING WORKING GROUPS REPORT

Engineering Concerns of Climate Warming in Permafrost Regions

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INTRODUCTION

The following summary was prepared in response to the 1993 IPA Council resolution to prepare reports on recent information relevant to global change. This report is presented on behalf of the two IPA working groups most directly related to engineering problems: (1) the WG on Foundations whose purpose was to collect information on the practice of foundation engineering in various permafrost regions of the world and to synthesize guidelines for effective engineering practice, and (2) the WG on Seasonal Freezing and Thawing of Permafrost Areas whose purpose was to improve the exchange of information on, describe the state of knowledge about, and stimulate research activities concerning frost action in soils and measures to protect against its harmful effects in permafrost areas.

This report complements the report by the WG on Global Change and Climate (see this volume).

BACKGROUND

The majority of engineering concerns related to climatic warming can be classified into those related to an increase in permafrost temperatures, those related to increases in the active layer thickness (annual thaw depth), and those related to the degradation of permafrost. Engineering concerns related to a general warming of the permafrost result primarily from the decrease of its mechanical strength in its frozen and eventually thawed state. Continued climatic warming will eventually cause much of the discontinuous permafrost to thaw, resulting in increasing rates of thaw settlement of structures in thaw-sensitive regions of the Arctic (Esch and Osterkamp, 1990; Esch, 1993).

While there is still a considerable disagreement among the climatologists about the most probable rate of future climate warming, it is nevertheless not too early to start thinking about the kind of effects a certain amount of warming would have on the behaviour and stability of natural and human-made structures in the North. It is understood that a steady increase of air temperature will result in two related effects on the ground temperature:

(1) An increase in the mean annual temperature at the ground surface, which will slowly propagate to depth and, depending on latitude, produce either a thinning or a complete disappearance of the permafrost layer; and

(2) An increase in the annual amplitude of seasonal ground temperature variation, damped with depth, and affected by the related changes in precipitation (snow cover), groundwater hydrology and vegetation.

The potential effects of warming of the mean annual temperature on permafrost will be very different for continuous and discontinuous permafrost zones. In the continuous zone, mean surface temperatures are typically colder than -5°C, so that no widespread thawing is anticipated, except that which will be associated with possible thickening of the active layer. Where the permafrost is ice-rich, this surface thawing will produce subsidence of the ground surface, resulting in thermokarst, commensurate with its ice contents and thickness of the active layer. Thawing at the base of permafrost would start several centuries later and would proceed at a rate of about a centimeter or more per year. In the discontinuous zone, mean surface temperatures are typically much warmer that -5°C, and are often within a few degrees of thawing. In Alaska, warming of the last century and of the last two decades has already caused some discontinuous permafrost to thaw, and much of it is currently thawing. If the permafrost is not ice-rich, the effects of warming and thawing of the permafrost will include thermal effects, release of carbon dioxide and the effects of converting the ice to water. However, where the permafrost contains massive ground ice or is ice-rich, an additional effect, extensive thaw settlement and thermokarst, is expected. Induced thaw settlement is presently responsible for damage to houses, roads, airports, military installations, pipelines, and other facilities founded on ice-rich permafrost (Osterkamp *et al.*, 1997).

Although many centuries will be required for the permafrost to disappear entirely, increases in the active layer and thawing of the warmest permafrost from the top could begin almost immediately (Esch and Osterkamp, 1990; Osterkamp and Lachenbruch, 1990). As a result, over the half of the discontinuous permafrost zone would disappear eventually. The boundary between continuous and discontinuous permafrost will shift northward by hundreds of kilometers, although the ultimate position and timing are uncertain. The active layer will deepen slowly in the discontinuous zone to perhaps double its current depth (Smith and Riseborough, 1996). Pronounced thermokarst topography and increased erosional effects on coasts are likely. There will be an increased frequency of occurrence of shallow landslides (Maxwell, 1997). A problem not widely recognized is the increase in unfrozen water content of warm and thawing permafrost, which will influence all its physical and mechanical properties (Osterkamp *et al.*, 1997).

As mentioned, the physical and mechanical properties of frozen soils are strongly temperature dependent, and this effect is most pronounced at temperatures within one or two degrees C of thawing. Most of the permafrost engineering concerns related to warming of permafrost were summarized earlier by Esch and Osterkamp (1990), as follows:

(1) Warming of permafrost body at depth.
   a. Increase in creep rate of existing piles and footings.
   b. Increased creep of embankment foundations.
   c. Eventual loss of adfreeze bond support for piling.

(2) Increases in annual thaw (active layer).
   a. Thaw settlements during seasonal thawing.
   b. Increased frost-heave forces on pilings.
   c. Increased total and differential frost heaving during winter.

(3) Development of residual thaw zones (taliks).
   a. Decrease of effective length of piling in permafrost.
   b. Progressive landslide movements.
   c. Progressive surface settlements.

RECENT DEVELOPMENTS

In order to quantify possible impacts of climate warming, there has been a trend in recent years to establish the sensitivity of the physical, biological, social and economic systems to climate and changes in climate. In the area of permafrost science and engineering, there have been some proposals for estimating the sensitivity of predictions on permafrost thermal regime, active layer thickness (Nakayama *et al.*, 1993), and permafrost strength reduction (Vyalov *et al.*, 1993, 1998; Ladanyi, 1995, 1996, 1998) .

Construction of permafrost sensitivity maps of Arctic regions, representing the relative intensity of these impacts, may become a useful basis for predicting the effect of climate warming on the existing constructed facilities in the Arctic, and for establishing guidelines for the design of the new ones. A proposal in this direction was made by Vyalov *et al.* (1993), who put forward a sensitivity zonation in the Arctic, based on the average annual ground temperature of permafrost, Tz. Four geothermal zones were proposed:

Zone I (very unstable) with Tz from 0 to -1°C;

Zone II (mildly unstable) with Tz from -1 to -3°C;

Zone III (stable) with Tz from -3 to -7°C; and

Zone IV (very stable) with Tz below -7°C.

A follow-up of this paper, which is presented at this conference (Vyalov *et al.*, 1998), contains, for each of the four geothermal zones, a computer simulation of the variations in average annual temperature, depth of thaw, long-term strength, and bearing capacity of structural foundations, caused by warming. In both papers, a series of mitigation methods are proposed and discussed.

As for the construction of permafrost strength sensitivity maps due to warming, Ladanyi (1995, 1996, 1998) proposes the use of a simple strength sensitivity index that expresses the relative loss of strength due to warming of a frozen soil at a given frost temperature. For example, according to this index, a frozen ice-rich silt at a temperature of -7°C would, for a temperature increase of 1°C lose about 7.5 % of its original strength, while the same soil at initial temperature of -3°C, would lose up to 15 % of its strength.

Since the Sixth International Conference on Permafrost in 1993, numerous assessments of climate change have been prepared and published. These include but are not limited to: the Canadian assessments (Cohen, 1997a, 1997b; Etkin, 1998); the Chinese assessment on the cryosphere which mentions construction (Cheng, 1997); the Intergovernmental Panel on Climate Change (Watson *et al.*, 1995); and the workshop on the Western Arctic (see Osterkamp *et. al.*, 1997).

In the following, a limited number of recent contributions related to the effect of climate change on engineering facilities are briefly presented.

Sadovsky *et al.* (1997) discuss the long-term stability of permafrost in urban territories under climatic warming conditions, and propose a series of technical solutions for lowering the frozen ground temperature of urban infrastructure.

Tong and Wu (1996) report on a serious deterioration of the asphalt pavement due to climate warming occurring along the Qinghai-Tibet highway, built on permafrost. They propose to subdivide the whole area of the highway into six zones, according to the average annual temperature and thickness of permafrost.

Wang and Allard (1995) present an example of climatic cooling, observed in Northern Quebec, Canada. They find that the ground temperature along the southern shore of Hudson Strait shows a cooling trend over the period of 1987-1993, and that this area experienced a continuous cooling for more than 40 years. The local cooling seems to be related to cold subpolar sea currents in the North Atlantic and Labrador Sea.

A comprehensive report by Maxwell (1997) presents a general overview of possible impacts of climate warming on physical environment including hydrology, permafrost, sea ice and icebergs, sea level and coastal processes, oil and gas, transportation, building and construction, among many other topics.

Another comprehensive study of the impact of climate warming on a particular permafrost region was carried out by Environment Canada, under the direction of Stewart J. Cohen (Cohen, 1997 a and b). The region under study was the Mackenzie Basin in northwestern Canada. The problems of maintenance of infrastructure and the impact of global warming on the existing and future constructed facilities in the North were covered in detail by Cleveland (1997) and Hanna (1997), respectively. The latter stresses the needs for budgeting for additional maintenance of existing facilities in the long term, and for a more conservative, and therefore more costly designs for new facilities. A final recommendation considers that there is a requirement for continuously monitoring the impact of changing ground temperatures on facilities and developments. It proposes the establishment of a centralized database system to compile all data so that it can be made readily available to scientists and professional engineers.

CONCLUSIONS

The impacts of warming and thawing permafrost on human activities and the physical environment will differ depending on the ground ice content. If the permafrost is not ice-rich, warming and thawing of the permafrost will be limited to thermal effects and to the effects of converting the ice to water. Impacts on the infrastructure will be relatively small. Where the permafrost contains massive ground ice or is ice-rich, extensive thaw-settlement (resulting in thermokarst) is expected. In Alaska, the induced thaw-settlement is presently responsible for damage to houses, roads, airports, military installations, pipelines, and other facilities built on permafrost (Osterkamp *et al.*, 1997).

On the other hand, as pointed out by Maxwell (1997), for building and construction, increased air temperature will have a number of positive effects, including: reduced power demand for heating, reduced insulation needs, and increased length of the season for construction activities occurring during the summer. More generally, affected in various ways will be: northern pipeline design (negative), pile foundations in permafrost (mostly negative), tailings disposal facilities (positive or negative), bridges, pipeline river crossings, dikes and erosion protection structures (negative), open pit mine wall stability (negative).

As for the effect of warming climate on the design of particular construction elements, such as foundations, roads and dams, eventual design guidelines should first establish if and how much the present normal safety margins cover the effects of climate warming during the lifetime of the structure, and how and when the climate warming will become a decisive factor in the design (Nixon, 1994).

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GLOBAL CHANGE AND PERMAFROST WORKING GROUP REPORT

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INTRODUCTION

The Global Change and Permafrost Working Group developed at the Sixth International Conference on Permafrost in Beijing, China in July 1993, following a plenary session featuring talks by A.H. Lachenbruch and others concerned with permafrost and climatic change (Nelson *et al.*, 1993). The previous group (chaired by Professor E.A. Koster) produced an annotated bibliography on permafrost and climate change (Koster and Judge, 1994), amongst other accomplishments. The IPA Council approved the new WG for a five-year period with a restated purpose: to identify the effects of global changes in temperature and related phenomena upon the nature of permafrost and its distribution.

This report summarizes the WG's activities and accomplishments during the past 5 years, some observations on global change and permafrost research, and recommendations for the future.

MEETINGS

Members held numerous discussions on an *ad hoc* basis, usually involving only some of the WG's membership and generally during scientific conferences. These discussions have been reported regularly in *Frozen Ground* and are summarized here, as follows:

San Francisco, California, USA (December 1994)

Several members of the WG (Anisimov, Fukuda, Nelson, Osterkamp, Taylor) and J. Brown met following a special session on permafrost during the American Geophysical Union meeting. The wide-ranging discussion included ideas on establishing long-term stations to monitor changes in permafrost, and a questionnaire to survey the permafrost-research community about important parameters to be measured.

Ottawa, Canada (April 1995)

Several WGs (represented by Nelson, Taylor, Åkerman, Lewkowicz, and Brown) met during the 6th International Tundra Experiment (ITEX) workshop to develop a plan and initial protocol for the integration of active layer measurements at ITEX field sites.

Yakutsk, Republic of Sakha (Yakutia), Russia (August, 1995)

Russian-Japanese Workshop on GAME (GEWEX Asian Monsoon Experiment) "Potential Joint Studies on Energy and Water Cycle in Siberia (1995, 1997)". M.K.Gavrilova and V.S.Cherdonova (1997) presented a paper on the effects of the Pacific Ocean on atmospheric circulation in Yakutia, selected as a reference area of classic permafrost in East Siberia.

Hanover, New Hampshire, USA (December 1995)

WG progress reports and informal discussions took place in the course of the IPA-sponsored workshop "Our Current Understanding of Processes and Ability to Detect Change".

Victoria, Canada (August 1996)

Taylor, W. Haeberli and R. Barry participated in a World Meteorological Organization (WMO) workshop on cryospheric measurements. Two permafrost parameters: permafrost active layer and thermal state, were identified for WMO's Global Climate Observing System (GCOS)/ Global Terrestrial Observing System (GTOS) plan for terrestrial climate-related observations (GCOS-32, 1997).

Boulder, Colorado, USA (December 1996)

Taylor and Anisimov participated with other WG leaders in the data workshop for the CAPS database. Taylor, with R. Paetzold and V. Romanovsky, developed minimum standards for metadata to accompany ground temperature measurements. Anisimov introduced a computerized system for analysis and display of spatially referenced geocryological data, and a bibliographic program for searching literature developed at the State Hydrological Institute, St. Petersburg. Both are incorporated into the CAPS CD.

Cambridge, United Kingdom (February 1997)

Nelson, and R. Barry participated in a meeting of the World Climate Research Program (WCRP) to discuss priorities for research on climatic change and the cryosphere. It was an effective forum for exchange of information between permafrost scientists and others working in the cryosphere and resulted in two chapters in the proceedings volume (Savtchenko, 1998). The first, an introductory chapter, discusses the roles of permafrost research in a cryospheric perspective and outlines IPA functions and contributions to global change research (Nelson, 1998). The second chapter identifies current gaps in cryospheric modelling and observational networks and offers suggestions on their closure (Goodison and Nelson, 1998).

Ottawa, Canada (March 1997)

At the 27th Arctic Workshop, Nelson, Taylor, Lewkowicz, Brown and others met to discuss issues of concern to the Global Change, Periglacial, and Data WGs. Discussion topics included a revised active layer protocol and a compendium of standardized field procedures.

SURVEY: ACTIVE FIELD PROGRAMS

In April, 1995 and in anticipation of IPA Council resolutions in Berlin (IPA Council, 1995), Taylor circulated a survey to obtain information about active field programs concerned with measuring climate-related parameters in permafrost and seasonally frozen ground over the next decade. A key purpose was to complement the Mountain Permafrost WG's inventory of similar information in the mountain environment, and the Data and Information WG's inventory of existing data. Nearly 40 research groups responded, representing active sites on all continents, but mostly from the northern hemisphere.

The survey's results demonstrated that permafrost researchers had taken leadership roles in several climate-change issues. The responses represent work associated with various arctic programs (ARCSS, GEWEX, ITEX, LTER, others), as well as independent projects. Although most of the responses reported work at individual sites, several reported transects across regions of diverse permafrost characteristics. Some sites were established recently, while others go back several decades and have accumulated substantial data archives. Ground temperatures and active layer thickness are monitored at many sites. The survey revealed opportunities for data recovery particularly in the Antarctica and Russia. Survey results (Taylor, 1996) are available on IPA's Home Page on the World Wide Web or from the Secretary of the WG in hard copy or via email.

Based on the results of the survey and toward implementing the Berlin resolutions, the WG developed an international network of stations for long-term monitoring of the thermal state of permafrost and the active layer (CALM). Further development of CALM has been greatly facilitated by a five-year grant from the U.S. National Science Foundation to the University of Cincinnati for infrastructure development and support of existing sites in Russia and the USA.

From other discussions, it has become apparent that there is a need for better communication amongst permafrost and active layer researchers. T. Osterkamp (1998), with support of the University of Alaska staff and computer facilities, has opened an "on-line", unmoderated and international discussion list to provide an international forum for discussion of the scientific and technical aspects of permafrost, active layer and frozen ground studies. Scholarly discussion of issues in a gentle way will help to draw the permafrost community closer together.

RESPONSES TO IPA RESOLUTIONS AND LINKAGES TO OTHER INTERNATIONAL GLOBAL CHANGE SCIENTIFIC BODIES

The WG responded to Council resolutions (IPA Council, 1995) on data and global change by developing the CALM protocol and network for measurements of active layer thickness and permafrost thermal regime, and by initiating contacts and joint programs with the following organizations:

Intergovernmental Panel on Climate Change (IPCC)

The WG provided substantial inputs on permafrost to the IPCC chapter on the cryosphere (Fitzharris *et al.* 1996). The chapter provided an integrated summary of the effects of global warming on ice sheets, glaciers, snow cover, sea, lake and river ice, and permafrost, which had an equal status with the other components. Maps depicting potential changes in permafrost distribution under climate change scenarios were included.

International Tundra Experiment (ITEX)

This is a field program to assess effects of climate change on plant species, communities and local environments. The impacts of climate warming on soil temperature and active layer thickness were identified as high research priorities of the program (Molau and Molgaard, 1996, p. 2). The WG selected the ITEX network for initiating the Circumpolar Active Layer Monitoring (CALM) protocol (Nelson *et al.*, 1996). CALM comprises 69 locations, including ITEX sites, at present (Brown, 1997).

World Meteorological Organization (WMO)

THE WORLD CLIMATE RESEARCH PROGRAM (WCRP)

The WRCP is concerned with a spectrum of research on climate and climatic change. The Cambridge meeting (see above) resulted in the identification of permafrost attributes required for producing high-resolution data sets in a standardized, spatially referenced format, e.g., surface elevation, land cover, soil properties and moisture content, subsurface composition, geothermal heat flux, and thermal profiles. The digital version of the IPA's Circum-Arctic Map of Permafrost and Ground-Ice Conditions (Brown *et al.*, 1997) will be useful in selection of areas and sites for such measurements.

GLOBAL CLIMATE OBSERVING SYSTEM (GCOS)/ GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS)

Permafrost-related measurements required for long-term observations have been identified (see Victoria meeting, above) and incorporated in the GCOS/ GTOS plan for terrestrial climate-related observations (GCOS-32, 1997). These coincide with CALM network requirements, and a collaborative program utilizing sites in both hemispheres is under discussion.

REFLECTIONS ON GLOBAL AND REGIONAL MAPPING AND MODELLING

The 1995 IPPC reports (Houghton *et al.*, 1996), as well as the extensive literature of global-change science makes clear that other branches of natural science have taken a broader perspective than that followed by most permafrost researchers. Investigations at local and regional scales are of inestimable value, particularly to achieve detailed understanding of interactions between climate and elements of the natural and human landscape (e.g., Boike *et al.*, 1998; Gavrilova, 1996; Smith and Riseborough, 1996). In the permafrost regions of the Canadian Mackenzie Basin, Dyke *et al.* (1997) modelled the influence of permafrost on land-altering processes such as thermokarst and landslides and the relationship to climate change, while in Alaska, climate warming will lead to long-term problems caused by thermokarst with profound and costly effects on infrastructure (Osterkamp *et al.*, 1997; 1998).

However, hemispheric and global patterns cannot be ignored. Our analyses and predictions over large areas should not rely solely on amalgamation of smaller units to form a regional or global picture ("scaling up"). Insights are gained through multiple scales and by scale-up and scale-down approaches (Root and Schneider, 1995). Careful spatial interpolation and modelling form a crucial part of such strategies.

Most other disciplines are working vigorously on local, regional, and global scales and have also developed methodologies that allow simultaneous analysis of specific problems at multiple scales, facilitated by the development of general circulation models. Geocryologists have made substantial progress in spatial-analytic methods. Granberg's (1973) work on the covariation of snow-cover regularities and permafrost distribution was an early demonstration of geographic information systems-type methods in the solution of permafrost problems. Other regional-scale work includes Thie (1974), Hoelzle *et al.* (1993), Vitt *et al.* (1994), Halsey *et al.* (1995), Leverington and Duguay (1996, 1997), Nelson *et al.* (1997) and Wright *et al.* (1998). Although these and others demonstrate an acceleration of permafrost research with a spatial focus, such work is a small subset of the total output of geocryologists. Very few papers (Anisimov and Nelson, 1996, 1997; Anisimov *et al.*, 1997) have focused on permafrost distribution in a format useful for impact modelling at the global scale.

Permafrost scientists must gain an appreciation for and expertise in spatial analytic and modelling techniques. Global change science has adopted a strongly spatial-analytic viewpoint (e.g., GIS); yet, permafrost-oriented journals reveal that only a small percentage of our research makes use of either the tools of spatial science or global databases. Results from our WG survey reflect that the majority of permafrost researchers investigate areas of limited areal extent. Too few attempts have been made to provide generalizations to the hemispheric or global scales.

The new IPA Circum-Arctic Map of Permafrost and Ground-Ice Conditions (Brown *et al.*, 1997), and particularly the digital version, will provide a basis for comparison of climate change scenarios with current conditions. The map is the first compilation assembled using standard criteria adopted by international agreement. Previous maps lacked such control, with details, and in some cases major geographical patterns, varying substantially from map to map (Nelson 1989; Nelson and Anisimov 1993).

THE ROAD AHEAD

Data Integration, Availability and Spatial Analysis

The primary mechanisms involve development of agreements and protocols for (1) standardized measurement techniques; (2) spatially distributed networks of monitoring sites; (3) data archives; and (4) access to data in electronic form. The CALM and CAPS/GGD projects are likely to result in large increases in geocryological research having a spatially distributed focus at a variety of geographical scales. Geocryological data now have an official repository, as well as a set of standards and priorities. Standard methods of data collection are under development and efforts are underway to rescue and digitize previously unavailable data sets. Within a few years, truly global geocryological data sets of documented accuracy will be available for use both within and outside the permafrost research community.

Working Group Responsibilities

The WG should play a role in broadening the scope of geocryological research and its availability to the larger community. The following should be goals over the next five-year period:

(1) Coordinate development of global-scale data layers in standardized format. This work may be accomplished in close association with all IPA working organizations. A preliminary outline of data needs is Table 1 of Goodison and Nelson (1998). The CALM and CAPS/GGD programs make this goal realizable in the short term.

(2) Promote the increased visibility and availability of the permafrost community's research results to workers in related fields concerned with global change and its consequences. This will be advanced primarily through linkages with international scientific organizations.

(3) Participate in the geocryological component of the Third Assessment Report of the IPCC, by ensuring that pertinent permafrost research is adequately described. This will be undertaken after a survey of the permafrost community.

(4) Refine data collection and organization protocols with important global change components and provide advocacy for long-term observational programs (e.g., CALM, PACE).

These goals require changes to the mission and membership of the existing Global Change and Permafrost Working Group. We look forward to working with the IPA Council in refining these preliminary goals and to helping to effect solutions to the problems they are designed to address.

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CRYOSOL WORKING GROUP

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Membership: D.A. Gilichinsky, Chair (Russia); C.L. Ping, Secretary (USA); J.G. Bockheim (USA); G. Broll (Germany); Wang Haoqin replaced in 1996 by Luo Goubao (China); B. Jakobsen (Denmark); G. Mazhitova (Russia); C. Tarnocai (Canada). *Ex-Officio:* J. Brown, IPA Executive Committee.

Corresponding Members: L. Beyer (Germany); I. Campbell (New Zealand); Qiu Guoqing and Gong Zitong (China); J. Kimble (USA); S. Smith (Canada); B. Van Vliet-Lanoe (France).

INTRODUCTION

During the First International Conference on Cryogenic Soils, held in Pushchino, Russia, in 1991, it was recommended that the International Permafrost Association (IPA) and the International Society of Soil Science (ISSS) establish Cryosol Working Groups (CWGS). Establishment of the IPA Cryosol Working Group (CWG) for five years was subsequently approved at the International Permafrost Association Council meeting on 8 July 1993, in Beijing, China. The stated purpose of the IPA Cryosol Working Group is to develop and maintain close working relations between soil and permafrost scientists throughout the bipolar regions, and to develop projects to correlate and/or consolidate the vast amounts of information, maps, and data on soils that are of interest to IPA. Activities for the past five years included characterization of soil climates and the effect of climate change on these soils, soil mapping, studies of the relationships between permafrost and cryosol distribution, and various field trips and conferences. These are summarized in the following report. It should be pointed out that most of these activities were carried out jointly with the ISSS. The author of this report appreciates the contributions and comments from members of both groups.

RESULTS OF MEETINGS

International Correlation Meeting on Permafrost-Affected Soils, Northwestern North America (18-30 July 1993)

This meeting was held in the Northwest Territories (NWT) and the Yukon Territory (YT) of Canada and in Alaska, (USA). It consisted of a two-day plenary session for technical papers and an 11-day field trip starting at Inuvik, NWT, proceeding along the Dempster Highway to Dawson City, YT, then along the Top of the World Highway to the Tanana Valley in Alaska, finishing at Fairbanks, Alaska. Fifty pedologists, geologists, botanists, climatologists, and agricultural and climate change program managers from Canada, China, Croatia, Finland, Germany, Hungary, Russia and the USA participated in this meeting and the subsequent field trip. Fifteen papers and 16 posters on the morphology, genesis, mapping and classification of permafrost soils were presented. During the 11-day field trip the participants examined 20 soil sites and discussed the soil genesis, especially as related to cryogenic processes, classification and land management with regard to climate change. As a result of this meeting, a Gelisol Order (to classify permafrost-affected soils) was proposed as the 11th order of the US Soil Taxonomy. Jim Bockheim of the University of Wisconsin was elected chairman of the International Committee On Permafrost-Affected Soils (ICOMPAS) which was formed to develop the classification system for this order.

Northeast Russia Field Program (26 July-9 August 1994)

In order to field test the Gelisol proposal and correlate the soil mapping systems used in Russia and other countries, a meeting/field trip was organized by the combined working groups and ICOMPAS for the lower Kolyma region. A joint soil mapping and sampling program of ten representative soils along several transects was conducted. During the site selection and sampling the participants exchanged ideas on the formation and classification of Cryosols. Participants exchanged ideas with Russian soil scientists on map unit design and delineation and on landscape attributes. This field activity provided an excellent opportunity for the working group to compare soil classification systems, to field test the proposed Gelisol Order and to compare soil mapping methods and map unit design concepts.

Symposium on Genesis, Classification and Management of Permafrost-Affected Soils, Seattle, Washington, USA (14 November 1994)

The symposium was held during the 86th annual meeting of the Soil Science Society of America and included eight oral presentations and 15 posters from cryopedologists from five countries. Members of the CWG met during this conference to discuss future plans, including the Second International Conference on Cryogenic Soils planned for 1997 in Syktyvkar, Russia.

Joint Session, Pushchino (24 April 1995)

The IPA CWG and the Soil Cryology Section of the Scientific Council on Earth Cryology, Russian Academy of Sciences met in joint session in Pushchino, Russia. The one-day CWG session included eight papers that dealt with cryogenic soil-ground processes, active layer dynamics, ecology and pedogenesis of Cryosols, and mapping and classification of Cryosols. A number of topics were discussed: (1) Definition of the Cryosolic Order to be included in the World Reference Base for Soil Resources (WRB). Those who attended this meeting agreed that Cryosols are mineral soils having permafrost within two metres of the soil surface. It was also agreed that this definition would be reviewed by cryopedologists during the following year. (2) It was agreed that the CWG would assist the IPA Terminology Working Group in preparing an international glossary of terms for permafrost and ground ice by providing additional terms relating to Cryosolic soils. (3) A new project to develop a circumpolar soil map of the Arctic region was planned. Source maps from the Russian, American and Canadian sectors would be digitized. This circumpolar soil map would be associated with a database that cross-referenced several soil classification systems, including the WRB, Russian, American and Canadian systems.

Tibet Field Trip (23 July-9 August 1995)

The field trip was organized and attended by members of both the IPA and ISSS working groups in cooperation with Chinese scientists from the Chengdu Branch of the Academia Sinica, Chengdu, China. The primary goal of this trip was to investigate the soils in high elevation landscapes in Tibet and to establish better linkages with soil scientists in the People's Republic of China. Nine pedons were sampled, none of which contained permafrost. It became apparent that true permafrost soils could not be examined and sampled as they occurred at much higher elevations and in isolated pockets. It was also evident that the Chinese soil scientists had a different concept of permafrost than was known internationally since they considered soils with seasonal frost for more than six months to be permafrost. The trip provided an excellent opportunity to discuss the concepts used in North America and Europe as related to alpine and subalpine soils and permafrost soils.

Joint IPA CWG/ICOMPAS meeting, Seattle, Washington (24-25 February 1995)

The purpose of this meeting was to review and refine some of the activities concerning nomenclature, classification and mapping of Cryosols and review plans and progress of ongoing activities. Items reviewed included: (1) Soil maps and report of the 1994 field activities around Chersky and the Lower Kolyma River region; (2) Circumpolar soil map of the permafrost regions; (3) Gelisol and the WRB Cryosol proposals; (4) Compilation of the historical soil temperature data; (5).Terminology; (6) Field excursions; and (7) Participation in the 1998 IPA conference and the 16th

World Congress of Soil Science in Montpellier, France, in August 1998. In addition, the membership of the IPA and ISSS CWGS was reviewed.

Meeting at the Soil Cryology Section of the Russian Scientific Council on Earth Cryology, Pushchino Russia (24-25 April 1996)

During this meeting essentially all topics presented at the Seattle meeting were discussed in detail. It was also reported that the ISSS Executive Council gave approval for a symposium entitled "Permafrost and Global Change Associated with Environmental Problems" to be held at the World Congress of Soil Science. The symposium would be co-chaired by David Gilichinsky and Brigitte Van Vliet-Lanoe and would consist of oral presentations and posters. In addition, the following items were discussed at the Pushchino meeting:

(1) Permafrost Soil Classification: The discussion continued on criteria to be used for classifying cold soils. In order to convey the different views regarding classification of permafrost soils in the World Reference Base for Soil Resources (WRB) system, three groups would present their proposals to the WRB meeting as follows: (a) Cryosols with permafrost within 1 m regardless of diagnostic horizons (Bockheim, Tarnocai, Broll, Ping); (b) Cryosols defined as permafrost soils subjected to cryoturbation only (Sokolov); and (c) No Cryosol/Gelisol Order, but rather a Gelic Subgroup in existing orders (Sletten).

(2) Circumpolar Soil Map: Sokolov's group will select and provide base soils maps of Russia for digitizing, and Kimble/Tarnocai will provide digitized maps from US and Canadian sources. The final scale will be 1:10,000,000. Although the coverage is limited to permafrost soils, and the boundary will correlate with the IPA permafrost map, some non-permafrost soils (discontinuous permafrost and shallow soils) will be included. The USDA-NRCS will provide legend translation and correlation and map compilation.

(3) Permafrost Soil Monograph: It was generally agreed that there is need for a monograph covering all aspects of permafrost-affected soils. The book must be refereed and saleable. Tarnocai will take the lead by preparing a provisional table of contents and a list of potential contributors.

(4) Databases and Correlation: There is a lack of databases for those soils under discussion for classification, including Chernozem, Solonetz, Solonchak, and the cold alpine soils that have permafrost within 1 m. The ICOMPAS encouraged Russian scientists to provide a database of permafrost soils to help test the Gelisol proposal.

Several informal technical reports were presented, including: (a) results of freezing experiments (D. Gilichinsky); (b) soil formation during the final stage of loess-ice sedimentation (S. Gubin); (c) permafrost soils' response to fire on the upper Kolyma (G. Mazhitova); and (d) pedological studies in the High Arctic of Taimyr Peninsula (S. Goryachkin).

Two special Cryosol sessions entitled Cryogenesis and Soil Formation Processes took place at the Pushchino conference. The first session, with 10 papers, was chaired by Gilichinsky and Tarnocai. The second, with six papers, was chaired by Targulian and Kimble. Abstracts in English and Russian appeared in the conference abstract volume.

Data Working Group Meeting, Boulder, Colorado (12-13 December 1996)

Tarnocai attended and presented the database system for the Circumpolar Soil Map and agreed to provide Cryosol-related data for the CAPS CD-ROM.

International Conference on the Problems of Earth Cryosphere, Pushchino, Russia (21-25 April 1997)

The combined CWGS met and discussed progress on the Circumpolar Soil Map and agreed on the need for better characterization of the map units. The draft map was well received. David Swanson is providing digitized maps of Russia so that percentages for each component can be assigned to the map units. It was also agreed that the correlation would be carried out by some members of the working groups.

Second International Conference on Cryogenic Soils, Syktyvkar, Russia (5-8 August 1997)

Some of the advances made relating to Cryosols and cryogenic environments in both the northern and southern hemispheres were presented at this conference. The combined CWGS played an important role in planning and organizing this conference, which was attended by 60 soil scientists from 14 countries. There were three days of oral and poster sessions with a one-day, mid-week soil tour near Syktyvkar. The papers presented covered topics relating to the chemistry, physics, biology, and mineralogy of Cryosols, agriculture on Cryosols, remediation of environmental problems (e.g., oil spills), and the general use and management of these soils. The post-conference field excursion to Vorkuta observed long-term research on natural tundra and on areas converted to agriculture. The latest draft of the WRB Cryosolic Order was field tested and discussed. This was the first time that a large group of soil scientists tested the proposal in the field, and a number of suggestions were made to further refine this proposal.

The conference participants, including the CWGS, decided that the Third International Conference on Cryogenic Soils would be held 27-31 August 2001 in Denmark, hosted by the Danish Polar Centre. A post-conference field excursion will take place in northern Scandinavia.

The meeting of the CWGS held in conjunction with the Syktyvkar conference decided the following: (1) Progress on the Circumpolar Soil Map was reviewed and it was agreed that work should be continued by adding the newly-developed soil map of Greenland, that digitization of the remaining areas of Russia should be completed, and that soil information for northern Scandinavia should be included. (2) Compilation of the long-term soil temperature data should be completed for selected stations in Russia for inclusion on the CD-ROM. (3) Plans for the Cryosol-related papers to be presented at the IPA conference in Yellowknife and the ISSS conference in Montpellier were reviewed. (4) The future direction of the IPA CWG was discussed and some plans were formulated for the following five years. Included in these plans is the preparation of a monograph on Cryosolic soils. This monograph will include papers from the members of both working groups and invited contributors. Topics in this monograph include cryogenic processes as a driving force for the development of Cryosols, soil properties resulting from cryogenic processes, biological activity in these soils, classification and distribution of Cryosols, and the effect of global change on these soils.

RELATED AND FUTURE ACTIVITIES

Since the three groups set up at the April 1996 working group meeting in Pushchino were unable to agree on the WRB Cryosol classification, the WRB Working Group of ISSS outlined a compromise proposal for the classification of these soils. J. Deckers, the chairman of the WRB Working Group of ISSS, asked Tarnocai to coordinate and submit a detailed WRB Cryosol proposal by January 1997. In cooperation with members of the CWGS and other cryopedologists, this proposal was completed and revised during 1997 and presented at the WRB meeting in Vienna on 22 November 1997. A modified version of this proposal will be included in the WRB publication that will be distributed in August 1998 at the ISSS Congress in Montpellier, France.

Members of both the IPA and ISSS CWGS participated in the International Workshop on Global Change and Carbon Sequestration in Tundra and Boreal Ecosystems, 30 March-3 April 1998, in Columbus, Ohio. The members and those interested in cryopedology met informally and discussed the future of the IPA and ISSS working groups including rotation of chairs and secretaries. Results of these and subsequent discussions will be reported to the IPA Council at Yellowknife and the ISSS Council for approval. Progress on the status of the Cryosol monograph and the Circumpolar Soil Map project was reported at this meeting. The effect of climate change on Cryosols in both the northern and southern hemispheres was discussed and a conference publication will present these results.

The CWG members foresee that their activities will continue into the next century. Projects such as the Cryosol monograph, completion of the Circumpolar Soil Map, preparation of soil carbon maps, and soil temperature studies at CALM sites will be completed or continue during the next five years. The Circumpolar Soil Map and the Soil Carbon maps should be included in a future version of CAPS. Other activities include the organization of the 3rd International Conference on Cryogenic Soils and the field excursion in northern Scandinavia. In addition, a proposal is being developed to generate a soil map of Antarctica and to install automated sites there to monitor soil moisture and temperature. Work planned also includes: installation of soil moisture and temperature recording equipment in Tibet in May 1998 and a joint field excursion and sampling trip there in July 1999; and a joint field project in early May 1999 at Barrow, Alaska to look at carbon storage in permafrost soils and how ground penetrating radar can be used in conjunction with coring of soil profiles. The working group also would like to cooperate more in projects carried out by other IPA working groups. It is visualized that the CWG activities will expand by including members from other countries, by interacting with other groups of permafrost scientists, and by initiating new projects relevant to present-day problems in both the northern and southern hemispheres.

Cryosols occupy the last widespread land resource of the Earth. Predicted increases in temperatures in the northern latitudes, resulting impacts on permafrost and the soil carbon balance, and population pressures of the 21st century, will place increased importance on these cold-dominated soils. For these reasons, the research communities concerned with the science and utilization of Cryosols should work closely together. At the same time, increased attention is required for the investigation of Southern Hemisphere Cryosols. The IPA and the ISSS offer the basis to organize complementary approaches in response to these opportunities and challenges.

SELECTED WORKING GROUP AND RELATED PUBLICATIONS

Anonymous (Conference Organizers) (1996). *Proceedings of the International Conference on Fundamental Research of Earth Cryosphere in Arctic and Subarctic, Pushchino, Moscow region.* (16 Cryosol-related papers, pp. 160-185).

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Kimble, J.M. and Ahrens, R.J. (1994). *Proceedings of the Meeting on the Classification, Correlation, and Management of Permafrost-Affected Soils, July 1994.* USDA, Soil Conservation Service, National Soil Survey Center, Lincoln, NE. 232 p. (includes 18 papers)

Melnikov, E.S. (ed.) (1997). *Advances in Basic Research in the Earth Cryosphere in Arctic and Subarctic, Proceedings of International Conference, Pushchino, April 22-26, 1996.* Nauka, Novosibirsk, Russia. Russian Academy of Sciences, 350 p. (in Russian; includes 45 papers).

Moore, J. P., Swanson, D.K., Fox, C.A. and Ping, C.L. (1993). *International Correlation Meeting on Permafrost-Affected Soils.* Alaska/Yukon Society of Professional Soil Scientists. Anchorage, Alaska. 153 p.

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TERMINOLOGY WORKING GROUP REPORT

Glossary Project

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INTRODUCTION

During the 5th International Conference on Permafrost, held in Trondheim (Norway) in August 1988, the Council of the International Permafrost Association (IPA) authorized the establishment of a Terminology Working Group with the mandate "to develop a set of internationally accepted permafrost terms for use in engineering and science, with equivalents in various languages, and to disseminate and encourage the use of such terminology". The Terminology Working Group was established in the fall of 1988, with members from Argentina, Canada, China, Finland, France, Germany, the USA, and the (former) USSR. Members from Italy, Norway and Sweden were added later. Over the years, a number of corresponding members also contributed to the project (see list above).

The Working Group agreed to use as the basis for its work the "Glossary of Permafrost and Related Ground-Ice Terms" (Permafrost Subcommittee, 1988), which had updated and expanded upon the "Permafrost Terminology" of Brown and Kupsch (1974). The initial effort was directed towards the preparation of a multi-language listing incorporating the primary and secondary terms from the 1988 Glossary, and a number of synonyms. The languages to be covered by the glossary were to be English, French, German, Spanish, and Russian. By the end of 1994, Italian, Norwegian, and Swedish were included. The effort was coordinated by the Chair of the Working Group, at the Arctic Institute of North America.

In December 1994, a pre-publication version of the IPA Glossary was printed for limited distribution, to solicit comments and corrections (van Everdingen, 1994). Corrections have been made and some additional terms have been incorporated since that time. In addition, Chinese, Icelandic, Polish, and Romanian terms were also included.

A Chinese/English/Russian "Geocryological Glossary", edited by Qiu Guoqing, Liu Jinren and Liu Hongxu, was published in 1994 (Qiu *et al.*, 1994).

In 1995, a five-language version (in English, French, German, Polish, and Russian) of the old "Permafrost Terminology" (Brown and Kupsch, 1974) was published in *Biuletyn Peryglacjalny* (Dylikowa, 1995). It incorporated the French translation published in 1979 (Brown and Kupsch, 1979); a German translation prepared in 1982 by J. Karte; a Russian translation prepared in 1981 by E.D. Shchapova and edited by V.N. Konishchev and A.I. Popov; and a Polish translation by A. Dylikowa and J. Gozdzik.

CHINESE

Listings of Chinese equivalents for the terms in the IPA Multilanguage Glossary were provided by Cheng Guodong, Qiu Guoqing, Zhao Xiufeng and Zhou Youwu. The search for appropriate software delayed the inclusion of Chinese terms in the Glossary database until late 1996. Word-processing for the Chinese entries by Zhao Xiufeng is gratefully acknowledged. Translations for a few additional terms were added in 1998.

PINYIN VERSION OF CHINESE

Pinyin conversions of the Chinese terms have been added to the Glossary for the convenience of non-Chinese users.

FRENCH

At the time of publication of the 1988 Glossary (Permafrost Subcommittee, 1988), a French translation was also published (Sous-comité de Pergélisol, 1988). From this, most of the French equivalents of the primary and secondary terms were incorporated in the database without change. Changes were made for 46 of the terms, following suggestions from the French Commission for the Study of Periglacial Phenomena (Commission Française pour l'étude des Phénomènes Périglaciaires), which were received from J.-P. Lautridou in January 1991. Examples of the changes include: "couche active" instead of "mollisol"; "géli-adhérence" instead of "congélation adhérente"; and "frange gelante" instead of "frange gelée". Corrections and several additions, provided by B. van Vliet-Lanoe, were incorporated in 1993, 1996, and 1998.

GERMAN

A German translation of "Permafrost Terminology" (Brown and Kupsch, 1974) had been prepared in 1982 by J. Karte; it was included in the five-language version published in Biuletyn Peryglacjalny (Dylikowa, 1995). The German equivalent terms from that translation were incorporated in the database, with a number of corrections and additions provided by J. Karte and L. King, in 1991. Translations for additional terms were added in 1994, 1996, and 1998.

ICELANDIC

Preparation of a listing of Icelandic terms for the glossary was undertaken by H. Pétursson in the spring of 1995. The list of Icelandic terms was received in December 1996, and the terms were incorporated in the database. Corrections were made, and additional terms incorporated in 1997 and 1998.

ITALIAN

Italian translations of the terms from the 1988 Glossary were prepared by C. Ottone and F. Dramis in 1992, and incorporated in the database after they were formally accepted in November 1992 by the Italian adhering body for IPA. Translations for additional terms were included in early 1994, in 1996, and in 1998.

NORWEGIAN

Preparation of a listing of Norwegian terms for the glossary was undertaken by O. Gregersen and O. Salvigsen in the fall of 1992. The list of Norwegian terms was received in April 1993, and the terms were incorporated in the database before the 6th International Conference on Permafrost in Beijing, July 1993. Translations for additional terms were included in 1994, in 1996, and in 1998.

POLISH

A Polish translation of Brown and Kupsch (1974), prepared by A. Dylikowa and J Gozdzik, was included in the five-language version published in *Biuletyn Peryglacjalny* (Dylikowa, 1995). Preparation of a listing of Polish terms for the IPA Glossary was started by K. Pekala in the spring of 1995, with the cooperation of J. Repelewska-Pekalowa, S. Kozarsky, and L. Marks. The list of Polish terms was received in July 1995, and the terms were incorporated in the database shortly thereafter. Translations for additional terms were incorporated in 1996 and 1998.

ROMANIAN

Preparation of a listing of Romanian terms for the glossary was undertaken by P. Urdea in 1996, and a list of Romanian terms was received later that year. Translations for a few additional terms were added in 1998.

RUSSIAN

A copy of the Russian translation of the whole 1988 Glossary, prepared by N.N. Romanovskii, G. Rozenbaum, and V.N. Konishchev (Moscow, Russia), was received in February 1991. The Russian equivalents of the primary and secondary terms have been incorporated in the multi-language database. Corrections and translations for a number of additional terms were provided by the same authors in early 1994. Revisions were made in the fall of 1995 during a visit by N.N. Romanovskii to The Arctic Institute of North America. Additional Russian terms, provided by Y. Shur, were incorporated in 1996 and 1998; final corrections were provided by M.O. Leibman and V.N. Konishchev in 1998.

TRANSLITERATED RUSSIAN

Transliterations of Russian equivalent terms, from the Cyrillic alphabet to the Latin alphabet, using the Library of Congress system, have been added to the multi-language database for the convenience of non-Russian users.

SPANISH

The Spanish translation of the terms from the 1988 Glossary was prepared by A.E. Corte, E. Buk, and D. Trombotto (Argentina). Their listing of the Spanish equivalents of the primary terms was received in February 1990; secondary terms were added in May 1990, and some additions and corrections were made in 1993, in 1995, in 1996, in 1997 and in 1998.

It should be noted that significant differences exist between Spanish terms used in South America and those used in Spain. Time constraints have prevented the inclusion of terms from Spain in the current Version 2 of the Glossary.

SWEDISH

Preparation of a listing of Swedish terms for the glossary was started by H.J. Åkerman in the fall of 1992. The list of Swedish terms was completed in April 1993 (Åkerman and van Everdingen, 1993), and the terms were incorporated in the database before the 6th International Conference on Permafrost in Beijing, July 1993. Translations for additional terms were included in late 1993, in 1996, and in 1998.

SYNONYMS

A number of synonyms (including terms designated as "not recommended" in the 1988 Glossary) are included in the current multi-language database, because many of those terms are found in the early permafrost literature.

DEFINITIONS

Definitions for most of the primary terms in the multi-language glossary were adopted, without change, from the 1988 Glossary (Permafrost Subcommittee, 1988). Permission for this was obtained from the copyright holder (National Research Council of Canada). Definitions for several terms describing permafrost-affected soils were taken from a listing prepared by Tarnocai (1992). Minor changes for some of the definitions, as well as definitions for additional terms, have been prepared by O.J. Ferrians, S.A. Harris, J.A. Heginbottom, B. Ladanyi, N.N. Romanovskii , Y. Shur, and R.O. van Everdingen. In the Definitions section of the printed version of the Glossary, terms defined elsewhere in the text (except "ice" and "permafrost") are printed in *italics*. Figure numbers refer to illustrations adopted from the 1988 Glossary (with permission from the National Research Council). New Figures 1, 9e, and 17i have been added, and Figures 2 and 3 have been modified.

DATABASE

To simplify editing and updating, the multi-language listing has been prepared as a database (using WordPerfect version 5.1 for IBM and compatible computers). The database consists of a master list of records, in which each record comprises the following fields: 1 - a sequential number; 2 - the English term; 3 - the French equivalent; 4 - the German equivalent; 5 - the Icelandic equivalent; 6 - the Italian equivalent; 7 - the Norwegian equivalent; 8 - the Polish equivalent; 9 - the Romanian equivalent; 10 - the Spanish equivalent; 11 - the Swedish equivalent; 12 - the Russian equivalent; 13 - transliteration of the Russian equivalent; 14 - an empty field for future use; 15 - an empty field for "house-keeping" use (e.g., "flagging" of synonyms); and 16 - the end-of-record marker. The database approach makes the future addition of other languages and new terms relatively easy.

Chinese terms, with their Pinyin conversions and their English equivalents, are stored in a separate database because of the character-handling limitations of most word-processing software. A Chinese word-processing utility is required to display Chinese characters properly.

In order to avoid possible confusion of entries such as "ice, wedge" and "ice wedge", all multi-word terms have been entered in the database using the natural word sequence (i.e., "wedge ice" and "ice wedge" for the above example). The elimination of commas also improved the quality of machine sorting.

The main database can be sorted alphabetically for any of the eleven languages; the Chinese database can be sorted alphabetically for Pinyin and English only. Small files of layout specifications can then be used to print separate versions of the glossary for each of the languages, with the terms in the selected language as the prime entries. In individual printouts, the sequence of the secondary entries can be varied as desired, but the Russian terms and their transliterations should preferable be kept together, as should the Chinese terms and their Pinyin equivalents.

Currently, the multi-language database occupies about 348,600 bytes, plus about 62,500 bytes for the Chinese and Pinyin. The revised definitions section occupies about 307,000 bytes, and the list of references about 54,400 bytes.

CURRENT VERSION

The current "Version 2" of the Glossary should be regarded as the latest stage of a work in progress, because terminology in permafrost science and engineering is continuing to evolve, and the Glossary should evolve with it. In the future, the addition of terms in other languages, e.g., Finnish, might also be considered.

Selected parts of Version 2 (Introduction, English plus other languages, Definitions, and References) are being added to the IPA CAPS CD-ROM being prepared under the auspices of the Data and Information Working Group. A limited number of printed copies of Version 2, to be produced by the University Printing Services of The University of Calgary, should be available for purchase at a modest cost from the Chair of the Terminology Working Group.

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