Ist European Permafrost Conference

Rome 26-28th March 2001

Abstracts

Sponsored by

The International Geographical Union Periglacial Commission

The International Permafrost Association

The International Glaciological Society

The European Commission

The PACE Project

Conference Hall, Consiglio Nazionale delle Ricerche, Piazzale Aldo Moro 7, Roma, Italy

Welcome to the Conference

The Organising Committee of the First European Permafrost Conference welcomes all delegates to Rome. We hope you enjoy the Conference and its setting in this historic city. The conference themes reflect the wide diversity of permafrost research in Europe and beyond, including permafrost research in high latitudes (both North and South), and at high altitude. Mountain permafrost has received increasing attention in the past decade, and in Europe, the International research initiative "Permafrost and Climate in Europe" (PACE), funded by the European Union, has provided the opportunity for interdisciplinary research in the high mountains of Europe from Svalbard to the Spanish Sierra Nevada. The Conference marks the completion of this three-year project, and sessions in the programme reflect the focus of PACE. In addition, the Conference provides an opportunity for two IPA Task Forces, on Rock Glacier Dynamics and Permafrost Creep, and, Mapping and Distribution Modelling of Mountain Permafrost, to organise special sessions. Finally, sessions are convened by two IPA Working Groups, the Coastal and Offshore Permafrost Group, and, the Southern Hemisphere Permafrost and Periglacial Environments Group.

This volume of abstracts is organised into the following Conference Sessions:

Session 1 - Permafrost Monitoring
Session 2 - Permafrost, Active Layer and Climate
Session 3 - IPA Task Force - Rock Glaciers
Session 4 - IPA Task Force - Permafrost Distribution Modelling
Session 5 - Hazards, Geotechnics, and Geophysics in Permafrost Regions
Session 6 - Antarctica
Session 7 - Coastal and Marine Environments

Abstracts for all papers presented at the conference, whether orally or by poster, are included.

In addition to the Abstracts Volume, the Editorial Board of *Permafrost and Periglacial Processes* has kindly produced a Special Volume of PPP to mark the 1st European Permafrost Conference. This volume includes papers summarising the work undertaken by the European PACE Project. The Special Volume of PPP forms a major part of the 1st European Permafrost Conference literature. The full bibliographic reference is given below. The Organising Committee wishes to thank Professor Hugh French, Editor of PPP, for his co-operation in producing the Special Volume for the conference.

The Organising Committee would like to thank all those who have contributed to this conference, particularly Professor Francesco Dramis, the local organiser in Rome, and Dr Brice Rea who undertook much of the editorial work for the abstracts volume.

The financial contribution of the European Commission Environment and Climate Research Programme to the conference is gratefully acknowledged (EPC1/EESD-ENV-99-2, Proposal No. EVK2-2000-0809) as are the facilities kindly provided by the Consiglio Nazionale delle Ricerche, Italy.

Charles Harris
Chair, Organising Committee

1st European Permafrost Conference

Organising Committee

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Abstracts Volume: Compiled by Dr Brice Rea (Cardiff, UK)

PPP Special Volume: Permafrost and Periglacial Processes, Volume 12 No.1

1st European Permafrost Conference - Programme

Monday 26th March

08.00-10.00 - Conference registration and coffee

10.00-10.30 - Welcome and Opening Ceremony

10.30-11.15 - Keynote lecture: Prof. W. Haeberli

11.15-13.00 - Oral Session 1 - Permafrost Monitoring
Chair: D. Vonder Mühll

11.15-11.20	Introduction - Dani Vonder Mühll
11.20-11.35	Burgess M., Smith, S., Romanovsky, V. and Brown, J. *The Global Terrestrial Network for Permafrost (GTN-P): borehole thermal monitoring.*
11.35-11.50	Vonder Mühll, D. *Permafrost monitoring in the high mountains of Europe: the PERMOS and the PACE Project in its Global Context.*
11.50-12.05	Isaksen, K., Holmlund, P. and Sollid, J.L. *Three deep alpine-permafrost boreholes in Svalbard and Scandinavia - climatic trends.*
12.05-12.20	Brown, J. *Long-term observations of soil thaw in the Arctic, Subarctic, and Alpine: Initial results based on the CALM network.*
12.20-12.30	Tingjun, Z. and Barry, R. *Global Geocryological Database (GGD): a continuing task for the international permafrost community.*

12.30-13.00 - Short (2 minute) Poster Presentations

Boike, J., Hinzman, L., Roth, K. and Ippisch, O. *Active layer dynamics – towards a unifying concept.*

Burgess, M.M. and Smith, S.L. *Development of a Canadian permafrost monitoring network as part of a national GCOS plan for the cryosphere.*

Chudinova, S.M., Bykhovets, S.S., Fedorov-Davydov, D.G., Sorokovikov, V.A., Gubanov, V.S., Smirnov, V.E., Barry, R.G. and Gilichisky, D.A. *Response of temperature regime of seasonally frozen soils of North-East of Europe to climate changes.*

Gorshkov, S.P. and Lomonosov, M.V. *First signs of response on the climate warming in periphery of permafrost zone, the Central Siberia.*

Hinkel, K.M. and Nelson, F.E. *Controls on the Spatial and Temporal Patterns of Thaw at CALM Sites on the North Slope of Alaska.*

Krobath, M. and Lieb, G.K. *Ground temperature monitoring in a permafrost environment of the Central Alps (Austria).*

Oberman, N. *Changes in the Cryolithozone Temperature of the European Northeast of Russia in the Context of 1970-95 Climatic Warming.*

Oht, M. *The effect of changing snow cover on temperatures in the active layer in the Longyearbyen area, Svalbard.*

Osterkamp, T., Romanovsky, V. E., Zhang, E.T. and Gruol V. *Warming of Permafrost in Alaska*

Shpolyanskaya, N.A. *Prediction of global climate and cryolithozone changes.*

Smith, S.L., Burgess, M.M., Nixon, F.M. and Taylor, A.E. *Canadian High Arctic and Western Arctic Permafrost Observatories.*

Velikin, S.A., Snågirev, A.M., Frolov, A.D., Istratov, V. and Skvortsov, A.G. *Ecologically geophysical monitoring in cryolithozone.*

Zamolodchikov, D.G., Karelin, D.V., Ivaschenko, A.I., Chestnykh, O.V. and Lopes de Gerenu, V.O. *Recent trends of climate, permafrost conditions and carbon balance in the East European tundra.*

13.00-14.30 - Lunch and Posters

14.00-15.30 - Oral Session 2 - Permafrost, Active Layer and Climate
Chair: C. Harris & L. King

14.00-14.15 Kuhry, P., Oksanen, P., Oberman, N. and Romanovsky. V.
Holocene, subrecent and future permafrost dynamics in the East-European Russian Arctic.

14.15-14.30 Ostroumov, V.Y.
Distribution of ions in frozen ground and possibility of paleoreconstruction on the basis of chemical data.

14.30-14.45 Meyer, H., Schirrmeister, L., Siegert, C., Hubberten, H.-W. and Dereviagin, A.
"Ice Complex" deposits of the Bykovsky Peninsula, Northern Siberia paleoenvironmental and paleoclimatic record for the last 60 ka.

14.45-15.00 Gorshkov, S.P., Dobrynin, D.V., Tishkova, M.A. and Lomonosov. M.V.
The resistance of permafrost landscapes to climate warming in the periphery of the permafrost zone of Central Siberia.

15.00-15.15 Christiansen, H.H.
Five years of active layer monitoring in NE Greenland: Meteorological control on inter-annual variability.

15.15-15.30 Melnikov, E.S., Vasiljev, A.A., Malkova, G.V. and Moskalenko, N.G.
Monitoring of active layer in western part of Russian Arctic.

15.30-16.30 - Short (2 minute) Poster Presentations

Axenova, J.O, Kalouzchskikh, A.A. and Mikheev, A.A. *Research on seasonal freezing at the centre of the Russian plain.*

Broll, G. and Tarnocai, C. *Turf hummocks on Ellesmere Island, Canada*

Carretero, M. E., Roig, F. and Pott, R. *Vegetation in high-Andean wetlands affected by cryogenic processes.*

Chuvilin, Y.V.S. Makhonina N.A. *Conditions of gas hydrate existence in frozen soils.*

Delaloye, R., Reynard, E. and Lambeil, C. *Marginal occurrence of permafrost in a low altitude talus slope (Creux du Van, Jura Range, Switzerland): snow and vegetation significance.*

Dikau, R. *Past and present permafrost distribution as a key to understand sediment budgets in high mountain geosystems - concepts and preliminary results of the Turtmanntal-project (Valais, Switzerland)*

Gomez, A., Luengo, E., Palacios, D., Tanarro, L.M., Fernandez, A., Schulte, L., Marcos, J. and Ramos, M. *Present mass wasting activity in relation to buried-ice degradation (Corral del Veleta, Sierra Nevada, Spain).*

Gude, M., Dietrich, S., Mäusbacher, R. and Molenda, R. *Exceptionally cold microclimatic conditions in blocky scree slopes in Central Europe.*

Hinzman, L.D., Kenji, Y., Verbyla, D., Kane, D.L., Goering, D. and Romanovsky, V. *Thermokarst Formation and Degradation as Influenced by Climatic Dynamics.*

Jeppesen, J. *Ice wedges as a palaeoclimatic indicators in Adventdalen, Svalbard.*

Kotarba, A. *Dynamics of high mountains talus slopes in the Tatra mountains of Poland lichenometric study.*

Mudrov, Y.V. *Cryolithozone Dynamics in the Western Section of Subarctic During Recent Holocene.*

Muller-Lupp, W., Bolter, M., Kardoma, Y., Ohata, T., Takata, K. and Yakubi, H. *Evidence of climatic and physical properties in permafrost affected soils.*

Osadchaya, G. *Active layer of the cryolithozone in the North-East of Europe: zone and regional aspects of forcing.* Gabriele, B. and Tarnocai, C. *Turf hummocks on Ellesmere Island.*

Pappalardo, M. and Ribolini, A. *Stratified screes in the Maritime Alps (Italy): an attempt to determine the role of permafrost in their formation.*

Rivkin, F.M. and Levantovskaya, N.P. *Talik Zones Dynamics In Holocene and Forming of Near Surface Gas Hydrate.*

Rivkin, F.M., Popova, A. and Eospa, A. *The Permafrost Conditions along Pechora Sea Coast (Varandey Peninsula, European North of Russia).*

Rivkina, E., Gilichinsky, D. and Laurinavichus, K. *Radiative Geogases within Permafrost.*

Rovdan, E., Brovka, G. and Dedyulya, I. *The Migration of Ions in Frozen Natural Dispersed Systems.*

Salnikov, P.I. *Peculiarities of ground heaving in Southern Zabaikalie.*

Sawada, Y. and Ono, Y. *Mechanism of sporadic permafrost preservation in the blocky slope at Mt. Nishi-Nupukaushinupuri, central Hokkaido, Japan*

Schulte, L., García-Blanco, J de M., Ortiz, A.G. and Palacios, D., Estremera, L. M., García, T. and Ramos, M. *Late Glacial Deglaciation and Subsequent Expansion of Periglacial Processes in the Mulhacen Cirque (Sierra Nevada, Southern Spain).*

Stalina, E.E. *Peculiarities of cryogenic eluvium in the mountains of Altai (South Siberia).*

Tishkova, M.A. and Lomonosov, M.V. *Peculiarities of permafrost landscapes in the middle taiga subzone. Podkamennaya Tunguska lower reaches area case study.*

Vandenberge, J. *The evolution of permafrost extent in north and central Europe during the last ice age.*

Vasil'chuk, A.C. *Re-Deposited Pollen In Ground Ices As Age And Origin Indicator.*

Vasil'chuk, Y.K., Jungner, H., Sulerzhitsky, L.D., Vasil'chuk A.C., Budantseva, N.A. and Chizhova, J.N. *Palsa In North-East Europe: Age And Potential Future.*

Viera, G. *New observations on the Pleistocene periglaciation of the Serra da Estrela.*

16.30-17.00 - Break and Posters

17.00-18.30 - Oral Session 2 - Continued

17.00-17.15	Pfeiffer, E.M., Samarkin, V. and Wagner, D. *Methane flux studies in Siberia – Conclusion about the impact of climate change on permafrost soils and open questions.*
17.15-17.30	Bolter, M., Muller-Lupp, W., Kodama Y., OhataT., Takata K. and Yabuki H. *Potential long-term CO2 flux in an Arctic Tundra Environment.*
17.30-17.45	Gilichinski, D. *Future study of the Cryobiosphere.*
17.45.18.0	Vasil'chuk, Y., Vasil'chuk, A. and Budantseva, N. *Non-climatic cyclic formation of thick syngenetic ice-wedges during the Late Pleistocene: isotope-geochemical aspect.*
18.00-18.15	Harris, C. and Merton, J.B. *Centrifuge modelling of ice wedge casting processes.*
18.15-18.30	Eissmann, L. Permafrost in the Pleistocene of Central Europe.

19.00-21.00 - Ice Breaker Reception

Tuesday 27th March

09.00 -10.30 - Oral Session 3 - IPA Task Force - Rock Glaciers
Chair: W. Haeberli

09.00 - 09.10 Haeberli, W. and Hallet, B.
IPA/ICSI Task Force on rock glacier dynamics.

09.10 - 09.30 Humlum, O. and Vonder Mühll, D.
Rock glacier thermal conditions.

09.30 - 09.50 Matsuoka, N.
Rock glacier composition: rock component.
Elconin, R.
Rock Glacier Ice Review: Distribution, Physical and Chemical Characteristics, Age, Diagnostics and Origin

09.50 - 10.50 - Short (2 minute) Poster Presentations

Arenson, L. and Springman, S. *Pressuremeter tests in the Murtèl-Corvatsch rock glacier, Upper Engadin, Switzerland.*

Arenson, L., Hoelzle, M. and Springman, S. *Borehole deformation measurements in Alpine rock glaciers.*

Berthling, I., Isaksen, K., Eiken, T., Etzelmuller, B., Odegaard, R. and Sollid, J.L. *Flow behaviour, internal composition and development of rock glaciers on Svalbard.*

Bucki, A. *Geophysical Investigations at Fireweed Rock Glacier, Wrangell Mts.*

Cannone, N. and Burga, C.A. *Vegetation as ecological indicator of rock glacier dynamics.*

Dramis, F., Giraudi, C. and Guglielmin, M. *Rock glacier distribution and palaeoclimate in Italy.*

Eiken, T., Kääb, A., Isaksen, K. & Sollid, J.L. *Rock Glaciers on Svalbard - some typical examples*

Elverfeld, K.V., Witsch, U.V. and Kääb, A. *Rock glacier kinematics in the Turtmanntal (Valais, Switzerland) using digital photogrammetry.*

Frauenfelder, R., Haeberli, W., Hoelzle, M. and Maisch, M. *Paleopermafrost reconstructions for the Younger Dryas in the Upper Engadin, Swiss Alps, using relict rock glaciers.*

Fukui, K., Iwata, S., Ikeda, A. and Matsuoka, N. *Rock glaciers and a protalus rampart relation to permafrost in the northern Japanese Alps.*

Giraudi, C. *The Apennine (Italy) Late-Pleistocene and Holocene rock glaciers.*

Grebenets, V.I., Titkov, S.N. and Malorossiyanov, V.A. *Technogenic rock glaciers: genesis, structure, mechanism of movement, forecast of development.*

Guglielmin, M., Camusso, M., Polesello, S. and Valsecchi, S. *The Foscagno rock glacier ice core: an example of old glacier ice relict preserved in permafrost environment.*

Haeberli, W., Castelli, S., Egli, M., Frauenfelder, R., Kääb, A. and Maisch, M. *Methods for absolute and relative age dating of rock-glacier surfaces in Alpine permafrost.*

Humlum, O. *Rock glacier active layer temperatures.*

Ikeda, A., Matsuoka, N. and Kaab, A. *Characteristics of pebbly rock glaciers in Swiss Alps.*

Kääb, A. and Frauenfelder, R. *Temporal variations of mountain permafrost creep.*

Kaufmann V. and Ladstaedter R. *Spatio-temporal analysis of the dynamic behaviour of the Hochebenkar rock glaciers (Oetztal Alps, Austria) by means of digital photogrammetric methods*

Kenyi, L.W. and Kaufmann, V. *Detection and quantification of rock glacier deformation using ERS D-InSAR Data.*

Korsgaard, S. *Observations on a Debris-covered Glacier in central Spitsbergen.*

Paar, G., Bauer, A. and Kaufmann, V. *Rock Glacier Monitoring using Terrestrial Laser Scanning.*

Palacios, D., Gómez, A., Ramos, M., Tanarro, L.M., Crespo, F., Salvador, F., Luengo, E. and García, A. *Present formation of ice-creep features in a deglaciated area (Corral del Veleta, Sierra Nevada, Spain).*

Reynard, E.C.L. *DC resistivity prospecting in rock glaciers and talus slopes in the discontinuous permafrost belt of the Western Swiss Alps.*

Ribolini, A. *Surface ground temperatures of rock glaciers in the Argentera Massif (Maritime Alps, Italy): one year of monitoring*

Roer, I.H., Gärtner, B. and Dikau, H.R. *Bioindication of rock glacier generations in the Turtmanntal, (Valais, Switzerland).*

Schneider, B. *Fluctuations of air temperature as a reason for short-term velocity changes at the rock glacier Äußeres Hochebenkar (Ötztal Alps, Tyrol)?*

Urdea, P. *Rock glaciers and dendrochronology in the Romanian Carpathians.*
Weiss, R., Kienast, G. and Kaufmann, V. *Presentation and analysis of geodetic observations carried out on three active rock glaciers in the Austrian Alps.*

10.50 - 11.50 - Break and Posters

11.50 - 13.00 - Oral Session 3 - Continued

11.50 - 12.10	Kääb, A. and Kaufmann, V. *IPA/ICSI Task Force on Rock Glacier Dynamics - Geometry and Kinematics.*
12.10 - 12.30	Ladanyi, B. *Rheology of ice and ice/rock mixtures.*
12.30 - 13.00	Haeberli, W. and Hallet, B. *Summary and Review*

13.00 -14.00 - Lunch and Posters

14.00-15.30 - Oral Session 4 - IPA Task Force - Permafrost Distribution Modelling Chair: B. Etzelmuller & M. Hoelzle

14.00-14.15	Hoelzle, M., Etzelmüller, B., Mittaz, C. and Haeberli. W. *Principles of permafrost and slope activity modelling.*
14.15-14.30	Gruber, S. and Hoelzle, M. *Statistical modelling of permafrost distribution.*
14.30-14.45	Malevsky-Malevich, S.P., Molkentin, E.K, Nadyozhina, E.D. and Shklyarevich, O.B. *Numerical simulation of current and projected permafrost parameters distribution in Russia.*
14.45-15.0	Ødegård, R.S. and Sollid, J.L. *Extraction of periglacial features from high-resolution digital images.*
15.00-15.15	Mittaz, C., Hoelzle, M. and Haeberli, W. *PERMEBAL: A mountain permafrost distribution model based on energy balance calculations.*
15.15-15.30	Zhang, T. and Barry, R.G. *Numerical simulations on the influence of snow cover on the occurrence of permafrost.*

15.30-16.00 - Short Poster Presentations

Heggem, E.S.F., Etzmuller, B. and Berthling, I. *SRAD - a spatially-distributed radiation balance model applied in geocryology.*
Holmlund, P. and Jonasson, C. *Permafrost in Northern Sweden.*
Kedzia, S. and Moscicki, J. *The occurrence of permafrost in the Polish part of the Tatra mountains*
Kneisel, C. and Lappat, M. *Modelling permafrost distribution in northern Sweden first results with PERMASIM - a radiation based model.*
Krummenacher, B. *Use of the Solar Compass to Estimate the Presence of Permafrost.*
Lambiel, C. and Reynard, E. *Regional modelling of present, past and future potential distribution of discontinuous permafrost based on a rock glacier inventory in the Bagnes-Heremence area (western Swiss Alps).*
Lugon, R. *Modelling Alpine Permafrost Distribution, Val de Réchy, Valais Alps (Switzerland).*
Lutschg, M., Bartelt, P., Haeberli, W. and Stockli, V. *Interaction between snow-pack and permafrost in the Alps: coupling of the snow-pack model and the ground heat flux model.*
Mamoru, I. *Micro-scale mountain permafrost distribution in the Diasetu Mountains, Hokkaido, Japan.*
Ramos, M., Tanarro, L.M., Crespo, F., Vicente, A., Gomez, A., Salvador, F. and Palacios, D. *The possible occurrence of permafrost in Corral de Veleta (sierra Nevada, Spain) according to thermal prospecting methods.*
Serrano, E. and Agudo, C. *Permafrost distribution in the Posets massif (Spanish Pyrenees).*
Tumel, N.V. *The map of cryogenic processes intensification in the North and its ecological application.*

16.00-16.30 - Break and posters

16.30-18.00 - Oral Session 4 - Continued

16.30-16.45	Ershov, E.D., Levantovskaya, N.P., Maksimova, L.N. and Medvedev, A.V. *Natural rhythms and modelling of the cryosphere.*
16.45-17.00	Marchenko, S.S. and Udartzev, S.V. *Mapping and distribution modelling of mountain permafrost in the Tien Shan, Kazakhstan*
17.00-17.15	Kashtanov, A.S. *Snow and freezing in mountain regions.*
17.15-17.30	Delisle, G., Caspers, G. and Freund, H. *A numerical model on the permafrost aggradation/degradation during the last 120 kyrs in northern Germany.*
17.30-17.45	Holmlund, P., Jansson, P. and Pettersson, J. *Climate Impact On The Thermal Regime Of Storglaciären, Northern Sweden.*
17.45-18.00	Christensen, J.H., Stendel, M. and Kuhry, P. *High Resolution Regional Climate Model Validation and Permafrost Simulation for the East-European Russian Arctic.*

18.00 - IPA Task Force - Permafrost Distribution Modelling - Meeting

19.30 - Banquet

Wednesday 28th March

08.20-10.30 - Oral Session 5 - Hazards, Geotechnics and Geophysics in Permafrost Regions
Chair: M.C.R. Davies & F. Dramis

Hazards

08.30-08.45 Harris, C. Davies, M.C.R. and Etzelmuller, B.
Assessing mountain permafrost-related geotechnical hazards – PACE Protocols.

08.45-09.00 Karstkarel, N. and Mazhitova, G.
Assessing the impact of possible future permafrost degradation on urban industrial infrastructure in the East European Russian Arctic using a GIS approach.

09.00-09.15 Anisimov, O.A.
Permafrost degradation and environmental hazards under global climate change.

09.15-09.30 Torgashov, V.
Work of the pile foundations in thawing water impregnated grounds in conditions of the development of negative friction forces and seismic effects.

09.30-09.45 Karlov, V.D.
Calculation of the influence of cryogenic processes in soils while evaluating the stability of buildings.

09.45-10.00 Keller, F.
Application of freezing indices for design and maintenance of buried water pipes in mountain permafrost areas.

10.00-10.30 - Break and Posters

11.00-12.00 - Oral Session 5 - Continued

Site Investigation

10.30-10.45 Shesternyov, D.M., and Filatov, A.V.
The remote investigation of cryogenic objects with microwave radiometric complex.

10.45-11.0 Hauck, C., Guglielmin, M., Isaksen, K. and Vonder Mühll, D.
Applicability of frequency- and time-domain electromagnetic methods for mountain permafrost studies.

11.00-11.15 Vonder Mühll, D., Arenson, L., and Springman, S.
Two new boreholes through the Murtèl-Corvatsch rock glacier, Upper Engadin, Switzerland.

11.15-11.30 Instanes, A. and Sundström, A.E.
Temperature regime and permeability of a tailing deposit on permafrost in Bjørndalen, Spitsbergen.

11.30-11.45 Nielsen, O.F., Baumgartner, F., Foged, N., Christensen, N.B. and Andreasen, F.
Ground Penetrating Radar (GPR) investigations in a discontinuous permafrost environment, Greenland.

11.45-12.00 Vonder Mühll, D., Hauck, C., Gubler, H., McDonald, R. and Russill, N.
New geophysical methods of investigating mountain permafrost with special reference to radiometry techniques.

12.00-12.30 - Short Poster Presentations

Alexseeva, I. and Torgashov, V. *Some Regularities of Development Negative Friction Forces on a Lateral Surface of Deep-Lying Foundations.*

Anisimov, O.A. *Permafrost degradation and environmental hazards under global climate change.*

Domnikova, E.A., Kondratiev, S.D. and Pavlunin, V.B. *Permafrost monitoring of the structure foundations of the gas regions of the northern part of the Western Siberia.*

Frolov, A.D., Voronkov, O.K. and Zykov, Y.D. *Interrelation between frozen soil and rock moduli of deformation obtained under various regimes of mechanical stresses.*

Grebenets, V.I. *Technocryogenesis as a leading exogenic process in industrial centres of permafrost zone.*

Gude, M., and Barsch, D. *Distribution and geotechnical implications of permafrost in the Zugspitze area (Bavarian Alps).*

Hormes, A., Ferreli, L., Guarneri, E.M., Perini, P., Rovinelli, W., Serva, L., Michetti, A.M. and Guglielmin, M. *The mass movement-permafrost couple: deep seated gravitational deformations and landslides in the Alta Valtellina (Lombardia, Northern Italy) influenced by the raising elevation of permafrost.*
Kerimov, A.G., Pikulev, V.P. and Burmensky, S.Y. *Development of deformations of buildings and constructions under changing geocryological conditions.*
Kondrateiv, V. G. and Broid, I.I. *Defrosting Of Permafrost With Using Of Jet Grouting Method.*
Konovalov, A.A. *The interaction of linear technogenic systems and permafrost rock on the economical developed territories of the cryolithozone.*
Merzlyakov, V.P., Brouchkov, A.V., Talonov, A.V. and Vlasov, A.N. *About the mechanism of creep of "high-temperature" frozen soils under external loads.*
Musorin, A.V. and Ivin, J.A. *Assessment of Working Shallow Foundation from the Influence of Frost Heaving Forces.*
Rogov, V.V. *Researches of a microstructure frozen ground as one of major directions in study of cryolithosphere.*
Roman, L.T. *Determination of long-term strength and strain of frozen soils under freezing temperature by time analogy methods.*
Shesternyov, D.M. *Frozen Heaving of Large Dispersed Soiled System.*
Zheleznyak, Y. *Stability of underground cables under influence of frosty ground cracking.*
Zhouxiaomin *Influence on the freezing performances of drilling slurry by additive.*
Zotova, L. *The cryoecological assessment of tundra geosystems under anthropogenic impacts.*

12.30-14.00 - Lunch and Posters

14.00-15.00 - Oral Session 5 - Continued

Natural Slopes

14.00-14.15	Harris, C., Rea, B., and Davies, M.C.R. *Centrifuge modelling of cryogenic slope processes.*
14.15-14.30	Mudrov, Y.V. *Peculiarities of cryomorphogenesis on the slopes of the Russian western Arctic sector.*
14.30-14.45	King, L. et al. *Permafrost in the Mattertal, Swiss Alps, monitoring, degradation and geotechnical consequences.*
14.45-15.00	Davies, M.C.R., Hamza, O. and Harris, C. *Centrifuge modelling of frozen jointed rock slopes.*
15.00-15.30	Discussion

15.30-16.30 - PARALLEL ORAL SESSIONS:

Oral Session 6 – Antarctica – Chair: M. Gugliemin

15.30-15.45	Gilichinsky, D. *Age of Antarctic Permafrost.*
15.45-16.00	Campbell, I. *Permafrost Properties and genesis in the Ross Sea region of Antarctica.*
16.00-16.15	French, H. *Frost Mounds, Northern Victoria Land, Antarctica.*
16.15-16.30	Viera, G. and Ramos, M. *Observations on the periglacial dynamics of the south slope of Johnsons ridge, Livingston Island, South Shetlands.*
16.30-16.45 -	Lewkowicz, A. and Guglielmin, M. *Thermal regimes of tors on Ellesmere Island, Canada (80°N) and Victoria Land, East Antarctica (75°S).*

Posters

Boelhouwers, J. and Holness, S. *Present-day soil frost activity on Marion Island, maritime sub-Antarctic.*
Boelhouwers, J. *Geomorphic responses to climate change in the Antarctic: science questions and possible approach.*

Hall, K. *The necessity for high-frequency rock temperature data for rock weathering studies: Antarctic and northern examples.*
Huiskes, A. *RISCC (Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems), a new international research programme.*
Motta, M., Diolaiuti, G., Motta, L and Smiraglia, C. *Snow metamorphic evolution in a permafrost site near Terra Nova Bay Station, Victoria Land, Antarctica.*
Raffi, R. *Ice wedges in the Terra Nova Bay Region, (Antarctica). Distribution and morphological features*

Oral Session 7 - Coastal and Marine Environments - Chair: H. Hubberten

15.30-15.45 Allard, M., Delisle, G., Fortier, R. and Calmels, F.
Permafrost properties and landforms in emerged marine sediments of Nunavik: a source of basic knowledge on permafrost formation in Quaternary marine sediments.
15.45-16.0 Delisle, G. and Allard, M.
Subsea permafrost in the Laptev Sea/Siberia and associated permafrost (?) features at the sea floor. Potential analogues from the emerging Hudson Bay region.
16.00-16.15 Kaul, N.
Temperature measurements and their variations on the permafrost bearing Laptev sea shelf, Germany.
16.15-16.30 Komarov, I.A. and Loukovkine, D.S.
Influence of salt transportation process on subaquatic permafrost dynamic in the course of the Holocene transgression.

Posters

Ershov, E.D., Danilov, I.D., Komarov, I.A and Loukovkine, D.S. *Dynamic of Barents Sea shelf permafrost development during middle Pleistocene - Holocene.*
Hubberten, H-W. and Romanovskii, N.N. *Onshore and Offshore Permafrost and Gas Hydrate Stability Zone on Shelf and Coastal Plains, Laptev Sea Region.*
Schwamborn, G., Rachold, V., Grigoriev, M.N. and Krbetschek, M. *Late Quaternary Sedimentation History of the Lena Delta.*

16.30-17.00 - Break and Posters

17.00-18.00 - Parallel Sessions 6 & 7 continue

Session 6 - Antarctica

17.00-17.15 Balks, M.R., Paetzold, R.F., Kimble, J.M., Aislabie, J., Campbell, I.B.C. and Balks, E.M.
Establishing base-line monitoring of permafrost in the Ross Sea region of Antarctica.
17.15-17.30 Sone, T., Strelin, J. and Junko, M.
Thermal characteristics of permafrost in Seymour Island and James Ross Island.
17.30-17.45 Ramos, M., Vieira, G. and Crespo, F.
Permafrost distribution in the area of the Spanish Antarctic Station (Livingston island): ground temperatures during 1995
17.45-18.00 Guglielmin, M. and Dramis, F.
Permafrost monitoring antarctic network in Northern Victoria Land (Antarctica): preliminary results.

Session 7 - Coastal and Marine Environments

17.00-17.15 Brouchkov, A.V.
Frozen saline soils of the Arctic coast: their origin and properties.
17.15-17.30 Ostroumov, V.Y. and Sorokovikov, V.A.
Drainage direction of super-permafrost waters and denudation of permafrost sediments at coastal cliffs.
17.30-17.45 Are, F.E.
Shore face of the Arctic seas - a natural laboratory for marine permafrost dynamics.
17.45-18.0 Rachold, V., Are, F.E., Grigoriev, M.N., Hubberten, H.W., Rasumov, S. and Schneider, W.
Coastal Erosion of Ice-Rich, Permafrost-Dominated Coastlines in the Laptev Sea Region.

18.00-18.30 - Closing Ceremony

Session 1. Permafrost Monitoring.

Oral Presentations

The Global Terrestrial Network for Permafrost (GTNet-P): Borehole Thermal Monitoring

Margo Burgess, Geological Survey of Canada, Ottawa, Canada
Sharon Smith, Geological Survey of Canada, Ottawa, Canada
Vladimir Romanovsky, University of Alaska, Fairbanks, U.S.A.
Jerry Brown, International Permafrost Association, Woods Hole, MA, U.S.A

In 1998 the International Permafrost Association (IPA) Council passed a resolution at the Yellowknife permafrost conference to lead the development of a functional international network for permafrost monitoring. An ad-hoc steering committee was established to develop a strategy for the organization, implementation and management of a global monitoring network for active layer and borehole temperature monitoring. In 1999, the Global Terrestrial Network for Permafrost (GTNet-P) was established under the Global Climate Observing System (GCOS) and Global Terrestrial Observation System (GTOS) of the World Meteorological Organization (WMO), with the request that IPA plan and implement the GTNet-P.
Active layer and permafrost thermal state, the basic GTNet-P measurements, were identified by GCOS in 1997 as two key cryospheric variables for monitoring. Active layer observations are obtained at over 80 sites in the Northern Hemisphere as part of the Circumpolar Active-Layer Monitoring (CALM); with plans to extend the network to the Southern Hemisphere. Over 300 boreholes sites in 14 countries have been identified as potential sites for thermal measurements. Site metadata compilation is well underway. The majority of the boreholes are between 10 and 125 m deep. Candidate sites will be assigned to one of the five levels of the Global Hierarchical Observing Strategy (GHOST). Final site selection will emphasize representative regional and global coverage while taking maximum advantage of existing facilities.
At the June 2000 International Permafrost Monitoring and Database Workshop in Fairbanks, a quality control and technical committee was established to determine procedures and standards for data acquisition and submission for the borehole thermal monitoring data. The inventory of sites and metadata are being incorporated into the GTNet-P web site hosted by the Geological Survey of Canada (GSC) (http://sts.gsc.nrcan.gc.ca/gtnp/index.html). Summary data will also be available on the web site through database model and web site development at the GSC. Final archiving of data will be through the National Snow and Ice Data Center and the WDC-A for Glaciology, Boulder, Colorado, as part of the IPA's Global Geocryological Database (GGD).
A letter from the Secretary General of the WMO was sent in September 2000 to ministers of countries with permafrost interests requesting active participation in GTNet-P. A summary of the GTNet-P program, recent activities and future steps are reported in the Geological Survey of Canada (GSC) Current Research report series (Burgess et al, 2000). The first five-year summary report, consisting of a series regional reports, is planned for the year 2004, with a draft presented and reviewed at the Eighth International Conference on Permafrost in Switzerland in 2003.

Permafrost Monitoring in the High Mountains of Europe: the PACE and the PERMOS Project in its Global Context

Daniel Vonder Mühll, Delegate for Permafrost of the Swiss Glaciological Commission

Over the past thirty years, activities investigating mountain permafrost in mountain regions of Europe have become intensified. Based on these efforts the three-year EU-Project "Permafrost and Climate in Europe" was funded by the European Commission and the Swiss government in 1997. Partners come from the United Kingdom, Norway, Sweden, Germany, Switzerland, Italy and Spain. One principal objective of PACE is to establish a framework for monitoring the impact of global climate change on permafrost geothermal regimes in the mountains of Europe in a transect from Svalbard (78°11' N) to Sierra Nevada (37°03' N). A number of at least 100m deep drillings in bedrock are equipped with temperature sensors: Janssonhaugen (Svalbard, 100m, May 98); Tarfala (northern Sweden, 100m, March 00); Juvvasshøe (southern Norway, 129m, August 99); Schilthorn (northern Sws Alps, 2x100m August 00); Stockhorn (southern Swiss Alps,

100m, July 00); Stelvio (Italy, 100m, June 98); El Veleta (Sierra Nevada, Spain, 100m, September 00). Temperatures are measured according to a PACE Project standard with 10 thermistors in the uppermost 5m (logged every 6 hours), another 7 sensors to 25m and additional 13 down to 100m (logged once a day).
According to the so far available data, none of the boreholes penetrated the permafrost base, although annual surface temperatures vary between –8°C and –2°C. At all sites, temperature profiles indicate a warming in the last century. At Janssonhaugen this amounts to about 1°C to 2°C over the last 100 years (Isaksen et al., 2000).
In Switzerland, a national network has been established officially in 2000 after long preparation time (e.g. Haeberli et al., 1993). Although a wide monitoring approach was proposed (thermal reaction, rheology and topography, hydrology, melt-out pattern of the snow, geomorphological activity, vegetation, geophysical surveys), the Glaciological Commission of the Swiss Academy of Sciences recommended to concentrate on as few parameters as possible during the pilot-phase 2001-2003. As a result the **PER**mafrost **MO**nitoring in **S**witzerland (PERMOS) is based on three items:

- Thermal state: borehole temperature and active layer thickness at 10 drill sites.
- Permafrost distribution pattern around the lower boundary: Single-channel temperature loggers are deployed on a line from "permafrost" to "no permafrost" to measure all year around surface temperature. In winter, additional BTS measurements are performed to transfer data to a larger area. There are 10 so-called BTS-areas in PERMOS.
- Ensure that aerial photographs are taken regularly, allowing later photogrammetrical processing, to monitor surface changes and deformation of creeping permafrost. There will be one flight taking aerial photographs a year.

Hence, PERMOS is a logic consequence of the Swiss permafrost research tradition: the BTS method has been developed there, which makes it possible to assess easily the permafrost distribution in the Alps. In addition, the core drilling through the Murtèl rock glacier in 1987 (Haeberli et al., 1998) provides one of the longest systematic time series of Alpine permafrost temperatures (Vonder Mühll et al, 1998). Finally there are large-scale aerial photographs regularly taken since the 1970s.

Three deep alpine-permafrost boreholes in Svalbard and Scandinavia - climatic trends

Ketil Isaksen, Department of Physical Geography, University of Oslo, Norway
Per Holmlund, Department of Physical Geography, Stockholm University, Sweden
Johan Ludvig Sollid, Department of Physical Geography, University of Oslo, Norway

The existence of permafrost is a result of the history and the present state of the energy balance at the Earth's surface, measured by the surface temperature and the Earth heat flow (Lunardini, 1995). Permafrost temperatures represents a systematic running mean that filters the high frequency signals of the atmosphere and preserve only the low frequency long term signals. In the context of changing global climate, analyses of permafrost ground temperatures and thermal properties in selected areas constitute a key research tool. Whereas great amount of permafrost temperature data and knowledge about permafrost thermal regime exists from Alaska and Siberia (e.g. Lachenbruch and Marshall, 1986; Pavlov, 1994), little temperature data from boreholes is available from the mountain permafrost environment (Haeberli, 1990).
The first deep alpine permafrost boreholes (> 10 m) ever drilled in Scandinavia for climatic studies constitute a part of the transect of deep mountain permafrost boreholes through the mountains of Europe established under the EU PACE (Permafrost and Climate in Europe) project. In Scandinavia, the PACE boreholes were drilled at Juvvasshøe, southern Norway (61°40′32′′N, 08°22′04′′E, 1894 m a.s.l.) in August 1999 and at Tarfalaryggen, northern Sweden (67°55′ N, 18°38′E, 1540 m a.s.l.) in March 2000. The northernmost borehole in the transect, at Janssonhaugen, western Svalbard (78°10'46"N, 16°28'01"E, 270 m a.s.l.) was drilled in May 1998.
The permafrost ground temperatures from the three mentioned boreholes form the basis for; (1) analysing the ground thermal properties, (2) computing past secular changes in ground surface temperature using inversion techniques with respect to heat diffusion at depth, (3) detecting signals of ongoing and potential future changes from trend analyses of collected time series, and (4) monitoring the evolution of the active layer on the basis of shallow temperature profiles.

Long-term observations of soil thaw in the Arctic, Subarctic, and Alpine: Initial results based on the CALM network

Jerry Brown, International Permafrost Association
(with contributions acknowledged from CALM participants)

The hypothesis that warming will increase the thickness of the active layer, resulting in thawing of ice-rich permafrost and surface subsidence and instability, requires further validation under differing contemporary environmental settings. Monitoring and modelling of the interannual, decadal, and secular variations in the active layer on regional and hemispheric scales are required to understand and predict the response of cold soils to climate change. The Circumpolar Active Layer Monitoring program (CALM) was established in the early 1990s as a long-term, observational program to assess changes in the active layer and to provide ground truth for regional and global models. The network currently incorporates more than 80 active sites involving 12 countries in the Northern Hemisphere. End-of-season thaw depths are measured on grids ranging from 10 m to 1000 m, along transects, from frost tubes, or interpolated from closely-spaced soil temperature sensors. Metadata and ancillary information are available at each site including climate, descriptions of terrain, soil type and vegetation. Data are electronically transferred to the CALM data repository (http://www.geography.uc.edu/~kenhinke/CALM/). The IPA-co-ordinated CALM network is now part of the Global Climate Observing System (GCOS) and the Global Terrestrial Network for Permafrost (GTN-P). Although many of the CALM sites were begun in the 1990s, several sites in the network have data extending back to the 1960s and 1970s. Other longer-term records from non-CALM sites represent similar physiographic and climatic regions and may be used to draw inferences from sites with shorter records or differing sample designs. These include a number of well-documented studies of active-layer response to disturbance (fire, drilling, trails, etc.), and they may serve as analogues of future natural changes and responses in soil climate. In general, several decades are required following disturbance for the active layer to recover or stabilise. Active-layer thickness has fluctuated over the period of record. In general, available evidence suggests differing responses to contemporary climates. In both the Subarctic and mid-latitude mountains, snow cover influences ground temperatures and subsequent summer thaw. Thaw subsidence and thermokarst have been documented at some of these warmer permafrost sites, indicating degradation of permafrost. However, many of the CALM sites lack precise elevation data. We cannot say with confidence how much ground ice has melted, particularly beneath a relatively constant, active-layer thickness. In contrast to the warmer permafrost conditions, sites in Arctic Alaska during the period 1995-2000 experienced maximum average thaw depth in 1998 and a minimum in 2000; these values are consistent with the warmest and coolest summers (Hinkel and Nelson this volume). The longer-term observations for this Arctic region indicate that both deeper and shallower thaws have occurred over the past four decades. Permafrost temperatures from boreholes of intermediate depth show both warming and cooling trends over decadal periods. Many of the questions raised by this international program to monitor the response of the active layer to climate warming will require multi-decadal observations, improved methods of ground control, and boreholes for thermal measurements in the upper layers of the permafrost.

Poster Presentations

Active layer dynamics – towards a unifying concept.

Julia Boike, Larry Hinzman
Water and Environmental Research Center, University of Alaska, Fairbanks, Alaska
Kurt Roth, Olaf Ippisch,
Institute for Environmental Physics, University of Heidelberg, Germany

Permafrost landscapes are characterized by small and large scale patterned ground formations, such as polygons, circles or stripes. These heterogeneities affect the thermal and hydrological dynamic of these structures. Our goal is to quantify the main processes that govern small scale systems (such as a non-sorted circle) using study sites on Svalbard, Siberia and Alaska. All these sites are instrumented to record high resolution data of microclimate and the soil thermal regime. Following the concept of soil formation by Jenny (1941), we propose to examine these sites with respect to their independent soil forming factors: 1. climate 2. topography 3. soil material and 4. time of development. Hence, the local form of the soil is determined by the spatial distribution and temporal evolution of these factors. As a first step, we will compare these sites in terms of their energy balance and heat transfer mechanisms. What are the main factors controlling the dynamic of the active layer? What is the importance of dependent variables such as snow height, soil moisture and vegetation? This understanding on a plot scale will aid our development and validation of physical models on a landscape scale, for example the modeling of hydrological processes in an arctic watershed.

Development of a Canadian permafrost monitoring network as part of a national GCOS plan for the cryosphere

M.M. Burgess and S.L. Smith, Geological Survey of Canada, Ottawa

Following the World Meteorological Organization's establishment of the Global Climate Observing System (GCOS) in 1992, Canada formed an ad hoc committee to assess its capacity to meet GCOS requirements. In 1999, with funding from the Government of Canada's Climate Change Action Fund (CCAF), the committee organized a national workshop, developed scoping documents and produced a draft Canadian plan (Can GCOS). In 2000, an assessment of the requirements to meet GCOS and Canadian monitoring needs was initiated, including preparing associated cost-effective proposals. The development of a Can GCOS plan for an initial observation system for the cryosphere involves five components: glaciers and ice caps, permafrost, sea ice, snow, and lake ice. The Geological Survey of Canada (GSC) leads the development of the permafrost and glacier component plans, and held a network definition workshop in January 2000, with funding support from the CCAF.

The Canadian permafrost and glaciers workshop was attended by some 50 participants, more than half of which represented the permafrost community (government, academia and industry). Joint and parallel sessions covered: i) an overview of international and national GCOS programs, ii) current monitoring activities, climate and process modelling needs, iii) monitoring technology and techniques, and iv) network requirements. While many regional and local permafrost monitoring activities are underway, there currently is no coordinated national program. A pre-workshop survey and workshop presentations allowed a more complete assessment and compilation of permafrost monitoring activities, including active layer, thermal regime and process monitoring. More than 15 projects were identified, involving more than 15 agencies. Most existing programs are woven into short-term targeted research projects, rather than operating (and being funded) as explicit long-term monitoring studies.

The key steps recommended at the workshop for the successful establishment and operation of a Canadian Permafrost Monitoring Network are, in order of priority:

1. Secure long term federal institutional commitment for co-ordination, management and operation of a national network. The GSC was identified as the likely lead agency for management and co-ordination.
2. Provide this co-ordination, and the necessary human and financial resources to: i) establish the national data compilation and distribution centre (web based), ii) support existing government, university and other agency observatories of active layer and permafrost thermal state (support equipment, personnel and logistics)
3. Support Canadian involvement and leadership in international GCOS programs, particularly its Global Terrestrial Network for Permafrost (GTN-P)
4. Restore key inactive Canadian sites where possible.
5. Augment the network by establishing sites to fill critical thematic and regional gaps working in partnership with communities, national parks and industry.
6. Support complementary monitoring of active geomorphic processes (e.g. slope and coastal stability) to detect long-term climate change and assess its impacts.
7. Support research into development and implementation of remote sensing techniques to extend point source permafrost monitoring to broader spatial domain.

Response of temperature regime of seasonally frozen soils of North-East of Europe to climate changes.

Chudinova, S.M.[1], Bykhovets, S.S.[1], Fedorov-Davydov, D.G.[1], Sorokovikov, V.A.[1], Gubanov V.S.[1], Smirnov, V.E.[2], Barry, R.G.[3], Gilichisky, D.A.[1],
Institute of Physical-Chemical and Biological Problem in Soil Science [1], Institute of Mathematical Problems of Biology [2], Russian Academy of Sciences, University of Colorado, USA[3]

The similar climatic changes can induce the different changes in the different soils. Therefore, the direct characterization of long-term soil temperatures variation under the climatic changes is of a great importance. The long-term variation of air temperature in the northeastern Europe was relatively the same, in spite of vast area and wide diversity of soils (from tundra to podzolic ones) and natural (tundra to taiga) conditions. Hence this region is more suitable for assessment of soil temperature variation under climatic changes. This assessment was made for the warming period 1966 to 1990, which followed the "cold 50-s". For 10 meteorological stations (Fig. 1), the mean annual and monthly values of air and soil (depths 20, 40, 80, 160, 320 cm) temperatures as well as snow depths were analyzed.

For continental (eastern) stations, the long-term variations of mean annual temperatures soil are similar to those of air. Here the harsh winters in the end of 60-s and in the middle of 70-s and 80-s, accompanied by the decrease in snow depths, led to a significant decrease in soil temperature. In the west-located stations, the increase in snow depths minimized the influence of cold winters in the end of 60-s. As a result, the strong decreasing of soil temperatures was not observed.

The ascending linear trends of air temperature (both winter and summer) are accompanied by different soil temperature trends. The mean annual and summer temperatures increase at all stations (Fig. 2). However, in winter, soil temperatures at few stations decreased, in spite of the increase of air temperature and snow depth.

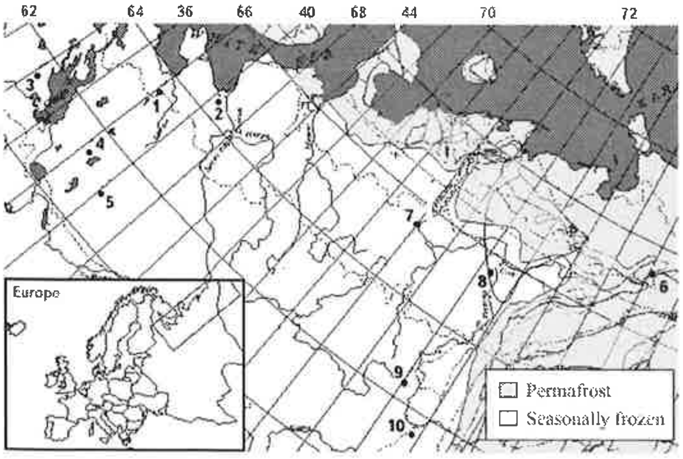

Fig.1. Study area and meteorological stations

1. Onega	**6. Eletskaya**
2. Arkhangel'sk	**7. Ust'-Tsil'ma**
3. Petrozavodsk	**8. Ust'-Usa**
4. Kargopol'	**9. Troitsko-Pechorskoe**
5. Konosha	**10. Ust'-Un'ya**

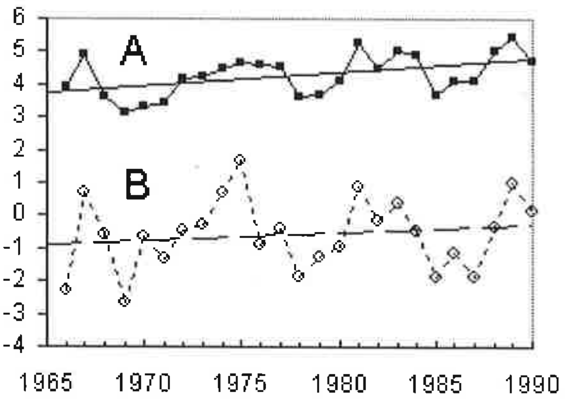

Fig. 2. Long-term dynamics and linear trends of mean annual temperatures of air (B) and soil for the depth of 20 cm (A) averaged over all stations.

First signs of response on the climate warming in periphery of permafrost zone, the Central Siberia.

Gorshkov, S.P. and Lomonosov, M.V.
Moscow State University, Faculty of Geography.

In the Central Siberia the western border of cryolithozone follows the Yenisey river, from the lower reaches of the Angara river (58° N.L.) until the mouth of the Bachta river (62.5° N.L.). The Yenisei ridge (58° – 61° N.L) and the Western edge of Middle-Siberia high plateau (north of 61° N.L.) lie just to the East of the Yenisei river. The ridge and the high plateau edge are the part of North-Eurasian permafrost ecotone, which is formed from of alternation of permafrost and non-permafrost landscapes. During last 20 years winters became milder and somewhat shorter. Transition periods became longer, especially from autumn to winter. The following processes can be singled out as likely responses to climate warming:

1. Appearance of patches of reindeer moss (*Cladonia rangeferina*) on open rock streams (kurum).
2. The cases of replacement solifluction mass movement in the lower part of accumulative glacis by local landslide as a result of lowering of the permafrost top surface and destabilisation of the glacis scarp especially being undermined by river.
3. Wide development of long-frozen rocks which can indicate to recent permafrost degradation.
4. Occurrence of young fir-tree forests on slash fire previously consisted of different tree species.
5. The presence of tree groups that being bent became vertical in their tops.
6. Frequent falling of trees with creeping rootage in the places of the hydromorphic clay rocks on a 2 meter depth or deeper. It happens because hydromorphic soils have viscous-plastic consistence.

It is possible that one of the evident responses of permafrost ecotone to the climate change in Central Siberia is the increase of active layer thickness and in some places even high temperature permafrost (0.1° – 1° C) degradation. This evidence combined with a factor of growing season duration with a temperature often crossing 0°C caused a certain intensification of permafrost processes. The author has made a program of collection and mapping of signs of permafrost ecotone response to the climate warming.

The research is completed in frames of RFFI project - 98-0564967.

Controls on the spatial and temporal patterns of thaw at CALM sites on the North Slope of Alaska: 1995-2000

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End-of-season thaw depth has been monitored at seven 1 km^2 CALM (Circumpolar Active Layer Monitoring) sites in northern Alaska since 1995. Grid nodes are spaced at 100 m intervals, yielding a regular array of 121 (11 x 11) data collection points. Three sites (Toolik Lake, Imnavait Creek and Happy Valley) are located in the Foothills physiographic province, and four are on the Arctic Coastal Plain (Betty Pingo, West Dock, Barrow and Atqasuk.) Air and soil temperature measurements are made at each site, and soil moisture is monitored at most.

Six years of record permit several general conclusions: (1) Sites on the North Slope of Alaska respond consistently to forcing by air temperature on an inter-annual basis. All sites experienced maximum average thaw depth in 1998 and a minimum in 2000, consistent with the warmest and coolest summers during the period of record. (2) There is significant intra-site variation in thaw depth and near-surface soil moisture content within each 1km^2 grid, reflecting the impact of vegetation, substrate, snowcover dynamics, and terrain. Sites on the Coastal Plain generally show less spatial variation than those in the Foothills. (3) On the Coastal Plain, thaw depth is significantly greater in drained thaw-lake basins, where soils are typically at or near saturation. This results in a bimodal distribution of thaw depths related to primary landscape elements. (4) Foothill sites demonstrate large spatial and inter-annual variability resulting from microtopography and temporal fluctuations of soil moisture content; this makes predictive mapping of thaw depth problematic at the scale and resolution of the grids. The spatial pattern of thaw depth across sites on the Coastal Plain is relatively consistent, although lake margins exhibit more complex patterns attributable to fluctuating water levels.

Ground temperature monitoring in a permafrost environment of the Central Alps (Austria)

Michael Krobath and Gerhard Karl Lieb
Institute of Geography and Regional Science, University of Graz, Austria

Ongoing temperature monitoring in high mountain permafrost is carried out by the Institute of Geography and Regional Science, University of Graz. Simple standard methods with low cost equipment has been installed to provide long-term measurements. Within the framework of several research projects basic information on the distribution and character of permafrost and of nearby glaciation have been elaborated.
The test site is situated in the centre of Schober group (46°58' N, 12°45' E) to the South of Grossglockner, Austria's highest summit. Geology consists of crystalline rock. Climate is quite typical for the Central Alps with a mean annual air temperature of 0°C at 2200 m a.s.l. and a precipitation of some 1500 mm at the same altitude. Low precipitation and steep relief restricts the glaciation to relatively small areas leaving enough space for permafrost and development of rock glaciers.
The occurrence of permafrost has been proven by different methods. Mapping of active rock glaciers and similar permafrost features – some of them developing from lateral moraines of Little Ice Age glaciers – was supplemented by repeated measurements of spring temperatures and bottom temperatures of the winter snow cover (BTS). A preliminary map of permafrost distribution was drawn. In addition, measurements of surface movement on two rock glaciers are done by the group of V. Kaufmann (Graz University of Technology). Moreover, the team of K. Krainer (University of Innsbruck) has been observing rock glaciers in same areas with special emphasis on their hydrology.
The results of 3 years temperature measurements using the single-channel UTL-1 datalogger (developed at the Geographical Institute of the University of Berne) are presented. The measurements are taken on a smooth crest within the active rock glacier in „Weissenkar" at an altitude of 2660 m a.s.l. The loggers register the BTS in winter. Since 1999, a temperature profile down to 1m depth has been installed at the same site. First results show a good correspondence with the course of climatic elements of nearby meteorological stations.
The major aim of these activities is to establish long-term ground temperature recording in order to study possible changes in the context of climate change using cheap and simple equipment. This guarantees continuation of measurements. At some other sites, similar monitoring has been started as well. In near future, other investigations such as geophysical soundings and studies on the relationship permafrost-glacier are planned.

Changes in the cryolithozone temperature of the European Northeast of Russia in the context of 1970-95 climatic warming

Oberman N. Stock Company Palyarnouralgeologiya, Syktyvkar, Russia

Temperature monitoring at a depth of annual temperature wave penetration was conducted by N. Kakunov and the author in the main landscapes of the region. In glacial-marine lowlands of the zone of discontinuous permafrost, the latter, during the whole period of warming, become warmer by 0.15-0.7°C, i.e., in average by 0.4°C. Taliks demonstrated in average twice as larger increase in temperature due to lack of heat losses for phase transformations of water. The higher the starting temperature of the permafrost was, the smaller increases in its temperature were registered. This was due to a decrease in temperature conductivity of permafrost following an increase in the content of unfrozen water in it. The minimum increase among the mentioned above was registered in the case of about complete mutual compensation of the effect of climatic warming and ongoing new-formation of permafrost, e.g. in the beds of drained thermokarst lakes. In the continuous permafrost zone temperature changes under lake bodies might be positive in the offshore zone and negative in the inner area. Shallow closed taliks in low lacustrine-alluvial and glacial-marine plains had about constant zero temperature. In the discontinuous permafrost zone of the Urals, amounts of increase in the temperature of thawed ground during the period of climatic warming varied from 0.2-0.7°C in low mountain to 1.2°C in foothills.
The effect of the climatic warming revealed itself in the plains and foothills down to depths of 30-40 m. Direction of temperature trends in the overlying rock mass experienced numerous changes during the warming. As a result, we observed equally frequent changes in talik types: open, closed, and lateral ones.
This work was supported by the grant INTAS Open-97-10984.

The effect of changing snow cover on temperatures in the active layer in the Longyearbyen area, Svalbard.

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Svalbard is a High Arctic area, located in the continuous permafrost zone, with a MAAT of -4°C. This region is very interesting when studying climate change, because of its location in the polar region at the end of the area in the North Atlantic Sea affected by the Golf Stream. The purpose of the investigation is to examine how temperatures in the active layer will respond to changes in air temperatures and snow regime. If higher winter temperatures occur at Svalbard this is estimated to result in more snow. Strong winds will redistribute the snow, and larger snowpatches than seen today could accumulate. The distribution and duration of snow are of great importance the active layer thermal regime due to delayed thawing in summer and isolation in fall.

The thawing of the active layer have been measured in two sites in the Longyearbyen area at Svalbard at 78°12' N, one in Adventdalen, at 10 m asl., and one at Sukkertoppen, at 373 m asl. This way it becomes possible to establish an altitudinal relationship in timing and rate of active layer thawing for the area. The site at Sukkertoppen (373m) is highly sensitive to the wind and a snowpatch is present on the lee side most of the summer. The site in Adventdalen at the floor of the valley does not have a late summer snowpatch, and thus experiences early snow melt, resulting in a longer growing season. Active layer development in both areas is monitored during the summer period in CALM grids. The soil temperature is measured at various depths down into the permafrost on an annual basis. The two sites show the gradient of temperatures and active layer as it is today. Any response from a changing climate can from these data be evaluated particularly with respect to the winter wind direction, temperature and precipitation. The two sites will respond differently to climate change, mainly because of the difference in sensitivity to wind and snowfall, and results of such differences will be shown.

Warming of Permafrost in Alaska

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Since 1977, a continuous program of measurements at permafrost observatories for investigating the effects of climate and environmental conditions on the active layer and permafrost has produced information on the variability of permafrost temperatures, evidence for a recent warming of permafrost on a North-South transect of Alaska and observations of thawing discontinuous permafrost. This is an ongoing study and the results to date will be summarized.

Temperature data from the observatories show that permafrost temperatures along a North-South transect from Prudhoe Bay to Glenallen and at Healy have generally warmed since the late 1980s. This trend was not followed at Eagle which is about 330 km east of the transect. The magnitude of the warming at the permafrost table was typically 1°Cto 2°C. There was more than 3°C of warming near the Arctic Coast over the last 15 years. The latter is about the same as the warming that occurred over the last century in this area and about the same as the warming predicted for the next half-century as a result of increased trace gas concentrations in the atmosphere. Discontinuous permafrost should be thawing at the base; however, no reliable trends in the depth of the base of ice-bearing permafrost nor in the depth of the 0°C isotherm have been detected. Thermal offset allows mean temperatures at the permafrost table to remain below 0°C with ground surface temperatures up to +1.6°C. Unfrozen water plays a significant role in the response of permafrost to climatic warming. Mean discontinuous permafrost temperatures in marginal areas are typically warmer than -0.5°C indicating that the above warming has caused thawing at the edges of permafrost bodies in these areas.

Thawing permafrost and thermokarst have been observed at several sites. Thawing rates at the permafrost table at two sites were about 0.1m per year. Time scales on the order of a century are required to thaw the top ten meters of ice-rich permafrost which is responsible for environmental and engineering problems. Permafrost persists at depth a long time after thawing begins with time scales of centuries to millennia required to completely thaw relatively thin discontinuous permafrost.

Prediction of global climate and cryolitozone changes

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The cryolithozone character is determined first of all by a climate. Therefore dynamics of a climate, both its natural course and under influence of anthropogenic factors. Modern researches have revealed steady cycles in a climate course. An of the same type global oscillatory in a climatic course is established, within the framework of which a long-term macrocycles (thousand and the tens of thousand of years) are complicated short-term (hundred and tens of years) cycles of fluctuations. A good cause are available to consider that oscillatory character of climate changes, being by natural property of its development, will be kept and in future. Therefore prediction of future changes in climate and cryolithozone can (and should) be based on the results of studying its variations in the past.

The reaction of cryolithozone on climate changes is connected to penetration of air temperature fluctuations into rock. The depth of such penetration is in direct dependence from long of period and amplitude of temperature fluctuation. Study of all climatic cycles allows to conclude, that the appreciable changes in cryolithozone are in connection with long-term (35-40-thousand years) climatic cycles, penetrating on all permafrost thickness. During the warmer epochs the air temperature exceeded its present value by more than 2-3°C, during the colder epochs it went down by 10°C. For instance, a warming that occurred 8000-4000 years ago (so-called epoch" Holocene climatic optimum") in the European sector of the Arctic within the framework of the cycle is linked with a deep (up to 80-150 m) or total thawing of the permafrost. The modern period lies on the descending branch of the climatic macrocycle, which indicates a movement of the climate to the next glacial period. Extrapolating these cycles to the future, one would expect a steady cooling, which in 15-20 thousand years must lead to an epoch of glaciation and expansion of cryolithozone comparable to cold epoch Early and Late Wurm. The short-term cycles, besides, with appreciably smaller amplitudes, penetrate only into the top permafrost layers. In high latitudes air temperature within the framework of the cycles, apparently, will not leave area of negative values, therefore the cryolithozone temperature will not be appreciably changed. In more southern regions, with temperature of permafrost close to 0°C, will be occurred degradation of permafrost or new formation of it (it indicates available factual data for Western Siberia).

The anthropogenic impact on the climate and on the cryolithozone (greenhouse-gas concentration in the atmosphere, effect of sulphate aerosols, ozone depletion etc.) is difficulty estimated, as still there remains a lot of uncertainties in the problem. The modern wave of warming falls into natural oscillatory cycle with period about 30 years (so-called Brukner's cycle), and already outlined a stop in growth of temperature.

Nevertheless the author together with A. V. Sashov spent modelling reaction cryolithozone at warming 1, 2, 3 and 4°C. The received results testify about slow reorganisation of permafrost temperature field, but can be interpreted differently, depending on real duration of period modern warming

Canadian High Arctic and Western Arctic permafrost observatories

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General Circulation Models predict increases in mean annual air temperature of several degrees in the Canadian permafrost region in response to a doubling of the concentration of atmospheric carbon dioxide. Recent studies indicate that trends in climate over the last century have not been uniform throughout northern North America. A general increase in air temperature has occurred in the western Arctic over the last century and evidence suggests that permafrost in Alaska is also warming (Osterkamp and Romanovsky, 1999). Studies in northern Quebec indicate that permafrost temperatures decreased into the early 1990s (Allard et al., 1995). The Geological Survey of Canada maintains an active network in the Mackenzie region of over 60 sites at which active layer, ground temperature, air and ground surface temperature are monitored. Evidence from these sites indicates that thaw depths and ground subsidence increased during the 1990s (Wolfe et al., 2000). Very little however is known about recent trends in permafrost temperatures in the High Arctic.

Ground temperatures to depths of 60 m have been measured since 1978 on a regular basis at five borehole sites at Canadian Forces Station Alert, Nunavut (82.5°N, 62.4°W) with the ongoing collaboration of the Department of National Defense. These boreholes represent the most northerly permafrost thermal monitoring sites in the world. The 22 year data set is one of the longest records of permafrost temperatures in Canada. Funding from the Federal Governments Climate Change Action Fund was awarded in 2000 to undertake an analysis incorporating the last decade of observations, to service site instrumentation and install data loggers. In summer 2000, ground temperature cables were connected to data loggers and air and ground surface temperature sensors were installed at three sites. Preliminary analysis indicates that air temperatures have generally increased since 1986 and this has been accompanied by an observed rise in shallow (upper 15 m) permafrost temperatures. Although snow cover is generally thin to absent in this area, it exhibits high spatial variability and this may be an important factor influencing the response of shallow permafrost temperatures to changes in air temperature. Data were also recovered in summer 2000 from loggers at two other High Arctic sites near Eureka and on Lougheed Island. The record of permafrost temperatures to depths of 60 m from 1991 to 1997 is now available for analysis.

Ecological-geophysical monitoring in the cryolithozone

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Firstly we discuss the peculiarities of permafrost as an open system in quasi-equilibrium state close to melting point of their principal component - ice coexisting with unfrozen liquid phases, hence easily is subjected to variations in response to small external effects. The temporal and spatial changes in frozen grounds are primarily conditioned by phase transformations ice-pore solution, which are much more complicated physical-chemical processes in comparison with ones known for free corresponding solutions. During these processes, all physical properties of frozen medium change but the most sensitive are electric, mechanical and thermal ones. To study, reliable control and forecast the situation in permafrost areas, in addition to traditional temperature borehole observations, requires the application of other geophysical techniques, primarily to use electrometric and some seismic-acoustic methods. Secondly, in the paper will be described and discussed the most prospect for these purposes electromagnetic (including radio-wave profiling, sounding, inter-borehole transmitting, logging etc.) and seismic-acoustic (especially using transverse waves) techniques and presented the examples of successful use of these methods to study and monitor the state of permafrost environment in several regions of Russia. The examples show the efficacy of geophysical methods in the field and the necessity of a wide application of them in the monitoring systems in cryolithozone. So, the reliable control and forecast of changes in nature-technogenic cryogeosystems can be realized by multi-channel ecologically-geophysical monitoring using statistical data processing to obtain the convolution of several geophysical and geological parameters and to find the most informative complex indices to characterize the changes under study. For instance, he local ecologically-geophysical monitoring systems is useful in some cases to unite with special engineering-geological and hydrogeological stationary observations.

Recent trends of climate, permafrost conditions and carbon balance in the East European tundra

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Both theoretical and empirical scientific approaches prove that the Global Climate Change is the most evident in high latitudes. However the local appearance of Global Change processes essentially varies in different Arctic regions. The goal of present survey is to estimate recent trends of permafrost conditions and ecosystems functioning in the East European tundra. The research sites are situated 20 km to the South from Vorkuta (Komi republic, Russia, 67°20'N, 63°44'E). Field measurements of CO_2 fluxes, thaw depth and soil moisture were initiated in 1996. Since September 1998 our permafrost studies followed CALM instructions, including temperature monitoring and surface soil moisture measurements by Vitel hydralogger. Specific regression equation (n=170, R^2=0.85, P<0.001) was developed to convert Vitel derived real dielectric constants to volumetric soil moisture.
Analysis of recent climate trends was done using the records of the nearest weather station (Vorkuta city). Both air temperature and sum of precipitation in snow-free season (June-September) had demonstrated a significant linear decrease in 1993-1999 (P=0.046, P<0.01, respectively). Hence the studied period is

characterised by gradual cooling and drying. The climate trends led to relevant changes in active layer depth and moisture. Thus late July thaw depth averaged 67 cm in 1996 and 31 cm in 1999, soil moisture 46% and 27%, respectively. Under these conditions dwarf shrub ecosystems increased carbon source activity in snow-free season from 21 gC m^{-2} $seas^{-1}$ in 1996 to 69 gC m^{-2} $seas^{-1}$ in 1999. The decrease of primary production due to cooling and rise of Gross respiration due to soil drying might be an explanations.

Session 2. Permafrost, Active Layer and Climate.

Oral Presentations

Holocene, subrecent and future permafrost dynamics in the East-European Russian Arctic

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A variety of techniques have been used to assess the sensitivity of permafrost to climate change in the Usa Basin, East-European Russian Arctic. The area is unique in continental Europe by having extensive lowland permafrost. Previous studies have shown that the permafrost is two-layered, the lower 'old' Pleistocene permafrost being separated from the upper 'new' Holocene permafrost by a layer of unfrozen ground. Only in the northern and eastern part of the Usa Basin have these two permafrost layers come together. Most of the permafrost in the Usa Basin is discontinuous and relatively 'warm', making it very sensitive to climatic change.
The timing of 'new' permafrost aggradation during the Holocene is traced in peat plateaux and palsas using detailed paleobotanical, gross-stratigraphical and radiocarbon analyses. Changes in permafrost conditions during the latter part of the 20th century are studied by analysing a time series of remote sensing images of thermokarst depressions covering the period of the 1960's till 1990's (a period of recent warming), by comparing mapping exercises for the region performed on data from a period of cooling in the 1950's and 1960's to a period of warming in recent decades (see above), and by analysing long-term monitoring data from boreholes. Future permafrost conditions in the area (over a period of 70-100 years) are derived from a transient permafrost model that utilises output from a General Circulation Model (Hadley Centre 750 ppm stabilisation run). Part of these analyses are at the time of abstract preparation in progress and final results will be presented during the conference.
This study is supported by a grant from the European Commission (Contract Nr. INTAS OPEN 97-10984).

Distribution of ions in frozen ground and possibility of palaeo-reconstruction at the base of chemical data

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Data of chemical analysis of permafrost deposits is a pool of important paleoenvironmental information. The problem of interpretation can be examined at the base of the mechanisms of transfer and transformation of mobile phases in the sediment. Particularly rules of the ion transfer in pore solution during ground freezing determine the distribution of ions. It makes in possible to indicate the direction of last freezing of ground. How the allocation of the ions varies, during ice segregation in the freezing ground?
This paper presents the results from the campaign using the system of chemical, microscopic, microcalorimetric and electromagnetic tests. For assessing the allocation of contaminants in the mineral layer between segregated ice lenses, chemical analysis was carried out using a technique of the small scale sampling. The contrast non-uniformity of contaminant allocation was found. The zones of high content of ions (HCI) arise at an advanced edge of growing ice lens during ice segregation. Such zones were described in the nature permafrost sediments. The HCI were studied with the environmental scanning microscopy under the temperature -12°C. The liquid inclusions of volume solution were found at the surface of ice crystals as the mobile drops in the HCI. The temperature relation of dielectric permeability was obtained for the sample of frozen loam with artificial HCI. There are the extremes on the appropriate curve which probably reflect the local low temperature phase transformation in HCI. The parameters of the phase transformation were measured with differential scanning microcalorimetry technique for the model samples. These data show a drop of temperature and bulk heat of phase transformation in accordance with increase of ion concentration in the HCI.

The ice segregation is accompanied by the formation of HCI in freezing loam. The HCI is a specific cryogenic type of non-uniformity of ion allocation in frozen grounds. A position of HCI relatively segregated ice lens can be used as an indicator of the direction of last ground freezing.

"Ice Complex" deposits of the Bykovsky Peninsula, Northern Siberia - a paleoenvironmental and paleoclimatic record for the last 60 ka

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Our studies focus on very ice-rich sequences with huge polygonal ice wedge systems, the so-called "Ice Complex", which was formed during the Late Pleistocene in wide areas of North Siberia. The Ice Complex is partially overlain by Holocene thermokarst and thermo-erosional deposits (alas and log). The study area, Bykovsky Peninsula, is located 50 km SE of the Lena Delta, belonging to the coastal lowlands of the Laptev Sea Region with continuous permafrost conditions. Genesis and age of the Ice Complex of Bykovsky Peninsula were matter of debate for decades. Therefore, we performed a large number (>60) of conventional and AMS ^{14}C datings in order to understand the growth of this peculiar cryolithogenetic formation and in order to reconstruct the development of permafrost during Late Quaternary in the Siberian Arctic. The results point to a continuous Ice Complex growth in the study area from 60 ka BP (at sea level) to the beginning of the Holocene (40 m above sea level).

Two main research interests dedicated to the Ice Complex were pursued: a sedimentological and pedological approach (including grain size analysis; mass specific magnetic susceptibility; C, N, S and carbonate contents; $\delta^{13}C$ of organic matter; analysis of bulk chemical composition as well as extractable Fe, Mn, Al contents) and a water isotope and hydrochemical approach (δD, $\delta^{18}O$, tritium, pH, conductivity, major ions). The results are firstly combined for this presentation.

Deposits of the studied Ice Complex sequence consist mainly of alternations of cryoturbated peaty soil horizons and grey ice-rich carbonated sandy silts. The cryostructure is dominated by sub-horizontal ice layers indicating stable surface conditions, which were interrupted by several accumulation events. A polygenetic origin of the Ice Complex can be postulated. The transport of clastic material from slopes by sheet flood, sheet erosion and by periodical river run-off from the Kharaulakh mountains were dominant, but sediments surely also contain eolian material.

Up to 5 m thick and 40 m high ice wedges of the Ice Complex can be considered as syngenetically grown with sedimentation, even though they are slightly younger than enclosed sediments. The variations of the ice wedge isotope record show changes in the climatic situation of the Bykovsky Peninsula "Ice Complex". For comparison, three younger generations of Holocene ice wedges were sampled such as ice wedges in alas deposits (1 _ 3 ka), about 1 ka old ice wedges in deposits of a shallow small stream (log), as well as modern ice wedges, which were identified by tritium analyses. Holocene ice wedges can clearly be distinguished from Pleistocene ice wedges by means of stable isotopes and by their appearance. The combination of both research topics clearly leads to three stages of development. The oldest part of the outcrop about 60-50 ka displays coldest winters and only weak paleosol formation. In an isotopically rather constant stage concerning winter temperature and sources of precipitation between 50 ka and 25 ka, variable environmental conditions were observed. The period between 25 and 12 ka is one of drier stable climatic conditions. The uppermost part of the outcrop was deposited during Pleistocene-Holocene transition (12-7 ka). Remains of trees as well as heaviest $\delta^{18}O$ values point to much warmer winters and Ice Complex formation ended. A shift in d-excess is interpreted as change of the main source of precipitation.

The resistance of permafrost landscapes to climate warming in the periphery of the permafrost zone of Central Siberia.

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Submeridional extended right bank of the Yenisei river (northern part of the Yenisei ridge and the western part of the Middle- Siberian High Plateau) presents a permafrost ecoton. The ecoton is situated in the taiga zone and consists of the permafrost and non-permafrost landscapes mosaic. From the South to the North the latter has been displaced by the landscapes on frozen rocks. In the Southern part of the ecotone (58° – 60° n. l.) within the range of low (up to 500 – 550 m) plateau and mountains the following landscapes are considered to be permafrost landscapes:

1. Rock streams of cold slopes, facing North and East;
2. Solifluction slopes and glacises of the same slopes;
3. Glacis-floodplains of small rivers.

The southern part of the ecotone is the area of an iseland permafrost development. In the middle part of ecotone (61° – 62° n. l.) rock streams are also spread on warm slopes, i.e. on the slopes of southern and western exposure. Vast areas are exposed to the impact of solifluction especially in connection with wide development of clay rocks. Permafrost occupies bottoms of all small river valleys and parts of the bottoms of major river valleys. The territory of thawed rocks here rapidly decreases from the South to the North and the total area of long-frozen and perennial frozen rocks grows accordingly. Thus in the middle part of ecotone the iseland permafrost is replaced by the discontinuous permafrost. In the northern part of the ecotone (61,5° – 63,5° n. l.) the following processes are typical for more than 90% of the total area: functioning of rock streams (kurum), solifluction, peatland build-up, accumulation of thin particle slope material and alluvial material (in a glacis-floodplains) with their subsequent freezing, as well as river sedimentation beyond taliks. The North part of the ecotone is the area where discontinuous permafrost gradually changes to continuous permafrost. Based on the comparison of frozen landscape spreading conditions in three different parts of the ecotone the following scale of their resistance to climate warming can be created:

1. The least resistant – permafrost landscapes of heat-sufficient slopes and glacises, and top surfaces, including rock streams;
2. More resistant - permafrost landscapes of heat-deficient slopes and glacises, and rock streams of warm slopes;
3. The most resistant – permafrost landscapes of heat-deficient slopes: rock streams and hanging peat bogs on buried rock streams.

The resistance of glacis-floodplains lowers with the increase of valley's range, i.e. valley's size growth. The further climate warming will cause shifting of the mentioned ecotone divisions to the north. The devolution of permafrost landscapes will occur in the succession corresponding to the ranks of their resistance. The use of the field research data and satellite images with the high resolution has allowed to map permafrost landscape ranks for the key areas of the ecotone. The program of thematic interpretation of raster images on the basis of ScanEx-NeRIS net in combination with MapInfo and ArcView was used.

The research is completed in frames of RFFI project _ 98-0564967.

Five years of active layer monitoring in NE Greenland: meteorological control on inter-annual variability

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Active layer monitoring was initiated in Greenland in 1996, when two CALM sites, called ZEROCALM1 and ZEROCALM2, were established in NE Greenland at the Zackenberg area (74°30'N) (Christiansen, 1999). Zackenberg Ecological Research Operations (ZERO), which was started in 1995 by the Danish Polar Center, provides meteorological monitoring data from the area. Collection of progressive thaw data in the two CALM sites has been carried out in co-operation with the ZERO monitoring programme on an annual basis. Miniature temperature dataloggers have been used to determine MAGST at distinct vegetation borders, controlled by snow cover duration in the ZEROCALM2 grid, which holds a seasonal snowpatch. These data have been used in combination with daily automatic digital photographing since 1998 (Christiansen, in press) in the same grid to establish snow cover duration, depth and distribution models for the ZEROCALM grids. This combination of data enables a detailed investigation of meteorological controls on active layer thawing during the period 1996 to 2000. In this period the annual meteorological conditions have varied significantly especially with respect to winter wind velocity and strength, amount of snow precipitation, timing of snowfall and first thaw. The effects of this meteorological interannual variability on active layer thawing are demonstrated, and the results used to evaluate the influence of interannual meteorological variations compared to long-term climate changes, as reconstructed at snowpatches in the Zackenberg area (Christiansen, 1998).

Monitoring of the active layer in the Western Part of the Russian Arctic

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There were established 5 sites on that the measurements of maximum thaw depth were performed by CALM program. Two of these sites had square 1x1 km and measurements on them were carried out in fixed on the locality points through each 100 m. The first site is situated on the Gydan peninsula by the Parisento lake in 70 km from the meteostation Tadibeijacha, and the measurements on it were performed 3 years (1992, 1993, 1995). The second site is situated on the Yamal peninsula in 1.5 km from polar station Marre-Sale, and observations were carried out here 6 years (1995-2000). Three sites had square 100 x 100 m. The third site is situated on the Yamal peninsula too, on the Bovanenkovo gas field. The fourth site was established in northern taiga 30 km from town Nadym and the same name meteostation. The measurements on it were performed 4 years (1997-2000). The fifth site is situated in southern tundra subzone in Pechora delta, the observations were carried out here 2 years (1999-2000).

Parisento and Marre-Sale sites are situated in typical tundra subzone on drained marine plains, composed by sandy deposits and covered by polygonal grass-dwarf shrub-lichen tundras. The frequency of these tundras on the sites was 39%. Subdominants on the Parisento site were weakly drained plains, composed from surface by peaty sands and covered by polygonal grass-dwarf shrub-lichen-moss tundras (19%), but on the Marre-Sale site - ravines with boggy bottoms (16%). The Nadym site was established on flat boggy surface of lacustrine-alluvial plain, composed by sandy deposits and covered by peat and forb-dwarf shrub-moss-lichen peatlands (69 %) in combinations with sedge-moss mires (31%).

A tendency to the rise of maximum active layer thickness has not appeared during the period of observations. The minimum values of thaw depth were noticed in 1992, 1997 and 1999, the maximum values - in 1995. In the different natural geosystems variations of thaw depth in years are 6-14%.

Methane flux studies in Siberia – Conclusion about the impact of climate change on permafrost soils and open questions.

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The main environmental changes during climate warming are expected for the permafrost regions. Soil carbon studies focussed on trace gas emissions of permafrost soils of different Siberian sites. The summer emission rates of methane ranged between 10 and 160 mg $CH_4 * d^{-1} * m^{-2}$ while the carbon dioxide fluxes reached maximum values of 4400 mg $CO_2 * d^{-1} * m^{-2}$ from typical wet polygon tundra sites (Taymyr Peninsula, Lena Delta, Kolyma Lowland). The main influencing parameters are the soil temperature and soil moisture regimes which are mainly depending on the soil organic carbon, the vegetation cover and the micro relief. Estimations for the summer period show that only 1 to 4 % of soil organic matter is released as methane. The methane production at near zero temperatures (-0,6°C to +1.2°C) in the anoxic horizons of wet Gelisols demonstrate a distinct methane production during the re-freezing time of the year. Nearly 25 % of the annual fluxes are captured in the upper frozen parts of Gelisols, which will be released during thawing periods. Methane oxidation – with maximum values of 55 mg $CH_4 * d^{-1} * m^{-2}$ in the polygon centres – is one major process controlling the methane release from the polygon tundra was investigated. Nearly 50-70 % of the methane produced in anoxic layers was oxidized by the methanotrophic bacteria. The results of methane fluxes are used to estimate the impact of environmental and climatic changes in permafrost affected soils.

Potential Long-term CO_2-Flux in an Arctic Tundra Environment

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Results from field experiments in an Arctic tundra environment at Samoilov Island have shown extreme high CO_2-fluxes for different soils in August 1999. Individual soils from 5 plots show significantly different patterns for CO_2-evolution rates for individual horizons. These pattern show high CO_2-evolution data for the top horizon (e.g., a loamy sandy Psammoturbel) and low values in deep layers and reverse orders (e.g., Glacic Aquiturbel). These data are extended to a long-term picture by using data from a field station near Tiksi (GAME-Siberia-project), which is located in an environment with comparable soil types. Soil properties show similar features like the profile in the loamy sandy Psammoturbel from Samoilov Island. The temperature data at Tiksi are recorded at 5 depths (0, 5, 10, 20, 30, and 48 cm) for hourly time intervals from September 1997 to August 1998. The data set is split into temperature intervals of -5 – 0, 0 – 5, 5 – 10, 10 – 15, and >15 centigrade, showing periods for potential microbial activity. The time periods of these intervals are used as bases for a CO_2-flux analysis for the individual horizons sampled for soil respiration measurements in August 1999. The results from this combined analysis show a high potential CO_2-flux per area. Data from soil physical analyses indicate several constraints for an appropriate CO_2-balance. Dominating features for microbial activity are water availability during the freezing process and the frozen state and the changing pore space. These figures are suggested as main controlling factors for possible CO_2-production as well as diffusion. Hence, the data show a considerable amount of potentially produced CO_2 but actual environmental constraints have to considered as effective limiting features for CO_2-evaluation.

Future study of the cryobiosphere

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Permafrost represents an isolated stable environment that has allowed the prolonged survival of ancient microbial lineage at subzero temperatures and can be characterized as a unique physical-chemical complex, which due the unfrozen water films, maintain life incomparably longer than any other known habitat. Up to 10^7 cells/g of viable micro-organisms are known to be present within permafrost that contain a total microbial biomass many times higher than that of the soil. Viable cells have isolated from the cores up to 400-m deep in Canadian Arctic and at the lowest ground temperatures (-25°C) in Antarctica. The age of cells corresponds to the longevity of the permanently frozen state of the soils. The oldest cells date back to 3 million years in north Siberia, and probably older in Antarctica. They are the only known organisms that have retained viability over geological time periods. Upon thawing the micro-organisms renew physiological activity and exposes ancient life to modern ecosystems. As a depository of ancient biogases, biominerals, pigments, lipids, enzymes, proteins, RNA and DNA fragments and cells permafrost is of interest from geological and biological points of view. It is now possible for the first time to use actual viable organisms for the purposes of reconstructing a past environment. In contrast to traditional methods using bioindicators, we can use not only of morphological indices of the fossil microflora, but functional indices as well. This highlights the permafrost as a natural biological database of Quaternary events and makes possible different paleoreconstructions of the frozen, i.e. most mobile, mantle of the Earth. For instance, its vertical dynamics. Unique to the permafrost environment is it possible to develop a microbiological time-scale using the progress in molecular biology. It should be possible, using phylogenetic trees developed from the same organisms (based on RNA sequences) from the modern layers to the several millions years old in the bore holes, to find out what are the differences among members of the same species as we go back in time. This would be a beginning of studies concerning the rate of evolution and biological clocks extending back the duration of the permanently frozen state in the soils and the age of biota. Its prototype is based on the reduction of the microbial community with the increasing permafrost age and the disappearance of some indicator microbial groups in the reference points of the Pleistocene sections. These studies may have wide implications because of the good preservation DNA in the frozen environment. In biology, established phenomena form the basis for various scientific fields in biotechnology, ecology, molecular paleontology and cryobiology. Of special interest is the interaction of knowledge to our understanding of the special and temporal limits of the deep cold biosphere. Among these new scientific directions, the most general is the fundamental question of the duration of life preservation. Because the length of time cannot be reproduced, permafrost is a unique observatory that makes possible the observation of the results of cryopreservation over geological time. From an exobiological point of view, the terrestrial permafrost, inhabited by cold adapted microbes and protecting the cells against unfavourable conditions can be considered as an extraterrestrial model. The cells and their metabolic end-products found in the Earth's permafrost provide a range of analogues that could be used in the search for possible ecosystems and potential inhabitants on extraterrestrial cryogenic bodies. If life should be found to have distribution in the Cosmos beyond the Earth and existed on other planets during the early stages of development, then its traces may consist of primitive cryogenic forms at the cell level within the extraterrestrial permafrost materials that should be soon returned from comets and Mars.

Non-climatic cyclic formation of thick syngenetic ice-wedges during Late Pleistocene: isotope-geochemical aspect.

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Cyclic structure of polygonal ice-wedges massifs is evident at the number of representative cross-sections in northern Russia: such as Duvanny Yar, the height above Kolyma River level is about 55 m, Seyaha in Yamal Peninsula, Ayon Island etc. The sequences mainly consist of sandy loam sediments with high content of allochthonous organic material, concentrated as 0,5-0,7 m lens. They contain large multistage syngenetic ice wedges. 3-4 m layer of sandy loam, which covered by 1-2-m layer of peaty sandy loam presents every cycle. Quasicyclic recurrence has been also marked in palynologic, geochemical and isotope data. The range of $\delta^{18}O$ in Duvanny Yar (dated by ^{14}C from 37 to 13 ka BP) is from –33,1 to –28,7‰ and δD from – 260,2 to –235‰, in Seyaha cross-section (dated by AMS immediately from ice-wedge ice from 22 to 11 ka BP) $\delta^{18}O$ ranges from –25 to –20‰ and δD from –189 to –153‰, i.e. climatic condition during their formation were almost stable. Changes of salinity, enzymatic activity and heavy metals content evidence that their changes caused by changes of sea or river level and associated with changes of facial environment, i.e. cyclic structure caused by sedimentation changes but not climatic. The study financed by RFBR (grants 99-05-65075 and 00-05-64736) and Program of Integration (grant 5.1-425).

Centrifuge modelling of ice wedge casting processes.

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Ice wedge casts are often critically important stratigraphic indicators of former permafrost and are often used to reconstruct palaeotemperatures. However, little observational evidence exists concerning mechanisms of ice wedge casting and factors influencing wedge cast geometry. Field observations of partially thawed ice-wedge casts suggest that the size and shape of the cast structure are influenced by the sedimentary characteristics of the host material, and its ice content. This paper presents preliminary results of physical modelling of the thawing of ice wedges penetrated frozen host sediments of differing granulometries and ice contents. Accurate modelling of soil behaviour during thaw requires that field scale stress conditions are replicated in the laboratory. This was achieved through scaled modelling under enhanced gravitational acceleration in a geotechnical centrifuge. Model ice wedges 150 mm high were thawed under a gravitational acceleration of 30 gravities, corresponding with prototypes 4.5 m deep. Following thaw the wedge casts were carefully excavated. Where the host material consisted of frozen sand, thawing produced a tunnel beneath a plug-like involution and above a sand-filled lower wedge-shaped section. In frozen ice-rich silt host sediments, the wedge casts were deformed. Contrasts in measured pore water pressures suggest that thaw consolidation led to enhanced pore water pressures in the latter case, resulting in thaw softening of the host sediments, and wedge cast deformation.

Permafrost in Pleistocene of Central Europe

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Essential features of Central European periglacial processes are impressively reflected in the sediments and frost marks of Central Germany outcropped in a lot of large lignite opencasts in the Leipzig and Lausitz area.

Six autonomous periglacial stages with appearances of permafrost are to be certainly distinguished: Three of the Early Pleistocene (pre-Elsterian) and since the beginning of the Elsterian glacial stage three multiple-phase ones.

- The oldest marks of cryoturbation in conjunction with intra-formational ice-wedge cast are developed in the oldest early Pleistocene gravel terrace of the area (? Brüggen cold stage).

- The first extended ice wedge polygons appear in the pre-Elsterian „Younger Early Pleistocene".
- During the Elsterian, Saalian and Weichselian glacial stages up to eight generations of ice wedge cast are known. In the anaglacial periods extended ice-wedge polygons were in existence.
- In the pre-Elsterian the frost cracks reached depths of at least 5 m (average 2 - 3 m), in the Elsterian stage 5 - 8 m (2 - 4 m), in the early Saalian stage 8 to 12 m (2 - 4 m) in the Weichselian stage 8 m (3 - 4 m).
The youngest frost cracks were observed in the Younger Dryas.
- From the diapiric upturnings of lignite (coal diapirism, "mollisol diapirs") the following minimum of thickness of permafrost can be deduced:

early Elsterian stage	18 m
early Saalian stage	30 m
high Saalian stage	40 m
Weichselian stage	50 m

Poster Presentations

Research of seasonal freezing at the centre of Russian plain

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Seasonal freezing is one of the major geographical characteristics which is determined by autumn of a ground, parameters of winter's air temperature and ground, prevailing directions of winds, features snow accumulation etc. On a number of attributes (depth, structure, the duration of existence seasonal frost) is made a classification of freezing types, that has practical meaning, as seasonal freezing and deformations, of the ground connected to it, render the large influence on engineering objects, in particular on frost jacking of the bases of cottages and structures. The size of cryogenic deformations depends on a number of factors influencing dynamics of seasonal frozen layer (granulometric structure of a ground, snow cover and its stratification, vegetation etc.). The distinctions in formation seasonal frozen layer are connected with conditions of penetration of waves of cold through surfaces distinguished by a landscape variety, and also snow accumulation conditions and snow melting. It was confirmed by a number of our researches, which were carried out on district, typical for Russian plain, (Kaluga area, 120 kms to a southwest from Moscow). The given researches have revealed dependence of seasonal freezing not only from the set forth above factors, but also from mezo- and microforms of a relief, from stratification of a snow cover and kinds of vegetation. By field researches were investigated also temperature and cryogenic textures of seasonal frozen breeds. The winter during which last researches were carried out was abnormally warm, it has rendered the certain influence on capacity seasonal frozen layer, its was revealed significant degradation during the winter period in comparison with its initial parameters. In the report the concrete geocryologic results, climatic and landscape researches are given, and also the influence of seasonal freezing on formation of landscapes, on ecological conditions is shown.

Turf hummocks on Ellesmere Island, Canada

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Turf hummocks are common features in the High Arctic environment. Hummocks occurring on slopes were examined in detail in the Tanquary and Lake Hazen areas on Ellesmere Island. The hummocks were 20–40 cm high and 40–60 cm in diameter. These hummocks are different from earth hummocks and peat hummocks since their entire development depends on the eolian materials captured by the vegetation (*Dryas integrifolia*) growing on the hummocks. Their internal morphology reveals multiple buried, organic-rich layers representing former hummock surfaces. The soil material occurring between these buried organic-rich layers also contains a high amount of well-decomposed organic matter, which is dispersed uniformly throughout the soil. Soil temperatures at the 2.5 and 5 cm depths were 3°–5°C higher under the tops of hummocks than under the adjoining interhummock troughs. Soil moisture was also higher in the hummock

than in the trough. The higher soil temperatures and moisture in these hummocks provide an excellent environment for plant growth and other biological activity in this High Arctic environment.

Vegetation in high-Andean wetlands affected by cryogenic processes (Laguna del Diamante, Mendoza, Argentina).

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Laguna del Diamante Reserve (elevation 3,600 - 2,600 m) is located in the paraglacial zone in the High-Central Andes, where intense cryogenic processes occur. In this area is possible to find plant species associated to these processes, such as: *Azorella monantha* and *Adesmia pinifolia* (shrub in cushion) in plains with ice at 50 cm deep in summer, and *Stipa chrysophylla* var. in subcircular settlement in soils with structure of selection and superficial dryness. In S-SE slopes with soil extrusion by acicular ice, in small terraces, dominate *Poa holciformis* and *Oreopolus glacialis*. In the wetland near the lake, cryogenic domes up to 50-60 cm high occur. In these domes it is possible to find a xericity gradient from the base to the top. In the lower part, the most wet, domain *Carex gayana* and *Eleocharis albibracteata*, among others; in the middle part *Wernerya pygmaea* and *Colobanthus quitensis* occur, and in the top dry area where eolic material is accumulated *Lecanophora heterophylla, Stipa sp.* and *Festuca desvauxii*, among others are present.

Conditions of gas hydrate existence in frozen soils

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Gas hydrate self-preservation phenomenon discovery as well as natural gas hydrates recovery from shallow permafrost made last years allow to declare that gas hydrate is one of main components of pore space in permafrost sediments as well as ice, unfrozen water and gases (Ershov et. al., 1991, Istomin, Yakushev 1992). Being formed in gas-saturated dispersed sediments gas hydrates, like ice, cement the sediments making them frozen-like. But differently from ice, conditions of gas hydrate formation and existence in pore space of different sediments are investigated very poorly.

New experimental data obtained from physical simulation and having large importance for clarifying of peculiarities of gas hydrate existence in permafrost sediments are discussed in this paper. Experimental simulation of methane hydrate formation and decomposition in different types of sediments confirmed the fact that hydrate stability conditions are distinct from the stability conditions for system "free gas – pure water" and are shifted to the field of lower temperatures and higher pressures (Chuvilin et al., 2000). This thermodynamic shift is dependent on initial composition and structure of sediment sample. The shift is growing with decreasing of the sediment grain size and reduction of initial water content. In the sediments studied the shift reached 0,8°C and 0,5 MPa in sands and 2,0°C and 1,3 MPa in clays.

It is proper to note, that in dispersed sediments only a part of pore water is converted to hydrate (Wright J.F. et. al.). Residual water (usually more energetically tied to mineral surface) is transformed to ice during further cooling. Appearance of ice in pore space stabilizes hydrate. As a result gas hydrate can exist in pore space of frozen sediments for a long time in meta-stable state at pressure considerably lower than equilibrium (self-preservation phenomenon).

The data obtained make possible the assumption that hydrate existence conditions in pore space of frozen sediments will be dependent on the structure of organic-mineral skeleton and on the ice phase presence and degree of its development in pore space.

Marginal Occurrence of Permafrost in a Low Altitude Talus Slope (Creux du Van, Jura Range, Switzerland): Snow and Vegetation Significance.

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Emmanuel Reynard & Christophe Lambiel, Institute of Geography, University of Lausanne, Switzerland.

The permanent frozen scree slope of Creux du Van (1180 - 1300 m a.s.l.) in the Jura range (north-western Switzerland, lat. N 46°55') occurs in accordance with a mean annual air temperature (MAAT) of + 5.5°C. The significance of both snow and vegetation covers to explain the thermal anomaly of the ground is suggested in this presentation.

Climatic data, near-surface ground temperature (12 loggers distributed along a slope transect), snow temperature and electrical measurements (DC resistivity soundings, mapping and 2D tomography) have been collected on the site since 1997. The sorted northern-oriented talus slope involved in the study is developed under a 150 m high limestone rockwall reducing significant solar radiation to only 4 months a year. In the lower half-slope, electrical resistivity indicates a 15 to 25 m thick frozen body while mean annual sub-surface temperature shows a strong negative anomaly (until 5°C) versus MAAT. A slight positive annual thermal deviation (1°C) is observed in the upper slope which is unfrozen.

As described in other similar sites, a downward ventilation system through the scree is observed when outside air is warmer than air contained in the porous underground. An inversion of the stream direction occurs when the atmosphere is colder than the ground. The magnitude of the air stream is directly function of the thermal difference between ground and outside air, both in winter and summer.

Condensation and/or evaporation processes caused by the circulating air, in addition to limited solar radiation, have been proposed as main factors for talus slope thermal anomaly, what seems not enough satisfactory. Two complementary hypotheses are proposed:

1) In winter, upward windy stream exists even under a continuous snowpack reducing snow insulation effect. Positive values (+1 to + 5°C) are registered at 10 cm depth in the gravel of the upper slope, while at the same time the ground temperature decreases towards –2° to –6°C in the frozen area indicating by this way the aspiration of air from or/and through the snowpack. The strong correlation found between both ground and snowcover temperature corroborates the hypothesis.
2) In summer, vegetation contributes to maintain cold ground conditions. The lower scree slope is covered by alpine vegetation groups (e.g. dwarf spruces) and peat mosses. While species are adapted to the fresh and humid conditions of the uppermost layer of the ground, vegetation avoids ground warming by both tree protection against solar radiation (-70 %) and moss thermal insulation (5°C/cm). Thus, with a high spatial variability, a sub-surface temperature varying between +0.1 and + 3.5°C is measured in the coldest part of the frozen area during all the summer season.

Past and present permafrost distribution as a key to understand sediment budgets in high mountain geosystems – concepts and preliminary results of the Turtmanntal-project (Valais, Switzerland)

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The study presented is related to the understanding of the characteristics of sediment movements through an high mountain geosystem in the Holocene time scale especially in areas with high concentrations of periglacial processes. These conditions are evident in the Turtmanntal, Valais, Switzerland, which is one of the catchments selected to investigate sediment budgets in high mountain environments. The Turtmanntal is a southern tributary of the Rhone valley in the central part of the Swiss Alps. It is characterised by a continental climate and a distinct periglacial belt between appr. 2300 and 3400 m in elevation. In previous studies it has been stated that rock glaciers in all stages of development are the most striking geomorphological features in the Turtmanntal, which is located in one of the centres of high rock glacier concentration in the Alps.

The presentation gives first an overview of previous conceptions and studies to reconstruct sediment budgets in the Holocene time scale. There are clear field evidences for Holocene climate change impacts on periglacial systems (e.g. fossil rock glaciers), however in only very few studies the system response (period of activity) could be dated and coupled with the specific driving forces of the system. Furthermore, sediment budget studies are often based on quantifying the sediment loss at the outlet of the system without an disaggregation into different processes, storage and types of coupling during the configurational development of the system. Based on these general statements a conceptual approach is presented which aims at a holistic geomorphic understanding of a high mountain geosystem with significant periglacial influences. Within this framework an overview of previous (van Tadenhove & Dikau 1990) and ongoing research will be presented which is related to

- regional permafrost distribution
- bioindication of permafrost
- rock glacier kinematics and
- morphometric structures of rock glaciers

in the study area. In a final statement the problems of reconstructing the Holocene activity of periglacial sediment movement processes in high mountain environments are discussed. It is suggested to strengthen in future research and a broader application of dating methodologies. They are one prerequisite to understand system development and change during long-term time scales.
This report was possible by contributions of the members of the Turtmanntal-project who present first results in extra contributions to this conference.

Present Mass Wasting Activity in Relation to Buried-ice Degradation (Corral del Veleta, Sierra Nevada, Spain)

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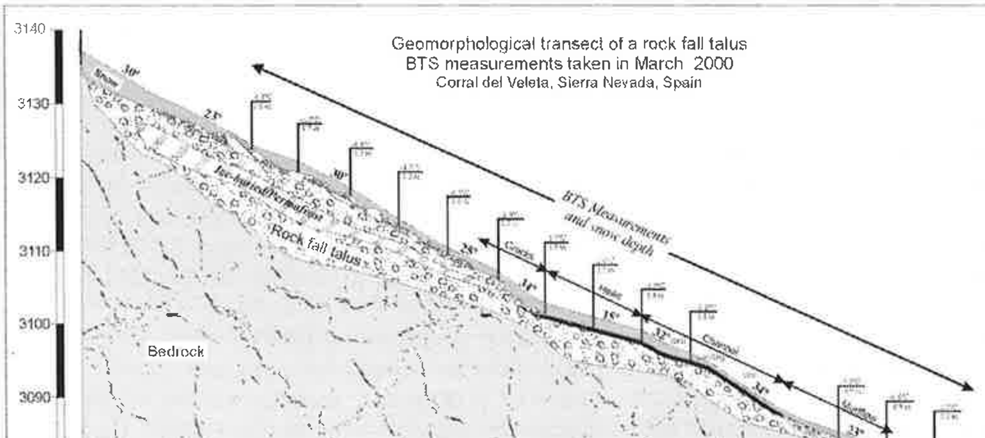
Corral del Veleta is a glacier cirque located in Sierra Nevada in the southern Iberian Peninsula (37º03'24" N, 3º22'05" W), on the north face of Pico del Veleta (3398m). The average altitude in the cirque is 3020m. Corral del Veleta is covered by a series of moranic ridges, the most recent of which dates from the Little Ice Age. Highly active large rockfall taluses that contain ice nuclei appear below the summit of Pico del Veleta and between the ridges and the cirque wall.
This paper analyses one of the most active sectors of the rockfall taluses and relates this activity to the evolution of the core ice mass. Observations in the spring and summer of 1999 revealed that the gravity cones in the central sector of Corral del Veleta were totally deformed by small gelifluidal lobes that had developed on the surface, and especially by major rotational-type mass movement, accompanied by the formation of many fissures with displacement and steps in the upper region, that developed into flow tongues or mudflows at the base. In the summer of this year, however, the fundamental process in effect in this sector was accompanied by the effect of highly efficient gelifluction that triggered the formation of many, small gelifluidal lobes. At the same time, the washout caused by snowmelt seemed to have provoked a gradual erasing of the features formed by the displacement from the previous year.



This paper manifests that the cold-climate morphogenetic processes taking place on a yearly basis in Corral del Veleta are very dynamic. The origin of these processes is related to deep, frozen masses that were detected by BTS measurements and observations of snow melting during recent years in the summer. In fact, the snow cover inside Corral del Veleta has almost completely disappeared since 1995. This would indicate that the thermal insulation provided by the snow was also lost and the subsequent and progressive degradation of the masses of ice along with the rapid compacting of the snow, triggered the development of frequent flows and mass movement.

Exceptionally cold microclimatic conditions in blocky scree slopes in Central Europe

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Particular periglacial microclimatic conditions are found in non-alpine regions in Central Europe. Although the MAAT is fairly above the freezing point in these sites (altitudes between 500 and 1000 m a.s.l.) prevailing temperatures around freezing point and permanent ground ice is found in several places. This phenomenon is typical for numerous isolated blocky scree slopes e.g. in the highlands of Germany, France and the Czech Republic. Ground ice and cold air outflow persisting during whole summer and the existence of alpine flora and fauna species characterise parts of these scree slopes.
Zoo-geographically important is the fact that numerous of these species have a disjunct distribution and possibly represent relicts from glacial periods comparable to boreo-alpine or arcto-alpine types. The specific ecological and landscape conditions characterise the habitats as terrestrial island biotops and "archives" of faunistic elements of former climate periods.
Mean temperatures near ground surface at the base of the scree slopes are between 0 and 3°C and hence remain several degrees below those of adjacent slopes without block cover and also significantly below mean air temperature (6-8°C). Whereas these periglacial climatic features are typical for the lower part of the scree slopes, a reverse effect with positive temperature anomalies is existent in the upper part.
In a long term investigation programme the extraordinary microclimate and fauna features are studied. Numerous measurements in several scree slope systems (temperature time series with high temporal resolution covering several years and measurements of air circulation), observations of ground ice in summer, and geophysical surveys (refraction seismic, geo-electric) verify the microclimatic effects and the existence of summer ice. The following microclimatic model is suggested based on these investigations. The open void system allows a circulation of air through the block accumulation. Basic driving force is the temperature gradient between the boundary layer atmosphere and the inner part of the scree slope. This effect allows air to circulate continuously and hence cause energy exchange between the atmosphere and the scree slope interior. During winter, this circulating air is heated within the blocky material, while the reverse effect is present in summer. An interruption of circulation occurs only during transitional periods with low temperature gradients in spring and autumn. A calculation of the energy budget of in- and out-flowing air indicates that the effectiveness of the heat exchange is hardly explainable only by sensible heat flux. Latent heat fluxes like condensation (sublimation) or evaporation are probably existent but knowledge about the physical processes within this system is still limited.
This model is to be checked in an intensive energy balance measurement programme in different scree slope systems in Central Europe.

Thermokarst formation and degradation as influenced by climatic dynamics

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Thermokarst topography forms as ice-rich permafrost thaws, either naturally or anthropogenically, and the ground surface subsides into the resulting voids. The important and dynamic processes involved in thermokarsting include thaw, ponding, surface and subsurface drainage, surface subsidence and related erosion. These processes are capable of rapid and extensive modification of the landscape and preventing or controlling anthropogenic thermokarsting is a major challenge for northern development. We will present an investigation of the physical factors that influence thermokarst pond formation and, in a warming climate, lead to their eventual drainage.

The active layer is that portion of the soil above permafrost that seasonally experiences thawing and freezing. The depth to which the active layer will thaw each summer season depends upon many local factors, especially site hydrology. Other seasonal factors that influence depth of thaw include temperature and levels of soil moisture due to variation in precipitation and evapotranspiration. The inter-annual variation of thaw depth at a site is quite large and consequently, utilising depth of thaw as an indicator of climatic change may be quite difficult as one would be looking for the response to a subtle change amidst large annual variations; however, the deeper permafrost acts an integrator of meteorologic variations and will respond to long term changes in climate. It must also be recognized that changing the surface configuration and condition (i.e. disturbance such as wildfires, construction or mining) will also impact deeper ground temperatures and thus may mask changes in temperature due to changing climate.

In response to some imposed disturbance, such as a tundra fire or perhaps climatic warming, massive ice permafrost may differentially thaw, creating irregular surface topography. Depressions forming on the surface soon form ponds, accelerating subsurface thaw through lower albedo and additional heat advected into the pond through runoff. In time a talik (a layer of unfrozen soil above the permafrost and below the seasonally frozen soil) may form below such ponds as the depth of water becomes greater than the amount that can refreeze during the winter. If the talik grows to a size that completely penetrates the underlying soil or connects to a subsurface layer that allows continued drainage, the pond may then began to drain. Several thermokarst ponds on the Seward Peninsula, Western Alaska and near Fairbanks, Alaska are examined to determine if recent changes in climate have impacted the dynamics of their development and degradation.

Ice wedges as a palaeoclimatic indicator in Adventdalen, Svalbard.

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The aim of this presentation is to inform on an ongoing project on timing of Holocene climatic cooling in Svalbard (78 N), providing conditions for permafrost establishment and relate this to sea level regression. The Svalbard archipelago is interesting for this study because it is situated in the High Arctic in the region of late Holocene continuous permafrost. Adventdalen is a valley partly filled with sediments consisting of outwash deposits, in some places overlain by peat and loess. The investigation started in July 2000 and is planned to last for one year.

The idea is to investigate ice wedges and this way obtains information relating to a palaeoclimatic reconstruction of the environment in which they have developed. Three study areas with large-scale polygons in different parts of Adventdalen valley have been selected. In two areas 2-3 ice wedges has been excavated and ice samples collected for isotopic analysis with a spacing of 2,5 cm. In the period of investigation samples of precipitation, snowmelt water and soil water is collected for correction of the isotope signal from the ice.

Based in these data a construction of a palaeothermometer for the ice wedges is intended and palaeotemperatures could then be estimated. These estimates will be used in an interpretation of the climate in the study area and to give an estimate of when permafrost conditions where established in Adventdalen. By studying the sediments in which the ice wedges are developed, including ^{14}C-dates of organic material from the sediment, an estimate of when this area where lifted above sea level ice wedges allowed to start growing can be given.

The three areas are monitored during the year of investigation to see if and when there is movement in the polygons and under what meteorological conditions these movements occur. Observation of the ice wedges in the study areas suggests that they are epigenetic ice wedges because of the thickness (up to 3.80 meters). By combining these observations with the results from the oxygen isotopic analysis and the information from the sediments an interpretation of the palaeo environment in the Adventdalen area is presented.

Dynamics of high mountains talus slopes in the tatra mountains of poland lichenometric study

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The climatic conditions in the High Tatra Mountains of Poland are such that mass wasting typical for arctic-alpine environments exist above the upper timberline i.e. 1550 m a.s.l. According to A. Jahn, one can distinguish mild periglacial realm characterised by geomorphic processes related to so called semi-nival climatic belt (mean annual temperatures: -2 to 0_ C). The climate of the Tatra Mountains is a transition between maritime and continental influences in Europe, and is mainly controlled by maritime polar air masses (65%), while continental polar air masses occur during 20% of the year. The passage of cold fronts, with high intensity rainfalls dominate in summer. High intensity rainfalls associated with summer thunderstorms are triggering substantial debris flows on granodiorite talus slopes. Rockfalls and rockslides occur mainly in spring, when snow-melt is associated with freeze-thaw cycles on alpine cliffs and rocky slopes.

Using aerial photography and detailed geomorphological mapping approximate distribution of diagnostic slope landforms are determined. Lichenometric growth data are available enabling the dating of debris flow deposits as well as rockfall/rockslide and dirty avalanche deposits. Lichenometric dating indicates that much of the debris-flow activity is very recent (last ca. 20 years), but most activity appears to post-date the final phase of the Little Ice Age, i.e. 1826-1835, 1843-1852 and 1860-1870 AD. Climatic regime at that periods was manifested by vast mass movements of talus slopes in altitudinal belt between 1500 and 2000 m a.s.l. Since 1750 AD statistically documented periods of increased rockfall/rockslide activity (R) and debris-flow activity (D) are evident within the age ranges of deposits that can be dated by lichenometry: 1810-1910 AD (R), 1860-1930 AD (D) and last ca. 20 years (D). Dirty snow avalanche activity is evidenced since 1940 up to present. The reason for the increased flow activity after 1860 AD appear to be related to the supply of regolith during the earlier period (19the century) and suitable meteorological conditions. Human impact on geomorphic slope process activity does not exist in the study area.

Cryolithozone Dynamics in the Western Section of Subarctic During Recent Holocene

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Cryolithozone of the North represents a complex of environmental conditions and has the prints of cooling and warming of past epochs.. We distinguish three main groups of landscapes where the cryolithozone evolution in Late Holocene passed differently. The permafrost in well drained and swell and swales relief areas with non-sorted circles of tundra, where the insulating properties of snow and vegetation are minimum quantity and more dynamic reacts quickly climatic changes. Here the cryolithozone carries the traces of climatic conditions only on the previous epoch. Permafrost in the undulatory relief areas with moss and underb rush tundra, where insulating properties of thickness of snow cover and mossy cover is important, react more slowly the climatic changes. Here the cryolithozone preserved the features of previous climatic epochs. Cryolithozone depressions of surface watershed with flat-topped polygonal peatlands are the most conservative because of the high insulating properties of snow cover and mossy cover, it preserved the features of "Small Climatic optimum". Investigations on the European North of Russia showed that intensity and duration of climatic changes in past epochs stimulated the cryolithozone evolution and determined in part particularities of composition, areal extent, thickness and thermal regime of permafrost. It is that two-layered permafrost is developed on the European North of Russia as well as in the Western Siberia. Upper layer is formed of the frozen grounds with the thickness of 50-150 m separated from the lower frozen layer (with the thickness of 100-150 m) by the unfrozen grounds with the thickness of the order of 100 m. The lower horizon of permafrost is the most ancient, which is formed in Late Pleistocene. In Holocene Optimum the deep thawing of the ancient permafrost took place. The unfrozen horizon in contemporary rock sequence is preserved just from that time. On the second half of Holocene a new cooling has occurred that was the reason of the long-term freezing of ground with the less depth than in Pleistocene. As a result the upper permafrost layer was formed in which all the changes (connected with many oscillations of the climate of the last 1000-years) were realized. These oscillation are confirmed by the following characteristics of frozen grounds: nonconformity of the thickness to contemporaneous landscape climatic conditions, the distribution of temperature up to 20-30 m characterized by anomalistic high temperature gradients wide development of closed taliks, accompanied by thermokarst. Analysis of frost-landscape conditions is made for three stages: maximum warming of "Small Climatic Optimum" between VII-XIII centuries, "Small Glacial Period" between XIV-XIX centuries, and warming of Arctic since 1920-40's of our age. The main approaches of reconstruction of the fossil permafrost conditions are the following: the use of well known methods in geocryology for determining the calculated permafrost thickness versus permafrost thickness observed in present conditions; the calculation of mean annual temperature of ground and air of epochs considered; the calculation of time of taliks formation; the estimation of insulating properties of snow and vegetation; cryogenic phenomenon. The most spreading landscapes in the Bolshezemelskaya and Malozemelskaya Tundra and their perennially frozen grounds are the objects of researches. Such landscapes are high drainage watershed with swells and swales occupied with non sorted circles tundra, slightly drained rolling topography, watershed surfaces with moss and underbrush tundras and of last depressions on the watershed surfaces with widely developed flat-topped polygonal peatland and peat mineral polygonal tundras.

Evidence of Climatic and Physical Properties in Permafrost Affected Soils

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Abiotic factors control soil processes as well as soil microbiological properties. Temperature is one of the most evident stresses in cold regions, but varies especially in the ground locally with specific conditions. These influences are modified by processes occurring in the boundary layer of snow, vegetation and accumulated organic material. As such the mean annual air temperature differs by several degrees from the mean annual soil temperature. Similarly soil microclimates depend on soil composition, structure and water content, e.g. snow can react as an insulator for the ground and this is the principal reason why the mean annual ground temperature can be many degrees warmer than the mean annual air temperature. During summer free water on and in the ground represented by melted water cannot drain due to the underlying permafrost. It poses special constraints for micro-organisms, as the thermal conductivity of the soil varies with moisture content.

All these parameters define not only the actual living space of the soil microbes, but also the annual soil properties. A rapid drop of the soil winter temperature is necessary to cause cracking, and this is impeded by an insulation snow cover. Soil water content at the time of freeze back influences not only the expansion forces in the ground, but also the amount of meltwater in the following summer. When coarse-grained soils thaw the water can drain relatively freely. The absence of excess ice minimises pore water pressures and there will be little loss of strength and little soil movement. Meltwater has a bigger influence on frost susceptible soils. Due to frost heave and ice segregation and with unfrozen water several degrees below 0°C, thawing can involve a loss of strength and the process of consolidation, with influence on the pore system.

With data, collected during the Lena-Delta expeditions in 1998 and 1999 and with data maintained by the GAME project, we have knowledge of the snow cover in spring, the annual soil thermal regime and the hydrologic regime in the active layer. With the help of these information we can predict soil properties and therefor the habitat of soil microbes. Artificial freezing tests are a help to predict changes of soil properties induced by cyclic freezing and thawing.

Active layer of cryolithozone in the north-east of Europe: zone and regional aspects of forcing

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There is a generally accepted point of view for the North-East of Europe that the active layer is formed under the influence of zone factors of natural conditions. As a whole the thickness of the seasonally-thawed layer (STL) changes from the north to the south from 0.3 up to 3.0 m; the thickness of the seasonally frozen layer (SFL) from the south tj the north is from 0.5 up to 2.5 m. However more than the twenty-years studies of the

author in this region allow tj contest conventional conception about importance and zone variability of the active layer's basic characteristics.
The variability of the STL is formed mainly as a result of the influence of natural conditions zone factors: the climate, the vegetation/ However within the limits of geobotanic zonality it is impossible to leave out of account the zonality of the moss covers developed everywhere in the region and having considerable thickness. The moss influence explain reasons for lack of the conventional zone variability of STL characteristics (the background values of loam type change from 0.4-0.8 m in the subzones of massive-island and continuous permafrost and 0.9-1.2 m – in the discontinuous permafrost; of peat type – even some increases to the north).
The variability of the SFL characteristics is mainly determined by influence of regional factors of natural conditions (cryogenic forms of mesotopography and so on). As a result it was not noted the zone variability neither of temperatures on the SFL base nor of it depth. The depth changes from 0.2-0.9 m in loam and peat and 0.8-1.5 m in sand.

Stratified screes in the Maritime Alps (Italy): an attempt to determine the role of permafrost in their formation

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Some outcrops of inactive stratified screes can be found in the Gesso, Vermenagna and Stura di Demonte Valleys, in the Maritime Alps. The different deposits have in common some characteristics: they all formed from Mesozoic limestone and marls at the toe of steep slopes and are presenting alternating open-work and matrix rich layers. In spite of this they display different features. In particular for what concerns their degree of hardening, the absolute dimension of clasts and the clasts versus matrix ratio. In general it cannot be recognised a true cyclical nature of the layers, as each grain supported layer displays slight macroscopic characteristics that differentiate it from the other open-work layers, an the same can be stated for matrix supported layers. Some of these stratified screes were studied and a detailed description of their sedimentological characteristics was performed (Pappalardo, 1999; Pappalardo and Spagnolo, 1999). Interpretation of their genesis accounts for the numerous theories suggested for their origin (Van Steijn et al., 1995). The occurrence of some processes was recognised, such as congelifluction, grain flow and rill erosion. In order to detail their conditions of formation (Harris and Prick, 2000) and in particular to highlight the role of permafrost in their evolution, microscopic analysis of the single layers of some screes is being performed (Van Viliet-Lanoë, 1995). Preliminary results are available for a few case studies. They are encouraging both for what concerns the recognition of primary depositional processes as well as for secondary, warm climate ones, responsible for the morphological evolution of the slope.

Talik zones dynamics in Holocene and forming of near-surface gas hydrate

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The field studies were carried out in the central part of Yamal Peninsula (71°N). During study of river-channel taliks in valleys of small rivers and creeks the leases fractionally or completely bridged over by short-term permafrost or "shirt tails" of frozen soils detected. At exposure of such leases a gas emission practically was always marked.
From one of the wells at an exposure of a frozen ground under river-channel talik the high flow of CH_4 - more than 9000ml/h was is fixed. The period of gas discharge amounted to more than 2 days.
The intensity of a gas emission from a frozen ground under talik base is great and can not be explained by conservation of methane in a gas phase.
The most logical explanation of intensive issue CH_4 is following. In warm periods during the Holocene in talik zones originated production and build-up of methane. As a result of freezing of methane saturated soils in conditions of enclosed system the lenses of near-surface gas hydrate could be formed.
On data of simulation models, the maximal depth of talik zones reshaped in zones heightened of snow accumulation in an optimum of the Holocene, is valued in 4-5,5 m.

The lenticles near-surface gas hydrate can be laid out in a section on different depth of a below modern base surface of talik. However maximal reserves of gas hydrate should be referred to depths in a spacing from 4-5,5 m up to 3 m depending on conditions in a zone heightened of snow accumulation.

The permafrost conditions along Pechora Sea Coast (Varandey Peninsula, European North of Russia)

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The study area is characterized by distribution of continuous anchored Permafrost with temperatures -1.0°C in the places with high snow depth to -3.5°C on the open peat plateaux. The Permafrost distribution is breaked by the supercooled sediments with marine type of salinity and brine lenses (mineralization up to 85 g/l). The thickness of subzero temperature zone is about 150 m. The upper 30-50 m are represented by frozen soils with methane, and below - supercooled saline sediments. The depth of seasonally thawing varies from 0.4 m in peat to 0.9 m in loams and 2.0 m in drained sands. Because of the humid summer conditions the significant emission of greenhouse gases from the surface of active layer to the atmosphere was found. During last 20 years the mean annual soil temperatures in the boreholes increased on 0.5-1.0°C, but the depths of seasonally thawing were not changed. In saline sediments the permafrost table lie on 20-25% deeper than the depth of zero isotherm penetration. From the surface the distribution of continuous Permafrost is broken by taliks of different origin. Most of them are caused by supercooled sediments. The temperature of these sediments reaches down to -4.0°C, but even in this case their physical and physicomechanical properties are similar to unfrozen sediments.

Radiative geogases within permafrost

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In the last decades an attention was focused on the radiative gases emission from high-latitude ecosystems. However much more carbon as CH_4 (up to 40 ml/kg) and CO_2 (up to 20 ml/kg) has been preserved in the permafrost below seasonal thawed layer. According these data, permafrost, which depth averages several hundred meters, is the significant reservoir and potential source of greenhouse gases. These gases, mainly of biological origin, that for CH_4 has been confirmed by carbon isotopic composition and presence of methanogenic bacteria. Though the biogenic origin, these ancient gases are virtually the sort of geogases (the review of geogas theory was published by G. Etiope and R. Klusman) peculiar to permafrost sediments only, since they have been excluded during frozen state from biogeochemical cycle for a long time from thousands to millions years. CO_2 is presented in permafrost layers everywhere, whereas CH_4 occurs in discrete layers that is determined by the age and genesis of the deposits and by the type of cryogenesis. In a generalized geological cross-section CH_4-containing layers would be sandwiched between layers free of CH_4 (Pleistocene and Holocene Icy Complexes, aeolian, riverbed and glacial deposits). The fact that for at least several hundreds of thousands years methane has not diffused from the CH_4-rich layers into adjacent layers which are devoid of methane implies that there is negligible diffusion of CH_4 in the permafrost under both present and past conditions, i.e. from the time of freezing it located *in situ*. Upon thawing, the CH_4 is released abruptly, in a phase change with associated enthalpy These facts suggest that CH_4 held within the sediments in a clathrate form in the upper layers of frozen sediments, independently from the of deep high-pressure CH_4-hydrates zones as a result of interpore pressure and subzero temperature of CH_4 contained sediments. Unlike the deep high-pressure CH_4-hydrates, this reservoir of bound CH_4 could be easy released by warming in the polar regions and anew involved in present-day turnover in the time of sediments thawing, in particular, during thermo-abrasion of marine and riverbanks and summer defrosting of outcrops. We have calculated the amount of CH_4, which could be released after thawing and abrasion of late Pliocene outcrops (if sediments contain 30 mlCH_4/kg and outcrop sizes: length -1 km, height - 50 m and thawing thickness -1 m). This value is close to 1 ton (the mean thermo-abrasion rate of Polar Ocean coast is even 3 m/year). It was also shown, that emission of old CH_4 from frozen late Pliocene geological sections on the north of Eurasia during their thawing makes up 40 mgC(CH_4)/m^2day. This is comparable with those from modern

Arctic tundra landscapes. Apparently in the future cryolithosphere will be more unstable in comparison with another Earth regions. Thermokarst processes, predominant in Holocene optimum and going on locally at present, can be rate as a prediction model of Global Warming consequence. Subsurface frozen layers are the reservoir of greenhouse gases, which can be released not only at Global Warming but also at local rise in temperature in Arctic. To evaluate the amount of geogases, which could be released to the atmosphere, we need to determine its content in all genetic types of permafrost. Important to note that permafrost sediments contains a tremendous mass of organic matter (1 m^2 section of the 100-m thick permafrost may contain hundreds kg) as well as viable methanogens which become activate and produce additional portion of CH_4 in the event of permafrost thawing. And what is more, experiments with radioactively labelled $H^{14}CO_3^-$ shown, that permafrost are not in completely biogeochemical rest. CH_4-generation (incorporation of ^{14}C in CH_4) takes place also at temperatures down to -16.5°C.

The migration of ions in frozen natural dispersed systems

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At present widely discussed are the issues of usage of permafrost as potential media for radioactive wastes burial. Chemical pollution of soils in cold regions and burial of liquid chemical wastes in permafrost require the investigation of chemical pollutant behaviour in permafrost under the impact of natural and anthropogenic factors.

The transfer of ions in frozen natural dispersed systems (soils, grounds) is determined by the diffusion of ions on molecular level, by the convection transfer of them with the moisture flux in non-freezing interlayers and by the divergence of the moisture flux due to the nonlinear distribution of driving forces of the transfer and water-ice phase transitions.

The proposed mathematical models are phenomenological and the transfer coefficients involved in this models should be determined experimentally. The mobility of chemical elements in frozen dispersed systems is basically determined by the effective diffusion coefficient, the distribution coefficient, the filtration coefficient of frozen ground, and the amount of nonfreezing water in the system.

Methods are proposed for investigation of transfer characteristic of mineral water soluble compounds in frozen grounds. The regularities of basic transfer characteristics of radionuclides in frozen grounds (peat, clays) have been revealed. It was shown that the presence of electrolytes affect the diffusion and convection mobilities of radionuclides in frozen ground .

On the condition that, in the a layer snow, there be a surface covered with connected films of nonfreezing water, the concentration gradient of water soluble compounds and the temperature gradient induce convection and diffusion fluxes of water – soluble compounds from boundary layers of soil to snow and in opposite direction. Real fluxes of moisture and water-soluble compounds will also depend on the hydrodynamics conductivity coefficient of nonfreezing water interlayers that is determined by specific surface area of snow, the thickness of these interlayers, and the extent of their connectivity. The migration of Cs^{137} from peat to snow experimentally have been investigated and conditions defining this process have been revealed.

Peculiarities of ground heaving in Southern Zabaikalie

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Southern Zabaikalie is characterized by continental climate, great solar radiation , middle mountain relief and specific hydrogeological regime. Annual amount of precipitation is 200-300 mm. 80-90 % of precipitation occur during warm period. It is necessary to stress that considerable changeability of precipitation takes place from year to year. Relief of this territory greatly influences distribution of warmth and humidity. Frozen grounds are represented by deep seasonally thawed and seasonally frozen heaving grounds and as well as perennially permafrost grounds of mainly an island distribution. Grounds of active layer represented by sedimentary quaternary deposits with prevalence of loam, sandy loam and sands are located in bottoms of hollows, hollows, valleys on supra-bottom terraces and middle mountain plains at height of 500-1000 m above sea level. They are characterized by parallel occurrence to day surface and

deposited layer by layer. Sudden change of differences of grounds occurs in massif of deposits at short distances. Depth of seasonal freezing and thawing of grounds reaches 3.5-4.5 m and depends on their dispersivity, humidity and availability of water-bearing horizon.
Ground and supra-permafrost waters circulate in loose quaternary deposits and they are referred to negative forms of relief. Vadose waters in form of lenses and strips in permeable grounds are observed on mountain slopes. Cryogenic pressure occurs in waters of active layer in conditions of deep seasonal freezing. But hydrogeological pressure takes place in these waters on mountain slopes. Frozen heaving occurs both in dispersed and coarse-grained dispersed grounds. Heave of dispersed grounds (fine, dusty and dusty-clayey sands) causes increase of volume of freezing moisture and ice accumulation at freezing. It appears due humidity migration. Greatest heaving deformations are observed when dusty and water saturated sandy and loamy grounds are frozen in open system. These grounds have small freezing speeds, close location of level of ground waters, additional moisture entering slopes (mechanism of heaving migration). Maximal rise of day surface of grounds at heaving reaches 40 cm and it takes place on slopes of northern exposure. Coarse dispersed grounds (middle gravel sands) are subjected to heaving in conditions of closed system when waters are pressed (injection mechanism of heaving). Processes of frozen heaving often appear in bottoms of valleys, hollows, on river terraces and deluvial trains near boggy slopes with close level of underground waters. Degree of ground heaving increases from slopes of southern exposure to northern slopes.

Mechanism of sporadic permafrost preservation in the blocky slope at Mt. Nishi-Nupukaushinupuri, central Hokkaido, Japan

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Sporadic permafrost was found in the blocky slope far below the timberline at the southwestern slope of Mt. Nishi-nupukaushinupuri(1254m a.s.l.), central Hokkaido. Permafrost exists only at the foot of blocky slope surrounded by mixed forest. In winter, snow is removed by the strong wind from the middle part of blocky slope, while a snow accumulation exceeds 1.5m thick in adjacent area. A year-round ground temperature monitoring at the foot, middle and upper part of blocky slope, together with BTS measurements revealed a permanent existence of air circulation through the voids between coarser blocks. The ground temperature at the foot of the slope dropped from -4.2 to -7.9ºC before the beginning of snowmelt, while that of the upper slope was between -10.0 to -2.6ºC during the winter. At middle parts of the slope, the ground temperature fluctuated following to the changes of air temperature. BTS values were -2.3º to -11.7º in lower part of slope, and 0ºC at top of the slope. This result supports a theory that the air circulation is an important process for preservation of sporadic permafrost in the blocky slope (von Wakonigg, 1996). Cold air penetrating into the blocky field through a thin snow cover in the middle slope flows down towards the foot of the slope through the voids between blocks, while the warmer air moves upward. The existence of a funnel with air temperature of +2ºC during the winter at top of the blocky slope verifies this mechanism.

Late Glacial deglaciation and subsequent expansion of periglacial processes in the Mulhacen Cirque (Sierra Nevada, Southern Spain)

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Semiarid Mediterranean mountains are in general very sensitive to global climate warming in terms of deglaciation and permafrost degradation. In the context of the PACE-Project (Permafrost and Climate in Europe) the aim of the undertaken research is to gain a better understanding of late Pleistocene and Holocene glacial and periglacial history of Sierra Nevada, the southernmost European range with subrecent glacial features and recent permafrost. Furthermore, this paper is focused on the complex relationship between the deglaciation and the subsequent expansion of periglacial processes in the Mulhacen cirque. Detailed morphological mapping on a scale of 1:5000 and morphometrical analysis of glacial and periglacial deposits along several cross sections were carried out in the Mulhacen cirque situated at an altitude between 2863 m (lowest area of the cirque bottom) and 3478 m a.s.l. (highest point of the headwall). High-resolution geophysical surveys were undertaken close to the Mùlhacen peak. According to the obtained geomorphological data up to five principal moraine complexes at different altitudes (2863 - 2940 m a.s.l.) were identified. Based on morphological criteria, E.L.A. calculations and correlation with the glacial records or the Veleta cirque (Gómez Ortiz et al., 1996) we propose a late glacial age for the different moraine stands. The small differences in altitude and geographical distribution of the end moraine arches indicate the high sensibility of the glacier to past climate changes. However, the Mulhacen cirque and the Valdecasillas valley offer one of the most complex moraine sequences in southern Iberian Peninsula. With regard to the periglacial dynamics rockfalls, debris flows, rock glaciers, protalus rampart, block fields, stone rivers and gelifluction lobes were identified and mapped. In the southwestern sector of the cirque the youngest moraine is nearly completely buried by younger rock glaciers and rock streams indicating the high efficiency of the periglacial processes during the Holocene. These processes are mostly controlled by the Holocene climatic conditions (cycles of freezing and thawing), topographical configuration and fragility of the outcropping schist related also to the postglacial release of the cirque headwall Resistivity tomography data obtained from the southern slope of the Mulhacen peak may evidence discontinues permafrost.

Peculiarities of cryogenic eluvium in the mountains of Altai (South Siberia)

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One of the most important process of cryolithogenesis is the cryogenic weathering. Its mechanism is quite well described by the large number of data obtained the last time. However the geography of cryogenic weathering distribution is not fairly determined. In particular, it is not clear whether this process occurs only in the northern part of the cryolithozone or it takes over the lager areas. We would like to consider the peculiarities, the composite and texture of one of south region of permafrost grounds distribution, the south-west part of the mountains Altai. The permafrost reaches 140-150m here, its temperature oscillates from -0,5 to -4 C, the taliks caused by lithology and relief frequently occur. The depth of the active layer changes from 0,5 to 3 m; upper front of the permafrost rocks is at the depth of 0,5 to 7 m; un-anchored permafrost is observed in the most cases. The samples were obtained from the active layer grounds of moraine , lacustrine and slop deposits at depth of 0,3 to 1,5 meters along the profile of the absolute height from 490 to 2400 m. The granulometric composition of deposits shows an increased content of silt fraction particles compared with underlying deposits, while the higher the site, the more clear this increase occurs. Mineralogical analysis of fraction shows the noticeable changes of ratios of the main rock- forming minerals - the quartz content grows in the coarse-silt fraction, the content of feldspars increases in the fine-silt sandy one. These change have a cryogenic cause, the height values of CCC confirm this statement - they are within 1,5-2,5 at heights from 1900 to 2400 m. The data of electronic microscope illustrate the transformation process of disperse material very well - the particles of sandy and coarse-silt fraction have a large number of cracks , cleavages and other defects that indicate directly on the active role of cryogenesis in dispensation of the particles. The carried out investigations increase the geography of cryogenic weathering and show its broad spreading in the mountains of south region of cryolithozone.

Peculiarities of permafrost landscapes in the middle taiga subzone. Podkamennaya Tunguska lower reaches area case study.

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The case study area is situated in lower reaches of the Tunguska river in Central Siberia. Permafrost landscapes here are widely developed on clay-aleurite glacial deposits. Between 61° N.L. and 62° N.L. swampy thin meagre taiga on peaty soils spreads rapidly on the whole territory of top surfaces and slopes. Many trees are tilted, soils are over-moist, there is water in small pit-fractures of the mossy cover. The top surface of the permafrost occurs not deeper than 1 meter. Dwarf birch forests cover usually bottoms of streams and small rivers. Permafrost occurs here on 0.5-2.5 m depth. Landscapes on the long-frozen rocks can be found on clay-aleurite deposits. Permafrost is absent under upright high-quality taiga forests which grow on slope and top surfaces with solid rock composition (limestone, sandstone, traps). This indicates the priority role of the lithological factor – presence of unconsolidated clay-aleurite deposits - in development of permafrost landscapes in the area. Heat –deficient slopes (those facing north and East) with traprock exposures are also considered as permafrost landscapes. This is due to:

1. The existence of very hard rocks,
2. Wet conditions,
3. Processes supporting rock stream (kurum) desorption.

In some places peat bogs develop and freeze on the top of kurum on the Northern slopes. Frozen moss slopes with scattered larch trees are known as "hanging" bogs. Thus mono- and multi factor permafrost landscapes can be distinguished. Permafrost conditions within peat bogs of inter-montane depressions are not clear yet.

Thus frozen rocks on the examined territory are developed in different stows with stunted dystrophic vegetation, visible relief disturbance and roughness, specific soils, overmoistured soils and surface deposits, clear manifestations of permafrost processes.

The evolution of permafrost extent in north and central Europe during the last ice age.

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In the last decades considerable specification of climate reconstructions from ice cores and ocean records revealed the existence of a high number of relatively short, but intense climate changes during the last glacial. The detection of such climatic events in terrestrial environments looks much more difficult, while the reconstructed permafrost occurrence seems -until now- only to follow the Milankowitch-type climate changes on a much larger time-scale. Then the question arises whether this discrepancy is real or imaginary. In the latter case it could mean that our knowledge is insufficient by now. But the reason may also that the used proxies are not adequately reacting, or the thresholds for any proxy-response were too far way, or permafrost were too slow in comparison with the climatic changes? Some examples are given that illustrate the existence of short events of permafrost degradation and extension. Furthermore, the boundary conditions will be given to enable the detection of possible permafrost changes on a millennial scale of climate evolution.

Re-deposited pollen in ground ice as age and origin indicator

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Ground ice existence in permafrost gives an additional possibility for palaeoenvironmental study. Pollen and spores often found in ground ice enough for reconstructions. Of special interest ^{14}Cdating problems in context of re-deposited pollen content. If distinctly (Tertiary and older) re-deposited pollen and spores are abundant in dated sediments it is possible to evaluate the ^{14}C age can be older than true. This approach was used for study of number of permafrost cross-sections with large ice wedges in the North of Russia. The ice wedges are considered as special pollen trap. Marine pollen spectra are characterized very high content of re-deposited pollen and spores. Thus allochthonous material was evaluated. Pollen can be used as indicator of water origin of ground ice, which has been formed from. If the ground ice has atmosphere origin the re-deposited pollen grains are unique, however if marine or river water participated in ground ice formation re-deposited pollen could be found at about 1-5%. When we have no re-deposited pollen in ice-wedge ice we can suppose that the ice has atmosphere origin. Comparing pollen spectra of host sediments with those in ice wedges we can separate that part of pollen, which come to the area in the spring, when ice wedges are forming (regional spring pollen rein). Thus it is possible to find the local components in pollen spectra of the host sediments.

Palsa In North-East Europe: Age And Potential Future

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A number of 30 new radiocarbon dates from palsa in north-eastern part of European Russia is considered. Age and recent state of 3 massifs of the palsa was studied: near Eletskaya, Nikita and Usa settlements. It was established that palsa formation took place in different time periods both in different geocryologic zones and within the separate palsa massifs. The oldest dates (7-5 ka BP) from bottom of peat in higher palsa (5-8 - m height) show, that the most part of palsas have been formed after Holocene Optimum. However the younger dates (1-3 ka BP) from bottom of peat in small palsa (1 - m height) show, that some palsas have been formed recently, and modern palsa can occur together within the separate palsa massif. Potential future palsa in different permafrost zones varies: in northern part in continuous permafrost they are stable and can grow even in global climate warming, in discontinuous permafrost conditions most part of palsa can thaw very fast. Various types of palsa are widespread: total height of ice inclusions may be more, less or equal to palsa height. RFBR (grants 99-05-65075 and 00-05-64736) and Program of Integration of Education Ministry (grant 5.1-425) partially financed the study.

New observations on the Pleistocene periglaciation of the Serra da Estrela, Portugal

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The location of the Serra da Estrela (1,993 m ASL) near the South-western tip of Europe (40°20'N, 7°35'W) and the extensive glaciation and periglaciation that affected it, makes it an important area for the paleoclimatic reconstruction of Western Europe and North Atlantic conditions during the LGM.
During the Last Glacial Maximum an ice cap occupied the higher plateau of this granitic mountain and glaciers flowed down the main valleys, which deeply dissect it. The ice cap occupied an area of *ca.* 70 km^2 and the ELA was calculated using the maximum altitude of lateral moraines method to be at about 1,650m ASL. Some valley glaciers flowed down to 700 m (Daveau, 1971).
Research on the periglacial geomorphology of the Serra da Estrela is scarce and the few existing publications are rather general and are parts of wider synthesis of the main aspects of the periglacial evidence in Portugal. Observations are sparse and not systematic. No conclusive proofs were yet presented in what respects to the possible occurrence of permafrost during the Pleistocene in Portugal.
The work that the author is conducting in the Serra da Estrela since 1995 tries to solve some pending problems on the periglacial and glacial geomorphology of the mountain, and also to present a more detailed survey and analysis of the forms, deposits and processes. This approach is based on the detailed geomorphological mapping at scales of 1:25,000 of the mountain and 1:10,000 in the more important areas. Exposures of deposits are also studied and dating of some deposits has been also done. The geomorphological data is integrated in a GIS used as a descriptive and analytical tool (Vieira, 2000). This approach allows the detailed study of the relationships between the glacial and periglacial morphodynamics that occurred during the Pleistocene.
The results that will be presented are a systematisation of the relict periglacial features that were identified in the Serra da Estrela, their distribution and relationship with the glaciated areas. The studied features include blockfields, blockslopes, protalus ramparts, stone-banked lobes, taluses, stratified slope deposits and head deposits. The different factors that may have affected their genesis will be discussed.

Session 3. IPA Task Force – Rock Glaciers.

Oral Presentations

IPA/ICSI Task Force on Rock Glacier Dynamics

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Rapid progress has been made during recent years with respect to our understanding of rock glaciers. Recognizing this fact, the International Permafrost Association (IPA) and the International Commission on Snow and Ice (ICSI) decided to establish a Task Force on Rock Glacier Dynamics in order to define the present state of knowledge with respect to possibilities of numerically modelling the flow and evolution of perennially frozen ice/rock-mixtures. In addition, an overview should be given of ongoing projects which provide quantitative information from drilling, geophysical soundings, geodetic/photogrammetric monitoring and measurements of surface conditions. The goal of the Task Force is to define the state of the art of, and to recommend strategies for, numerically modelling the dynamics of steadily flowing ice/rock-mixtures. It attempts at combining scientific concepts of thermo-mechanically coupled flow under permafrost conditions with the rapidly increasing evidence from sophisticated field experiments (drilling, geophysics, photogrammetry) in order to improve our understanding of the involved processes by using quantitative, numerical models. The focus of the Task Force on Rock Glacier Dynamics is, therefore, on perennially frozen debris and involved dynamics of deep-seated, large-scale creep. The following colleagues serve as lead authors with respect to the main topics:

thermal conditions	Humlum (surface), Vonder Mühll (boreholes)
composition:	Matsuoka (rocks), Elconin (ice)
geometry/kinematics	Kääb, Kaufmann (photogrammetry, geodesy)
rheology	Ladanyi (lowlands), Springman (mountains)

The term "rock glacier" is here loosely defined as large masses of talus or debris containing perennial subsurface ice and exhibiting signs of long-term cohesive flow. A clear distinction is made between two fundamentally important but different and complementary aspects involved:

- the ground thermal conditions (permafrost) which allow for the formation and/or the long-term preservation of subsurface ice; and
- the composition of the ice/rock-mixtures, i.e., the amount and distribution of ice existing below the surface and enabling the steady-state creep of the considered ice/rock mass.

Permafrost is, thereby, defined as a special ground thermal condition (negative temperature throughout the year), irrespective of ice content or lithology.

Rock Glacier Thermal Conditions

Daniel Vonder Mühll, University of Zurich

Rock glaciers are particular geomorphic debris-forms in mountain permafrost areas. Only few drillings have been performed through rock glaciers permitting investigation of the thermal characteristics of the subsurface.
In the 1970s, two boreholes were performed in the Swiss Alps (10m at Murtèl: Barsch 1977, 7m at Gruben: Barsch et al. 1979) and in Canada (Kluane Range: Johnson and Nickling 1979). In the latter one, temperatures were remeasured some 6 years after drilling. No negative temperatures were registered any more, indicating a very fast melting of the permafrost (most probably supported by water advection). In 1987, when the 58m deep borehole was drilled through Murtèl-Corvatsch rock glacier, one of the longest time series measurement of Alpine permafrost temperatures started (Vonder Mühll and Haeberli 1990, Haeberli et al. 1998, Vonder Mühll et al. 1998). At Pontresina-Schafberg, two boreholes were drilled in 1990 (37m and 65m deep) within a snow avalanche structure project (Vonder Mühll and Holub 1992). A core drilling down to 10m depth was drilled in 1995 at Galena Creek (USA, Ackert 1998). Within a joint project of three ETH-

Institutes, several core drillings were carried out in the uragl rock glacier (4 drillings, ca. 70m deep, 1999) and again in the Murtèl-Corvatsch rock glacier (2 drillings, 51m and 63m, 2000; Arenson and Springman 2000).
Most of the mentioned boreholes were used for temperature measurements, some of them to determine subsurface deformation and/or in-situ stress data, chemical and isotopic compsition. The drilled rock glaciers are mostly located near the boundary of permafrost distribution. Thermal characteristics (temperatures, gradients, thermal properties) are quite different from one place to another and even change over short distances (e.g. Muragl).The following table summarises the main results:

site	number of drillings	max. depth	temperature permafrost-table	Permafrost thickness
Murtèl-Corvatsch (Switz.)	5	63m	-2.0	> 50m, talik
Gruben	1	7m	-1.0	80m
RG II, Kluane Range	1	17m	-0.6	> 20m
Pontresina-Schafberg 1/1990	1	65m	-1.5	> 60m
Pontresina-Schafberg 2/1990	2	37	-0.5	30m
Galena Creek	1	10m	?	?
Muragl	4	72m	> -0.5	20m

Heat flow was determined in drilling Murtèl 2/1987 by measuring thermal conductivity of the frozen cores. Due to a high temperature gradient, heat flow value is about 150 mW m^{-2}. At the same site, the data series indicate, that snow and in particular the time of year when the first heavy snow fall arrives, influences the temporal fluctuations markedly. Since 1987, temperatures ranged from -2.6°C to -1.2°C at 10m depth, and –2.1°C and –1.4°C at 20m, respectively.

Several particularities are worthwhile to mention when comparing the rock glacier drillings to permafrost drillings in bedrock (e.g. the PACE transect with seven 100m deep boreholes from Svalbard to the Spanish Sierra Nevada):

- Technically, it is much more difficult to drill a rock glacier (both for percussion and core drilling!) due to the ice/rock-mixture.
- Only very little is known about the rock glacier hydrology. Intrapermafrost taliks and zones with unfrozen water were encountered during the drillings on Muragl and Murtèl.
- Temperatures inside a creeping permafrost body are governed by the two boundary conditions "mean annual surface temperature" and "permafrost base" (see below).
- Large lateral variations of the ground thermal regime. This is partly due to the fact, that the surface often consists of boulders, blocks, stones and pebbles of various diameter.
- "Mean annual surface temperature": Under these surface conditions, the energy balance is very much different to what i expected on a smooth, bedrock or alpine vegetated surface. A rock glacier therefore generates cool surface conditions by creeping down-valley.
- "Permafrost base": In the lowermost part (below approx. 45m) of rock glacier Murtèl consist of an aquifer with seasonal temperature variations (Vonder Mühll 1992). On Muragl rock glacier, below about 20m depth, temperatures are above 0°C. The formation at this depth is very porous and air was lost during drilling. Both cases indicate, that strong lateral fluxes are present at the "permafrost depth".

The list shows that there are a number of open questions. Internal characteristics and processes are investigated by long-term monitoring projects, core analysis, physical (centrifuge) and numerical modelling.

Rock glacier composition: Rock component.

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Characteristics and origin of the rock component of talus-derived rock glaciers are reviewed in the light of the lithological influence, weathering and transport processes and subsurface structure. Lithologies that produce blocky materials and thick talus deposits favour the generation of permafrost creep. Lithologies mainly producing pebbles and finer materials, including shale, phyllite and schist, are generally unfavourable for rock glaciers, and rather preferred by active layer soil movement. Where debris becomes thick enough initiating permafrost creep, however, these lithologies result in small protalus lobes.

The initiation of permafrost creep requires shear stress greater than a critical values, which is favoured by a large slope angle and a debris thickness. Rapid debris accumulation resulting from postglacial unloading, catastrophic rock avalanches or landslides, followed by ice cementation in voids, is probably the most important trigger of rock glacier movement. The growth of the rock glacier thus requires continuous supply through rockfalls. Frost weathering would be the dominant cause of such rockfalls, releasing rock debris up to a few metres thick during seasonal thawing periods. The rate of rockwall retreat behind active rock glaciers is estimated to be of the order of millimetres per year, by means of the measurement of annual rockfall volume or using the debris involved in the rock glacier.
Most rock glaciers are composed of upper blocky sediments corresponding to the active layer and the lower frozen core. The upper blocky layer lacks interstitial fine materials that have probably been washed away by meltwater flowing over permafrost. The openwork structure may enhance cold air storage that impedes further melting of permafrost. The boulders are much larger than those comprising talus slopes above a rock glacier, partly reflecting fall sorting such that during a rockfall event only a few of the greatest blocks can reach the rock glacier surface. The lower frozen core is a mixture of clasts, fine materials and various types of ground ice. The wide range of the grain size distribution indicates that the debris is fed by, in addition to rockfalls, debris flows and snow avalanches.

Rock glacier ice review: distribution, physical and chemical characteristics, age, diagnostics and origin

Roger Elconin

Direct observations of rock glacier internal structures reveal three general types of structures in which ice occurs: 1) massive ice with dispersed debris and thin layers of debris-laden ice, overlying a basal layer of ice and rock, 2) a few meters to tens of meters of debris-laden ice overlying massive ice, and 3) ice-rock mélange throughout. Small- to large-scale depositional and deformational structures are present. Interlocking crystals 5-30 mm in diameter have been reported. In one ice core sample C-axis orientation was measured which was roughly parallel to the surface. Spherical and elongate air bubbles are common and bubble foliation was reported in one study. Post-depositional processes, most notably flow metamorphism, are responsible for glacier-like crystal morphology and bubble foliation. Geochemical analyses show low ion content. Age of the ice ranges from contemporary to ~8000 years BP. The differentiation of glacial or non-glacial ice origin in permafrost is difficult because they have similar petrographic, stratigraphic and chemical qualities. It is very difficult to observe modes of ice formation other than snow metamorphism and surface icings. However, negative ground temperatures and abundant surface and subsurface liquid water in the accumulation zone assure subsurface ice growth in the form of interstitial, segregation, injection or vein ice. Sources for the liquid water include rain, snow and ice melt, and groundwater.

IPA/ICSI Task Force on Rock Glacier Dynamics - Geometry and Kinematics

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The basic focus of mapping, monitoring and modelling geometry and kinetics of rock glaciers is to understand the development and dynamic sensitivity of the frozen bodies. This understanding implies, for instance, general morphology, evolution of micro-topography, velocity field and its spatial and temporal gradients, settlement and heave, or age and age structure. Mapping and monitoring of geometry and geometry changes, displacements and deformation is mainly done by terrestrial and satellite-based geodetic measurements. More seldom applied is photogrammetry, or even laserscanning and InSAR. Some of the most important outcomes from such work are the typical smooth and continuous morphology of rock glaciers which points to the absence of pronounced differential melting the range of creep speeds from several m yr^{-1} down to the significance level of the applied monitoring techniques (some mm yr^{-1} to cm yr^{-1}) the range of annual speed variations reaching up to several ten percents the surface flow fields – better known as for many other slope instabilities – which clearly show a both spatially and temporally continuous deformation pointing to stress transferring ground ice the fact that the evolution of geometry is both due to cumulative deformation and three-dimensional straining, and frost heave and thaw settlement the age of rock glaciers which seems to be counted more in millennia than in centuries or even shorter times.

The knowledge of geometry and surface kinetics of rock glaciers is comparable highly developed, whereas the basic understanding of the involved processes (by physical and numerical modelling) is by far not adequate compared to the above data base. This lack of understanding implies flow laws or creep mechanisms, but also speed variations, sensitivity to external forcing, and the development of (and implications from) micro-topography. Furthermore, a larger number of systematic, globally distributed monitoring series could substantially help to extract the basic processes of rock glacier creep from the high dynamic variability of individual exemplars.

Rheology of ice and ice/rock mixtures

Branko Ladanyi

As mentioned in the Introduction to the Task Force Report, the term "rock glaciers" has been used for various complex landforms of cold mountain areas. The two extreme end members are (a) debris-covered glaciers in permafrost-free areas, and (b) steadily creeping perennially frozen and ice-rich debris on non-glaciated mountain slopes. "The goal of the Task Force is to define the state of the art of, and to recommend strategies for, numerically modelling the dynamics of steadily flowing ice/rock mixtures".

As described above, there are essentially two separate but interdependent problems to be solved:

A. The effect of ice/rock interface roughness conditions on adfreeze strength and creep of glaciers, and

B. The large-scale creep of ice and ice/rock mixtures.

For solving the first problem, it will be necessary to combine the rheology of ice with the data on the strength of irregular rock surfaces. A basis for this study can be found in the literature dealing with the shear behaviour of irregular and filled joints in rock (e.g., Ladanyi and Archambault, 1977, 1980, Ladanyi, 1994), by considering ice as the joint filling. This study should also consider the shear of rolling ice-filled debris on irregular rock bottom surface, as well as the effects on creep and strength of dilatancy hardening and weakening, as shown, e.g., in Ladanyi and Morel (1990).

For solving the second problem, the creep behaviour of ice/rock mixtures should be studied in the whole range of mixtures, from no ice to pure ice, taking into account (as shown by Goughnour and Andersland, 1968; Baker, 1979; and Ting et al., 1983) that shear behaviour of frozen, ice saturated, sand is essentially controlled by the following four physical mechanisms:

1. Pore ice strength
2. Solid particles strength, which consists of interparticle friction, particle interference and dilatancy effects,
3. Increase in the effective stress due to adhesive ice bonds, resisting dilation during shear of a dense mixture, and
4. Synergistic strengthening effects between the particles and the ice matrix, preventing the collapse of the solid skeleton.

The relative importance of the various mechanisms depends on the volume fraction and character of solid particles in the mixture (e.g., Iannacchione & Vallejo, 2000 Nickling & Bennett, 1984, Shibata et al. 1985). Under high overburden pressures, dilatancy effects may be suppressed, because of grain crushing and associated pressure melting.

The purpose of this whole exercise is to eventually establish a sound basis for prediction of creep behaviour of rock glaciers under varying conditions of temperature and ice saturation.

Poster Presentations

Borehole deformation measurements in Alpine rock glaciers

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Information about the deformation of creeping rock glaciers is very important for a better understanding of their history and future behaviour. A powerful means of determining the deformation fields are surface (deformation) measurements (e.g. Kaab et al., 1998). However, only borehole deformation profiles deliver information about the movements within a rock glacier and hence are essential for creep analyses. Three active rock glaciers in Switzerland have been instrumented with inclinometers, magnetic rings as well as with thermistor chains at various times during the last 13 years (Wagner, 1992; Haeberli et al., 1998; Hoelzle et al., 1998). All three sites are located in the Upper Engadin, Swiss Alps at elevations between 2530 and 2750 m a.s.l. and these rock glaciers show similar patterns of deformation behaviour: A distinct shear horizon passes through all boreholes, with a zone of no deformation in the lower part and a zone with some additional creep in the upper part. The velocities, however, are rather different. At the Schafberg and Murtèl-Corvatsch sites, average total deformations of about 0.08mm/day and 0.19mm/day respectively are measured. Larger deformations are measured at the Muragl site (1.2mm/day), where the temperature at the shear zone is only slightly below 0°C while the temperatures on the two other sites are marginally (0.5-1.5°C) colder. In addition, seasonal changes in deformation rate can be observed at the latter site while the others show constant movements during the year. At the Murtèl-Corvatsch site, a slight increase of the deformation could be observed during the most recent years, which might be induced by an increase in temperature during the years 1991 – 1995 (Vonder Mühll et al., 1998). Data will be compared to establish further understanding of how the temperature profile within a rock glacier may influence the deformation response. And since multi-year cycles are important, this monitoring is ongoing.

Pressuremeter tests in the Murtèl-Corvatsch rock glacier, Upper Engadin, Switzerland

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The accurate determination of mechanical soil parameters in situ is complicated since either a testing device has to be brought into the ground without causing excessive disturbance which will change these properties significantly, or samples have to be cored and tested afterwards in a laboratory. A very useful device for measuring the creep parameters of frozen materials in situ is the pressuremeter (Kjartanson et al., 1988; Murat et al., 1989; Ladanyi and Malouki, 1993). However, pre-boring is necessary in frozen material, so relaxation and hence both thermal and mechanical disturbance of the wall will occur, which must be taken into account while analysing the results. Pressuremeter tests were performed in the Swiss Alps with the Cambridge Insitu HPD 95 pressuremeter in one borehole in the Murtèl-Corvatsch rock glacier (Arenson and Springman, 2000). Creep tests were conducted at several different depths, at varying stress levels. Figure 1 shows the set of all test data. Even though the soil was very heterogeneous a clear trend can be observed. With increasing pressure, the strain rate increases exponentially. Due to the disturbance in the borehole and temperatures of the pressuremeter above 0°C (Tests marked with an 'x') there is a larger scatter for data at lower pressures. Using an exponential creep law (e.g. Ladanyi and Melouki, 1993), creep parameters b of 0.6 – 2.3 and n of 0.6 – 1.0 can be found. However, these parameters are very difficult to analyse, since irregularities in the test results can have a major influence. In addition, unload-reload loops were analysed in stress-strain space to study the homogeneity of the soil material. Using a creep law on such a 'loop', a shear modulus can be found. The tests show, that as soon as the pressuremeter is properly 'bedded into' the ground, the modulus is quite consistent over the chosen depths. However, since creep dominates the soil behaviour, assumptions of a shear modulus which is not time dependent can be misleading.

Flow behaviour, internal composition and development of rock glaciers on Svalbard

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The flow behaviour, internal composition and development of seven rock glaciers in the continuous permafrost zone on Svalbard were studied, utilizing DC resistivity soundings and Ground Penetrating Radar (GPR) in addition to displacement measurements. The investigated rock glaciers are located on Prins Karls Forland (number 7, 9, 12 and 15), close to Ny Ålesund (the Brøggerbreen rock glacier) and in the vicinity of Longyearbyen (the Hiorthfjellet and the Birkafjellet rock glaciers). The rock glaciers are both of the lobate and the tongue-shaped type, located in diverse topographic and partly climatic settings.
Despite these differences, the investigated rock glaciers show many similarities. All the rock glaciers have a simple surface geometry, except for the pronounced inner depression found on most of the lobate rock

glaciers. DC resistivity soundings reveal a high-resistivity internal layer (100-900 km), resting on sediments or bedrock of much lower resistivity (0.01-13 km). These resistivity values point to a high ice content within the rock glaciers. GPR soundings were performed along the central flowline of all rock glaciers except for the Birkafjellet rock glacier. They show a system of reflectors that was generally similar between the different rock glaciers, with a layering parallel to surface in the upper talus part, and slanting up against the surface slope further down and towards the fronts. On Hiorthfjellet, at the transition between talus and rock glacier, the reflectors slant downwards in relation to the rock glacier surface but then turns within a short zone.
Displacement measurements were performed on rock glacier 12 and 15 on Prinsk Karls Forland, and on the Hiorthfjellet and Birkafjellet rock glaciers. Velocity measurements at Brøggerbreen rock glacier are published by Sollid and Sørbel (1992). The Hiorthfjellet rock glacier flows generally about twice as fast as the remaining rock glaciers, with annual velocities of up to about 10 cm a^{-1}. All rock glaciers show higher velocities on their upper parts, and there is a tendency for extending flow along the talus cone towards the rock glacier, and a compressive flow regime further towards the front.
Coupling flow regime and DC resistivity values, our measurements give support to the conceptual model of Haeberli and Vonder Mühll for the origin and development of ice within the rock glaciers. Mass movements of higher magnitude, covering either snow patches or active layer above supersaturated permafrost, probably form the layering structure shown by the GPR soundings. We propose that the structural development along the rock glaciers is caused by an accumulation gradient along the talus cone – rock glacier system, and use the changes in angle of the layers to calculate this accumulation gradient.

Geophysical investigations at Fireweed Rock Glacier, Wrangell Mts., Alaska: methods and results

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Geophysical survey has just been completed (Fall 2000) at Fireweed rock glacier, and data analysis is in progress. The purpose of this study is to correlate the geophysical data to the direct observations of internal structure made in 1994 at the rock glacier's terminus and head (Elconin and La Chapelle, 1997). Methods and results from the seismic, resistivity and radar soundings will be presented. Results from geodetic survey of surface velocities 1997-2000 will also be presented. Lastly, ground temperature measurements (BTS) were collected continuously by miniature data loggers from 1997-2000 and will be presented.

Vegetation as ecological indicator of rock glacier dynamics

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Aim of this work is to demonstrate that vegetation can be used as an ecological indicator of rock glacier dynamics. The study sites are located in the Central Alps, in Upper Engadin (Switzerland) and in Upper Valtellina (Italy), on five rock glaciers: two dynamically inactive (Murtel and Lago Blu), three active (Murtel I, La Foppa I, Pisella I). Vegetation survey has been carried out using the phytosociological method of Braun Blanquet (1964) in all the study sites. Lichenometry has been carried out only on Murtel I, lacking epilithic lichens on the Italian active rock glaciers. In the same edaphic conditions (elevation, substrate, aspect, slope), there are many differences between the vegetation of rock glaciers and the one of the surrounding areas outside rock glaciers in terms of coverage, associations and species. Vegetation shows strong differences also between active and inactive rock glaciers. Active rock glaciers are characterised by discontinuous vegetation with low coverage (less than 20%) and pioneer associations. Vegetation of inactive rock glaciers is almost continuous, with higher coverage (70% or more) and is composed by evolved associations and/or by the climax.
These data show that the surficial disturbance produced by permafrost creep is a determinant factor controlling vegetation colonisation and its development inside rock glaciers. Previous measurements carried out inside three active rock glaciers (by aerial photogrammetry or theodolite) show that the patterns of movement are not homogeneous (Kaab *et al*, 1998; Smiraglia, 1989; Guglielmin, unpublished data). The

distribution patterns of vegetation, in particular of coverage percentage, type of association and indicator species of surficial movement, have been compared with the measured movements. Vegetation coverage decreases with the increasing of movement and it tend to disappear with a velocity higher than 30 cm/y. In particular, for rock glacier Pisella I, following the increasing of surface velocity (ranging from less than 10 cm/y to 30 cm/y), it is possible to observe the decreasing of species number and coverage (%) and the selection of the more stress tolerant species. In all the active rock glaciers, the more tolerant species are: *Geum reptans*, *Cerastium uniflorum* and *Saxifraga bryoides*.

Rock glacier distribution and paleoclimate in Italy

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Rock glaciers are considered as the best geomorphological indicators of mountain permafrost. For this reason their spatial distribution has been used to model the present (Ihmof, 1996; Fraundelfeder *et al.*, 1998) and past permafrost distribution (Guglielmin and Siletto, 1999) in mountain areas. Relict rock glaciers have been also used to describe past climatic conditions in terms of paleotemperature and paleoprecipitation (Kerschner, 1985).
For what concerns the distribution of active rock glaciers in Italy, the lower altitudes are reached on northern slopes of the Central and Western Alps (2,228 and 2,230 m a.s.l. respectively) (Guglielmin and Smiraglia, 1997). All the active rock glaciers of known age in the Alps are younger than 2,200 yr B.P. (Calderoni *et al.*, 1998) but older than the Little Ice Age. In the Appenines only one dinamically active rock glacier occurs on the northern slope of Mt. Maiella, at around 2,500 m a.s.l. (Dramis & Kotarba, 1992).
In this paper the occurrence of permafrost in Italy during the Holocene is mapped at a very general scale, basing on both the spatial distribution of relict rock glaciers and their radiocarbon ages. Both in the Alps and the Apennines at least three different sets of radiocarbon ages related to rock glacier creeping on older surfaces have been recognised: (a) 2,700-3,400 yr BP; (b) 4,000-5,500 yr BP; (c) undetermined age, during the Late Glacial. Moreover, some rock glaciers in the Apennines seem to be related to the Last Pleniglacial. Relevant paleoclimatic information can be provided by the distribution of the minimum mean elevation of the fronts of relict rock glaciers (MEF) in the different mountain sectors of the Alps and the Apennines. It is remarkable how during the (a) period the MEF reached the elevation of 1,600 m a.s.l. in the Apennines and 1,744 m a.s.l. in the Eastern Alps, on northern exposed slopes while, during the (b) period, the MEF was 2,270 m a.s.l. in the Apennines and 2,300 m a.s.l. in the Central Alps.

Rock Glaciers on Svalbard - some typical examples

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Understanding the basic processes of rock glacier development and creep is best done by detailed process studies combined with intercomparison of the large natural variability of such creep forms. Such combined studies are presently performed on Svalbard. Most rock glaciers on Svalbard are located in coastal areas at altitudes just above sea level, often situated below the escarpment which delimits the inner part of the strandflat (Sollid and Sørbel, 1992). The rock glaciers have surface temperatures of several degrees °C minus under especially cold permafrost conditions and can to a large extent be assigned to two typical but very different looking types:
- a ramp type often showing a surface overdeepening above the front and high ridges terminating laterally, but no ridge-and-furrow structure. Related detailed investigations exist for Forlandet (Berthling et al., 2000) and Brøggerbreen rock glaciers. Since this rock glacier type is rarely found in lower latitudes, the special climatic conditions on Svalbard combined with its special topographical setting presumably have a major influence on its evolution. Special interest will be given to differential heat exchange between ground and atmosphere (including thermokarst processes) and the influences of snowdrifts.
- a second main type of Svalbard rock glaciers shows a pronounced sequence of transverse ridges and furrows and reaches a significantly larger extent than the above type. In addition, this rock glacier type is, in contrast to the above, able to spread far into flat terrain (strandflat). Presently, detailed photogrammetric

investigations on such rock glaciers have been started at the Nordenskiöldkysten, western Svalbard, and will be presented.
Both types are able to exist close to each other. Up to now, it is not clear which factors lead to the fundamental differences between the two rock glacier types. First important answers will be given by age assessments based on geodetic and photogrammetric velocity measurements, and by analysis of geological and geomorphological conditions.

Rock glacier kinematics in the Turtmanntal (Valais, Switzerland) using digital photogrammetry

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Rock glaciers are defined not only by thermal and mechanic characteristics, but as well by their kinematics. In our study, digital photogrammetry is applied to analyze changes in elevation and horizontal surface velocities of rock glaciers. The main question was whether it is possible to determine surface topography and surface kinematics from small-scale photography (approx. 1:20'000) of two different years (1975 & 1993).
First, Digital Terrain Models (DTM) for both years were computed on a digital photogrammtric station. They cover the whole Turtmanntal-area as well as its tributaries with a resolution of 25m and 10m, respectively. It turned out that the main problem in generating DTMs with digital photogrammetry is its inaccuracy above snowfields and in shady areas: errors can be more than 10m.
In a next step digital orthophotos were produced for both years 1975 and 1993, and subsequently used for the measurement of rock glacier-movement. Thereby, the position of individual features was digitally compared in two orthophotos. The fully automated software CIAS then measures the dislocation of the feature and calculates displacement rates. The main problems were:

- Due to the small scale of the aerial photographs many features are too small to be identified in both pictures. Hence, measurements were only possible on parts of the rock glaciers.

- Measurements within the vicinity of snow are not possible.

Resulting velocities in the Turtmanntal area range from 15 cm a^{-1} up to ca. 65 cm a^{-1}, with fastest speeds occurring at the central flowline and in the middle altitude of the rock glacier.
A further analysis of the DTMs using a GIS allows quantification of vertical changes. They show a more complex pattern with both surface heaving and settlement on one rock glacier. Settlements are interpreted as mass losses and mainly occur at the lower part of the rock glacier reaching values of up to -16 cm a^{-1}, whereas mass gains (up to 27 cm a^{-1}) are mainly found in the middle parts.
Digital photogrammetry produces dense geometric and kinematic information in a short time. Hence, even the analysis of small-scale aerial photography is a very useful and effective technique to examine rock glacier activity as long as the user is aware of the problems mentioned above.

Paleopermafrost reconstructions for the Younger Dryas in the Upper Engadin, Swiss Alps, using relict rock glaciers

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Long-term creep deformation of ice-containing debris requires permafrost conditions. Therefore, relict rock glaciers below and outside present-day Alpine permafrost belts can be used to reconstruct past permafrost conditions. These past permafrost conditions, in turn, reflect past climatic conditions, especially solar radiation and air temperature determining radiative and sensible heat fluxes as primary drivers of the energy balance at the earth/atmosphere interface. Solar radiation and mean annual air temperature can be estimated for present-day conditions using weather-station data in combination with corresponding algorithms and digital elevation models. If solar radiation and local temperature gradients are assumed to have remained roughly constant in time, depressions of paleotemperatures can be calculated for paleopermafrost. Comparison with strongly temperature- and precipitation-dependent paleo-equilibrium lines on glaciers then enables estimates to be made about paleoprecipitation. Analysis of relict rock glaciers together with GIS-modeling of paleopermafrost in the Julier Area, Upper Engadin, eastern Swiss Alps, indicates that mean annual air temperature during the Younger Dryas time period had been at least 3°C lower than today. The lower limit of permafrost occurrence was probably depressed considerably more than glacier equilibrium lines. This indicates strongly reduced precipitation and much larger abundance of mountain permafrost at that time.

Rock glaciers and a protalus rampart in relation to mountain permafrost in the northern Japanese Alps.

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In order to examine the relationship between rock glaciers, the protalus rampart and permafrost in the northern Japanese Alps, this study has investigated: 1) the bottom temperature of snow (BTS) on the Kuranosuke rock glacier and protalus rampart in the Kuranosuke Cirque, north of Mt. Tateyama (3,015 mASL); 2) the mean annual ground surface temperature (MAST) during the past year on Syakushi rock glacier around Mt. Shirouma (2,932 mASL) and; 3) the electrical resistivity soundings and seismic refraction soundings of the rock glaciers and the protalus rampart.
The results of this investigation are as follows:

1) As a result of measuring the BTS, MAST and seismic refraction soundings, permafrost is found in the Syakushi rock glacier, the protalus rampart and upper half of the Kuranosuke rock glacier. However, permafrost is absent in the lower half of the Kuranosuke rock glacier.

2) The active layer thickness of the Kuranosuke rock glacier is about 5-8 m and in the Syakushi rock glacier it is about 6-8 m measured using seismic refraction soundings. This shows that these rock glaciers are not moving at present. Therefore, these rock glaciers should be classified as inactive rock glaciers.

3) Ono and Watanabe (1986) suggest that the protalus rampart rests only on the surface of the perennial snow patch (fossil ice body). However, the fossil ice body is not found under the protalus rampart by the electrical resistivity soundings. This shows the protalus rampart was formed earlier than the fossil ice body. Moreover, since permafrost exists in the protalus rampart, the formation of the protalus rampart seems to be related to permafrost.

The Apennine (Italy) Late-Pleistocene and Holocene Rock Glaciers

*Giraudi Carlo**

The inactive rock glaciers found in the Apennine have developed at different times, according to their present weathering conditions, vegetation cover and elevation. In this paper the results of the investigations carried out to date these periods are reported. The chronological assessment has been obtained by analysing the stratigraphical and/or geomorphological relationships among rock glaciers stadial moraines of known age, and radiometrically dated aeolian and tephra layers.
Five periods of rock glacier development have been recognized:

- the first has been referred to the Last Glacial Maximum, because the rock glaciers occurred before the deposition of a loess layer dated about 15.000-16.000 years B.P.;
- the second has been referred to the Late-Glacial, because the rock glaciers developed before the fall of a tephra layer dated about 12.000 years B.P.;
- the third occurred during the Younger Dryas according to the stratigraphical-geomorphologic relationships between the rock glaciers and some stadial moraines and lacustrine sediments;
- the fourth is fully Holocene even though older than about 4.000 years B.P. as recorded by a tephra layer dated about 3.500-4.000 years B.P. which covers the rock glaciers;
- the fifth, bracketed by the development of dated soils, is more recent than about 3.500 years B.P. and older than about 800 years B.P.

Technogenic rock glaciers: genesis, structure, mechanism of movement,

forecast of development

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In mountainous regions, dangerous negative phenomena occur as result of the technogenesis effect. This presentation deals with the problems of technogenic dumps sliding down the slopes of the mountains. Thereby the effect of the cryolithogenic and glacial factors was revealed. It has been noticed that permafrost degradation in industrial zones strengthens the development of dangerous processes. The peculiarity of the internal structure of technogenic rock glaciers as compared with natural ones is presence of ice-rich layers of coarse material marking seasonal cycles of debris supply. The movement of the largest in the North of Russia technogenic rock glacier at the slope of Rudnaya mountain in Norilsk was analyzed. Similarity of the embankment with a rock glacier is shown. It was established that the average speed of the movement is 40 mm/day, sometimes - up to 800 - 1000 mm/day. In the period 1992-2000, the technogenic rock glacier replacement was from 180 up to 360 m in different parts of it's front. The front of the rock glacier crossed the river valley and caused the formation of the lake. Three models of movement were revealed. Different variants of the dump displacement taking in account global climate warming were developed and the practical proposals for the stabilization of the situation were given. Authors are grateful for the sponsor support to Russian Foundation of Fundamental Research, grants #99-05-65590.

The Foscagno rock glacier ice core: an example of old glacier ice relict preserved in permafrost environment.

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Within the E.U. funded project PACE (Permafrost and Climate in Europe) a borehole 24 m deep was drilled on Foscagno active rock glacier (2,510 m a.s.l.)in Upper Valtellina, Italy. The frost table was found at 2.3 m depth. Immediately under the active layer, between 2.5 and 7.65 m, was cored a massive ice layer overlapping frozen sediments. Schematically the ice core can be divided according the macroscopic characteristics in three layers. The first (2.5-4m) is characterized by a massive, clean and fractured ice, with very rare clasts and bubbles random distributed; the second one (4-6.1 m) is characterised by several layers of clean ice with a low bubble content and several layers of fine debris, in general horizontally oriented. The third part is more complex with several layers of clean ice with different ice crystal orientations and dimension and different content in bubbles. 58 thin vertical sections were carried out between 4 and 7.65 m of depth to determine the diameters, shape, c-axis of the crystals and the content, shape and orientation of the bubbles. Major inorganic components (chloride, nitrate, sulphate, sodium, ammonium, potassium, calcium and magnesium) were determined by ion chromatography in the ice core every 9 cm from 400 to 755 cm depth. Two samples at lower depth (250-270 cm) in the first part of the core were also analysed. The crystal size (0.5-3.3 cm) and the marked sub-horizontal elongation (with a ratio between vertical diameter and horizontal one almost always lower than 0.8) and the microfabric of the ice (with C-axes random oriented or sub-horizontal banded oriented and a mylonitic texture) according Shumskii (1964) allow to refer the ice to the friction - cataclastic ice type. The chemical analysis showed that samples at 250-270 cm and 755 cm were more concentrated that the inner layers and probably were contaminated by exchange with surrounding soil. In the inner layers (from 400 to 746 cm) of the ice core two different zones can be evidenced. The first one (from 400 to 560 cm) was characterised by slightly higher levels of ions, with a good correlation among ammonium, nitrate and sulphate, which denotes the presence of an atmospheric source. Below 560 cm, very low levels were determined, similar to that measured in alpine glacier ice cores and in general lower than the values found by Haeberli (1990) in the Murtel rock glacier. No evidence of fractionation processes has been found. From all these results the ice body preserved in the permafrost of Foscagno rock glacier can be explained as a body of dynamometamorphic buried ice probably formed earlier the maximum advance of the Little Ice Age in the Foscagno valley.

Methods for absolute and relative age dating of rock-glacier surfaces in Alpine permafrost

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Rock glaciers originate from the slow but long-term cumulative deformation of ice-rich, perennially frozen debris. Characteristic time scales involved are centuries to millennia. Surfaces of relict, inactive and active rock glaciers, therefore, reflect debris accumulations produced, deposited and deformed during late-glacial, Holocene, historical and recent time periods. Dating of such surfaces can best be achieved by using a combination of absolute and relative age determination methods. Corresponding potentials of radiocarbon dating, optically stimulated luminescence, cosmogenic exposure dating, lichenometry, Schmidt-Hammer measurements, weathering-rind mapping and photogrammetric determinations of flow trajectories are presently explored. The principles of the applied methods are presented, their advantages and shortcomings discussed and first results presented.

Rock glacier active layer temperatures.

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Active layer temperature measurements have been carried out on active rock glaciers in Greenland and Svalbard. The thermal characteristics of the coarse-grained active layer on rock glaciers are described and compared to thermal characteristics of other types of active layers. Conductive as well as non-conductive heat transfer processes appear to represent important controls for active layer temperature and thickness. Phenomenon such as wind pumping and refreezing of percolating surface meltwater may temporarily provide conditions for rapid, non-conductive heat transfer processes. Different surface roughness, such as represented by the typical rock fragment size, could further contribute towards different degrees of active layer ventilation. The calculated apparent diffusivity varies considerably during the year, apparently on a seasonal basis. Meteorological controls on this variation are discussed, and from this, the environmental controls on rock glacier formation. In general, the coarse surface layer on rock glaciers acts as an efficient thermal filter, protecting the permanently frozen rock glacier core when a snow cover is absent or thin, and conversely when a thick snow cover is present. This may partly explain why rock glaciers tend to be frequent in dry, continental areas, but less so in humid areas.

Characteristics of pebbly rock glaciers in Swiss Alps

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In terms of the clast size, rock glaciers are classified into *bouldery rock glaciers* whose active layer consists of matrix-free boulders and *pebbly rock glaciers* consisting of matrix-supported pebbles and cobbles. In general, pebbly rock glaciers have smaller bodies and develop on steeper slopes than bouldery rock glaciers. Pebbly rock glaciers originate mainly from the shale bedrock, which rarely produces clasts larger than 20 cm in diameter. Electrical DC resistivity soundings indicate the presence of ice-poor permafrost in pebbly rock glaciers. The rounded front of pebbly rock glaciers, which contrasts with the sharp edge at the

front of bouldery rock glaciers, implies that solifluction in the active layer is superimposed on permafrost creep.
We present the results of field observations on two pebbly rock glaciers located respectively on the northern slope (BN) and western slope (BW) of Piz dal Büz, the Upper Engadin. Both rock glaciers originate from talus slopes below the shale rockwall. BN rock glacier consists of the upper lobe (BNU) and the lower lobe (BNL). These rock glaciers are lobate in plan, with length of less than 100 m and width of about 100 m. Both BW and BNU have a steep front 10 m in height, but BNL does not have a distinct front. The upper surface of BW and BN inclines downslope at 20°-25°. The mean annual surface temperatures recorded with data loggers are –0.5 °C (1998-1999) and –0.7 °C (1999-2000) on BW, –0.1 °C (1998-1999) and 0.9 °C (1999-2000) on BNL and 0.2 °C (1999-2000) on BNU. A borehole 5.1 m deep dug on BNU in early August, 2000 revealed that pebbles are the major component of the rock glacier. Except for the uppermost 50 cm, the pebbles are embedded in loamy matrix. The frost table lay at about 1 m deep in early August; the active layer thickness is unlikely to reach 2 m or deeper even in the end of summer. Permafrost is ice-saturated and includes a number of small ice lenses. The ice content is 45-60 % by volume at 4-5 m depth. The annual displacement of the two rock glaciers was measured by triangulation for two years (1998-2000). Whereas BW and the lower part of BNL moved downslope only slightly (< 7 cm a^{-1}), BNU showed rapid movement. In the first year, BNU moved downslope at 50-80 cm a^{-1}; the movement slightly accelerated to 65-90 cm a^{-1} in the second year. The high velocity may reflect the high permafrost temperature close to the melting point, but the cause of the acceleration is so far unclear. In order to acquire more detailed data on subsurface velocity and temperature profiles, inclinometers and temperature sensors were installed in the borehole on backfilling.

Temporal variations of mountain permafrost creep

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Beside its thermal characteristics creeping mountain permafrost is substantially defined by its kinetics. Due to their – in general considerable – ice content rock glaciers represent especially sensitive systems of the high mountains. Monitoring and modelling of temporal variability of mountain permafrost creep helps understanding its dynamic properties and its past, present and future reaction on external forcing.
Speed variations with frequencies of centuries or several decades may result from general spatio-temporal changes in boundary conditions as material supply, thermal regime or terrain topography. Comparison of present day flow-fields of rock glaciers with their present day shape – cumulatively reflecting their dynamic history – clearly shows such past temporal variability (Frauenfelder and Kääb, in press) .
Photogrammetric and geodetic monitoring series of up to several decades suggest that velocity changes of mountain permafrost creep in pluri-annual time scales is mostly due to variations in climate conditions. Some monitoring series show clear correlation with meteorological measurements or other climate indicators (Kääb et al., 1997).
Yet, the above sensitivity of permafrost creep to external climate forcing is strongly dependent on the individual internal conditions of a rock glacier, as clearly shown by seasonal velocity variations. Related geodetic observations in the Swiss Alps yield seasonal speed variations from nearly zero percent to many ten percents (Haeberli, 1985). Numerical modelling of deformation variations due to oscillating surface temperature shows that pure heat conduction is, however, not able to fully explain the observed variability.
Our monitoring and modelling work implies that 'warm' rock glaciers creep faster than 'cold' ones. Furthermore, the findings suggest that the creep of 'warm' permafrost (close to 0°C) is more sensitive to climate forcing than 'cold' one. From this, we conclude that increasing rock glacier temperatures may lead to its marked, but both spatially and temporally highly variable speed-up, before a significant loss of ice content by melt-out is able to reduce the deformation rate of the frozen mass towards its entire deactivation.

Spatio-temporal analysis of the dynamic behaviour of the Hochebenkar Rock

Glaciers (Oetztal Alps, Austria) by means of digital photogrammetric methods.

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The spatio-temporal variations of the surface of a rock glacier, i.e. the change of elevation and the three-dimensional directional deformation, can be determined using various quantitative measurement methods, i.e., geodetic survey, satellite-based positioning with GPS/GLONASS, photogrammetry, radar interferometry, and also laser scanning.
In this paper we introduce a new concept of mapping and monitoring of rock glaciers by means of digital (softcopy) photogrammetry. Digital photogrammetry is based on digital image data and computer processing. Image matching, i.e. digital point transfer, is used as a powerful tool for automatic measurement of homologous, i.e. conjugate, points in the digital data sets. This technique enables a semi-automatic or even automatic triangulation of digital photographs, the automatic computation of digital terrain models, and subsequently, the automatic measurement of a dense field of three-dimensional flow vectors based on multi-year image data, in particular. Various aspects of the proposed processing chain are discussed in detail.
The present concept has been implemented in a software package called ADVM (Automatic Displacement Vector Measurement), which is written in Visual C++ for running on a Windows-based personal computer. A case study has been carried out in the Oetztal Alps, Austria, in order to demonstrate the applicability of the concept. Aerial photographs (1953, 1969, 1971, 1977, 1979, 1981, 1990, and 1997) covering two adjacent rock glaciers, i.e. the Outer and the Inner Hochebenkar rock glacier, were acquired from the Austrian Federal Office of Metrology and Surveying. The various steps of the evaluation process, i.e., scanning of the analogue photographs, photogrammetric orientation, orthophoto production, computation of digital terrain models, and the determination of three-dimensional flow vectors, are described. Examples of the results obtained are presented numerically and graphically. For the first time it has been possible to reveal the dynamic behaviour of the Hochebenkar rock glaciers with high spatial resolution and with full coverage of the area of interest. The ease of the proposed method was confirmed, and moreover, the overall accuracy is high and the processing time of the given multi-year data set is promisingly low. The paper concludes with recommendations for further developments and improvements.

Detection and quantification of rock glacier deformation using ERS D-InSAR data

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Synthetic Aperture Radar (SAR) systems normally record both the amplitude and the phase of the backscattered echoes. However, the phase of a single backscattered image is of no use and therefore, conventionally the amplitude or intensity image is usually provided to the user. But on the contrary, the phase difference of two backscattered SAR images of the same area on the ground taken at slightly different view angles can be utilised to generate digital elevation model (DEM) of the imaged terrain. This technique is known as SAR interferometry (InSAR) and can be extended to differential SAR interferometry (D-InSAR) to detect surface changes in the order of few centimetres. Although the D-InSAR has been shown to successfully derive surface displacement in the radar line-of-sight caused by earthquakes or mass movements in alpine and arctic terrain, a number of questions related to the properties of rock glaciers and the imaging geometry of the SAR sensor remain to be answered. These include the relative small size of the rock glaciers in comparison to the SAR pixel resolution, the rough surface topography composed of debris and rocks, the perennial snow patches and snow cover most of the year in the areas of interest, the rather small flow velocities of active rock glaciers in the range of centimetres to few meters (in some cases) per year, the look angle of the SAR sensor, and the geometric and temporal baselines requirements for successful D-InSAR data sets.
In this paper, the detection of active, i.e. creeping rock glaciers and consequently the quantification of the observed surface deformation, its temporal change using D-InSAR methods and the prerequisites to perform such analysis on a regional scale is presented. In one of the study cases, the active Doesen rock glacier (Hohe Tauern range, Austria), where the coherency of interferometric pairs was very high and the perpendicular component of the baselines were almost zero, an average deformation rate of about -0.77 cm/35 days (summer 1992) in the radar line-of-sight was estimated (cp. Fig. 1). In the following sections the

description of the SAR data compiled, the interferometric processing procedures used to generate the D-InSAR products and the discussion and quantification of the results achieved are presented.

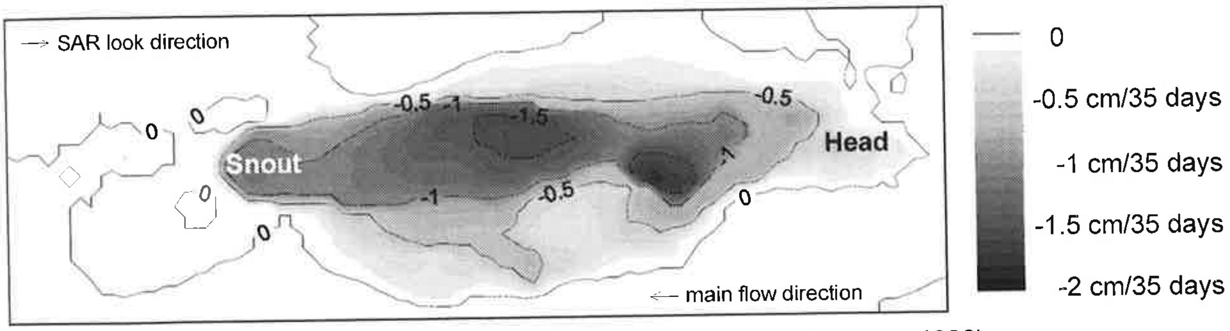

Fig. 1: Radar line-of-sight displacement map of Doesen rock glacier (summer 1992).

Observations on a Debris-covered Glacier in central Spitsbergen

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A large debris-covered glacier is situated in Ugledalen north of the valley Adventdalen on Spitsbergen 78°13' N in the zone of continuous permafrost. It measures approximately 3 km in length, 600 meters across and the front rises 80 meters. In the upper part a small glacier is present and massive ice is observed in excavations al way to the front. Sedimentary rock types dominate the geology in the area of investigation and due to the high weathering rate of the head wall the glacier is totally covered with debris shortly below the ELA. Since the permafrost inhibit melting from beneath and the debris-cover insulate against melting from the air, the debris-covered glacier potentially contains a climate record since the day of initiation.
This project aims to investigate how long a late Holocene climate record the debris-covered glacier represents. Ice samples has been taken from natural exposures along a melt water channel and in ice caves and is to be analysed for the oxygen isotope composition. The results will be used to describe the temperature fluctuations during the late Holocene in the study area and they will be compared with the ice-core taken on Lomonosov Fonna on the eastern part of Spitsbergen and other investigations made in the Adventdalen area. The idea is to estimate when permafrost conditions were established in the area in the Holocene.
Furthermore, the age of the glacier is investigated by lichenometric measurements and Schmidt Hammer rebound analysis. Velocity measurements was initiated in august 2000 and is to be followed up in summer 2001 on 60 marked points on the upper half of the glacier.
On the upper part of the glacier large cone-shaped hills are present and their formation and are investigated. A talus sheet is build up on a layer of ice at the head wall, resulting in a layer of debris within the glacier. The debris insulates the glacier and rises more than 8 meters above the ice surface when the surroundings relatively melt down. Rows of these cones can be found almost to the terminus. They are found along both longitudinal and transversal lines.

Rock Glacier Monitoring using Terrestrial Laser Scanning

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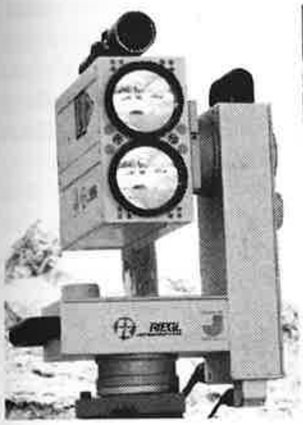
The evaluation of longterm changes of rock glacier surfaces needs fast automatic sensing methods with an accuracy in the range of a few centimeters.
We report on an ongoing experiment using a new technology long-range laser scanner which covers a region with 2000 m radius from one viewpoint. Single time-of-flight measurements with a distance accuracy of 2 cm are automatically combined to a measurement grid that enables the generation of a dense digital elevation model (DEM) of the rock glacier surface. Repeatable sensor orientation is performed using

reflective targets fixed on stable surfaces somewhere in the spherical field of view of the sensor. The DEMs of different measurements can be easily compared to get a full description of change in volume, spatial distribution of shape, or arbitrary profiles on the surface.
During Summer 2000 the Hinterer Langtalsee rock glacier in the Austrian Alps was measured twice. We could show that already the current state of technology (Laser Scanner LPM2k produced by Riegl Laser Measurement Systems, Austria, combined with software for scanning and data evaluation by JOANNEUM RESEARCH) is capable of updating the data base for the surface change of the rock glacier within a single day's measurement campaign, including logistics and evaluation. Only one person is necessary to operate the system.
In addition to the Hinterer Langtalsee area, an adjacent debris covered glacier (Goessnitzkees) was measured to verify the applicability of the proposed method for (ice) glaciers.
For both cases the results clearly show the usability of this approach. The accuracy gained is within a range of 5 cm in elevation. Currently the measurement results are verified using geodetic measurements performed by Graz University of Technology.
In Summer 2001 the measurements of the two reference areas will continue using an updated version of the scanner and scanning software. In the meantime research will emphasize the automatic orientation of the sensor using natural targets, detection and correction of measurement outliers, accuracy investigations, as well as an optimized sensing strategy.




Left: Riegl Laser Scanner.

Right: Scanner at Hinterer Langtalsee rock glacier: Volume change (Range difference Pseudo Color coded with maximum 3 m) within 1 month, caused by water leakage.

Present formation of ice-creep features in a deglaciated area (Corral del Veleta, Sierra Nevada, Spain)

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During the Little Ice Age, a small glacier occupied the base of Corral del Veleta (37°03'24" N, 3°22'05" W, 3398m), a glacier cirque located on the north face of Pico del Veleta (3398m) in Sierra Nevada in the southern Iberian Peninsula. From about the mid-nineteenth century to the mid-twentieth century, the glacier gradually shrank to near non-existence. Aerial photographs from the period show that as the ice retreated, a rock fall talus quickly formed on the eastern half of the cirque. During its formation, creeping features appeared at the base of the talus. Today, an active boulder tongue, rock glacier like, stands out in this area. This tongue is 180m long and 45m wide, and its terminus is 12m high. Its source area is located in an active talus found at the base of the wall of the cirque. The tongue flows at an irregular rate of 2-5cm per year. Its core consists of a mixture of ice and blocks in an unknown proportion. This tongue displays classic rock-glacier morphology consisting of an alternating pattern of crests and depressions located perpendicular to the flow, a nearly vertical terminus, and levees that form on the sides.

This paper provides a detailed analysis of the characteristics of the tongue's flow, as well as its geophysics, geomorphology, and sedimentology. Daily surface and subsurface temperature readings at various key spots on the glacier were recorded from 1998 to 2000, and the data was used to develop maps of superficial soil isotherms. During the period of 1999 and 2000, a string of thermal sensors installed in a 2-meter deep borehole that reached the ice nucleus, was used to track the evolution of the thermal gradient in the active layer.
The results reveal a contrast between moderate thermal conditions inside the boulder tongue and sedimentologic characteristics that indicate intense geomorphologic activity in the feeding area. The conclusions of this paper focus on the conditions that are necessary for the formation of a ice-creep features, where glacier ice has been trapped by debris fallen from the active wall, and clarifies which processes gave to one of these features its present "rock glacier like" morphology in so short a time. These conclusions provide the basis for a discussion on the speed in which rock glaciers could be formed, particularly during periods of deglaciation.

DC resistivity prospecting in rock glaciers and talus slopes in the discontinuous permafrost belt of Western Swiss Alps.

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DC resistivity prospecting performed in periglacial areas of western Swiss Alps (Mont-Gelé – 46°21'N/7°13'E, Diablerets – 46°06'N/7°17'E) demonstrates that two different types of ice (low and high resistivity ice, as defined by Haeberli & Vonder Mühll 1996) can conduct to the formation of similar active rock glacier features. On another hand, two different geomorphic features (an active rock glacier and a talus slope without creep) can contain comparable type/quantity of ice. The objectives of the study were to use DC resistivity methods (sounding and mapping):

- to specify ice content of various active rock glaciers;
- to know if some talus slopes which present no evidence for creeping features still contain ground ice.

Eleven DC resistivity soundings (dissymetrical Schlumberger array) and 17 mapping lines (Wenner array) were carried out on 4 small but well-developed active rock glaciers and 4 talus slopes (3 small homogeneous formations and a more heterogeneous large talus). The results particularly show the presence of two co-existing types of active rock glaciers according to the nature of their ice content.

- The rock glaciers "with low resistivity ice" primarily contain ice formed by in-depth freezing of percolating water. The specific electrical resistivity of the frozen layer of the rock glacier is lower than 100 k_m.
- The rock glaciers "with high resistivity ice" are characterised by the existence of buried ice patches layers. The specific resistivity of the "permafrost body" is higher than 500 kΩm and even reaches several MΩm. Outcrops of ice patches were directly observed covering the whole roots of two rock glaciers. Downwards, DC resistivity methods were not able to map the extension of these ice patches, which are integrated into the rock glacier. The internal structure is assumed to be the result of a complex Holocene

history alternating cold and wet phases favourable for the formation of ice patches (e.g. Little Ice Age) and phases more favourable for the accumulation of rock sediments (e.g. the current period).

- All prospected talus contain a certain quantity of low resistivity ice, rather located in the lower part of the slope. The specific resistivity calculated for the frozen layers are below or of the same order as those observed in the rock glaciers "with low resistivity ice".
- The ground ice distribution is far from homogeneous in the large talus slope of Lapires (Mont-Gelé). The fact might be related to the combination of several geomorphic processes (e.g. summer insulation of avalanches snowpatches, debris flows modifying superficial fabrics of the talus slope). A 20 m depth borehole has been drilled in order to monitor the thermal evolution of the frozen ground in this scree located at the lower limit of discontinuous permafrost.

Surface ground temperatures of rock glaciers in the Argentera Massif (Maritime Alps, Italy): one year of monitoring

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The more than 70 rock glaciers surveyed in the South-East Argentera are the most widespread landforms in the periglacial belt of this alpine region, especially if taken together with the approx. 120 landforms mapped in the French part of the Massif. Even if most of these rock glaciers may be considered fossil, for some landforms above 2500 m a.s.l. discontinuous permafrost presence cannot be excluded, as showed by recent geophysical soundings in the French Alps. As surface ground temperature (T_s) analysis is a useful method for predicting the presence of permafrost, a continuous monitoring was programmed for six rock glaciers that seemed affected by permafrost, as suggested by surface morphology and mean altitude. The T_s has been analysed by means of 7 miniature digital data loggers (DTL) and the monitoring has been carried out for one year at intervals of 1 hour. Three rock glaciers showed a mean T_s (MAST) below –1 °C, three slightly negative (-0.9 °C to –0.4 °C) and only one positive (2.27 °C). In all the logger recordings it is possible to recognize the onset of ground freezing, generally in November, and the summer thaw period from the end of May to October. The T_s of all the rock glaciers monitored remains in a transitional zone (-6 °C to 0 °C) for over 6 months. Six DTL showed a reduced variation in ground surface temperature during the December-May period, with a mean value well below 0 °C (< -5 °C) and no temperature variation for several days consecutively. Only one DTL experienced ground temperatures that remained remarkably constant during the same period, but in the range –1 °C to 0 °C. This T_s trend (transitional zone) may be considered above all a consequence of both snow cover and compensation of the upward heat loss associated with the drop in air temperatures by the freezing latent heat of the soil ("zero curtain effect"). Moreover, the mean T_s during the December-May period recorded by the six DTL, may be interpreted as the combination of the downfreezing from the surface and the upfreezing from a perennial frozen ground. Therefore, the T_s analysis suggests that only one rock glacier is not affected by permafrost, while in the ground thermal regime of the other registration sites the freezing from the permafrost surface upward seems to play an important role, as confirmed also by MAST values. To improve this consideration, the Bottom Temperature of Snow cover (BTS) has been extrapolated from T_s trend, according to tests recently carried out in the Swiss Alps and the three thermal conditions of BTS generally assumed for probable/possible/improbable permafrost occurrence was used. Permafrost occurrence can be predicted for the five rock glaciers with extrapolated BTS < - 3 °C and negative MAST, while permafrost absence can be stated for one rock glaciers with - 1 °C <BTS > 0 °C and positive MAST (2.27 °C). The T_s and the extrapolated BTS suggest permafrost presence also for corresponding mean annual air temperature (calculated by means of thermal lapse rate) slightly positive, highlighting that solar radiation and snow cover may be the main factor in determining permafrost distribution. T_s data, BTS extrapolation and geomorphological observations suggest that rock glaciers above 2600 m a.s.l (mean elevation) are permafrost affected. These active landforms represent 11.2% of all the rock glaciers on the Italian side of the Argentera Massif. The most elevated rock glacier occurs at 2900 m a.s.l. (mean elevation), making the width of the present day periglacial belt almost 350-400 m. Most of the rock glaciers in the elevation range 2500-2600 m a.s.l. are to be considered mainly inactive (climatic inactive), some affected by discontinuous permafrost (especially in the uppermost parts) and only a few complete fossil landforms. The T_s data suggest that the rock glaciers with mean altitudes below 2500 m a.s.l. are fossil, even if island permafrost presence cannot be excluded a priori in areas with low solar radiation. The recognition of the lower discontinuous permafrost boundary at about 2600 m a.s.l. and the glacial reconstructions proposed for the Western Alps suggest a rock glacier chronology. Most of the huge rock glaciers formed during the Younger Dryas, while three Holocene generations formed respectively during PreBoreal, SubBoreal and SubAtlantic.

Bioindication of rock glacier generations in the Turtmanntal, (Valais, Switzerland)

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One aim of the Turtmanntal-project is the reconstruction of past and present permafrost distribution and the impact of climate change in a palaeoenvironmental context. The key objective will be achieved through the combination of different approaches and methods in various spatial scales.
One approach is the use of plants as indicators of permafrost distribution. Although there is a strong impact of climatic and topographic conditions on the vegetation, "biomonitoring" and "bioindication" enables getting information on presence or absence of permafrost and the influence of creeping permafrost. Permafrost acts on vegetation by selecting species and associations, which are adapted to these conditions, e.g., to slope movement.
First a geomorphological map based on field data and remote sensing imagery is important to get the distribution of permafrost indicators. Features such as rock glaciers and protalus ramparts are geomorphic expressions of permafrost. The additional mapping of the front scarp (length, slope and aspect) and the structure of these features enables estimating the degree of activity (active, inactive, relict). The presented investigation will focus on a cascade of rock glaciers with different degrees of activity (rock glacier generations).
As a second step vegetation cover, the vegetation structure (herbs, shrubs and trees), and the phytosociological associations (Braun-Blanquet, 1964) were mapped. These results served as a basis for the analysis of the indicator-values (Lauber & Wagner, 1996) of all species to determine the geoecological coherency's, especially the plant/permafrost relationship. This includes the interpretation of the local processes, here especially the identification of slope activity. Additional studies focussed on the age of some dwarf shrubs, found on inactive rock glaciers, and some trees, growing on an investigated relict rock glacier, by using dendrochronological methods. On this poster the presented studies will be summarized in distribution maps, profiles and diagrams.
A wide range of corresponding investigations (mapping and modelling of permafrost distribution, geophysical studies, etc.) are established within this project; so the future work will be to evaluate the conformity of the presented results.

Fluctuations of air temperature as a reason for short-term velocity changes at the rock glacier Äußeres Hochebenkar (Ötztal Alps, Tyrol)?

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Since 1938, velocity measurements - at first by terrestrial-photogrammetric profiles, from 1951 onwards by direct geodetic methods - have been carried out on three transverse profiles/stone lines at the active tongue-shaped talus rock glacier Äußeres Hochebenkar (Ötztal, Tyrol). The present data series, comprising more than 60 years, is world-wide the longest of its type. It was summarized for the first time and interpreted according to the latest state of rock glacier research in the diploma thesis, recently presented by the author to the University of Innsbruck (Schneider 1999). Special attention has been given to the evaluation, graphical representation and tabular registration of the so far unpublished original data records since 1972. In addition, the already published older data up to 1970 have been submitted to a critical sifting and assessment, including historical photos and maps, thus facilitating a high degree of homogenization of the entire measuring series.

The detailed analysis of the data showed that the dynamics of movement of the rock glacier is strongly influenced by the particular relief situation in the Outer Hochebenkar. The short-term velocity changes, determined since the beginning of the measurements, reflect the repeated sliding down and breaking off of the rock glacier-tongue as a consequence of the steeper terrain below the edge of the ground along which the rock glacier is moving downwards. The excessively high flow velocities in the 1950s and

1960s (with mean velocity rates of up to 3,9 m/a and maximum values of up to 6,6 m/a at the beginning of the 1960s) as well as the repeated acceleration of velocity since 1990 (with mean values of up to 1,15 m/a and maximum values of 2,00 m/a for the measuring period 1998/99) do at first sight seem to have been caused by topographical reasons only. However, the lower flow amounts and the smaller velocity fluctuations in the period in between (from the beginning of the 1970s until 1990) cannot be explained in this way. The therefore aimed at comparison of the long year measuring series with the temperature data of the neighbouring climatic stations of Obergurgl and Vent showed that the short-term velocity changes correlate to a high degree with the mean annual air temperature values. In the time intervals, when the movement of the rock glacier is accelerated due to the relief (mid-1950s and mid-1980s), the curves correlate less well. However, for the period from 1959 until 1984, the correlation coefficient amounts to 0,83. Above-average temperatures do generally result in an immediate acceleration, below-average temperatures in a immediate decrease of the creeping movement. From the surprisingly short reaction time it may be concluded that the short-term velocity changes depend for the major part on the state and depth of the active layer - findings which are an essential contribution towards a better understanding of the dynamics of the movement of rock glaciers.

Rock glaciers and dendrochronology in the Romanian Carpathians

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The existence of rock glaciers in the Romanian Carpathians is an undoubtable geomorphological reality. As many of the identified rock glaciers belong to the category of the inactive-active ones, one of the most important problems is that of finding out the moment they turned inactive. Taking into account the fact that many rock glaciers are covered by dwarf pine (*Pinus mugo*) bushes or even forest vegetation, the use of the dendrochronological method is the most appropriate (Alestalo, 1971).

This paper intends to follow the preliminary dendrogeomorphological approaches that have been done in the Retezat Mountains (Urdea, 1998). The investigated areas are situated in the Retezat Mountains and In the Parâng Mountains, in Transylvanian Alps, and in Detunata Goal_ Mountain in the Apuseni Mountains.

The dendrochronology investigations in the Retezat Mountains deal with the rock glaciers called Pietrele, situated in the homonym cirque, between 2020 and 2080 m.a.s.l., and other two incipient ones (protalus rampart) in the Stâni_oara cirque, between 2130 and 2190 m.a.s.l. In the case of the Pietrele rockglaciers, dwarf pine are 137 maximum year-old on the marginal side and 125 year-old ones on the inner side.

Situated at 2000-2030 m.a.s.l., the Mija rock glaciers has been dendro-chronological investigated in the Parâng Mountains, and the dwarf pine are 120-148 year-old.

The discovery of two rockglaciers and permafrost, at a height between 1050-1100 m.a.s.l., under Detunata Goal_, in the Apuseni Mountains (Urdea, 2000) and their location in the forestry realm, precisely at the spruce fir level (*Picea excelsa*), have specific morphoclimatic and morphochronologic implications. If the marginal areas have been invaded by trees more than 200 year old, the axial-median area, where cemented ice has been discovered (Urdea, 2000), the isolated tree have 89 year-old at the most.

The dendrochronological data obtained in these areas lead to the conclusion that the period of inactivity began after the Little Ice Age.

Presentation and analysis of geodetic observations carried out on three active rock glaciers in the Austrian Alps

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The present poster shows the results of geodetic work carried out on three active rock glaciers located in the Hohe Tauern National Park, Austria. Doesen rock glacier, Hinterer Langtalsee rock glacier and Weissenkar rock glacier have been chosen to facilitate a long-term monitoring program studying creep phenomena of permafrost in the Hohe Tauern range (Central Alps) because of their geographical location and their main characteristics.

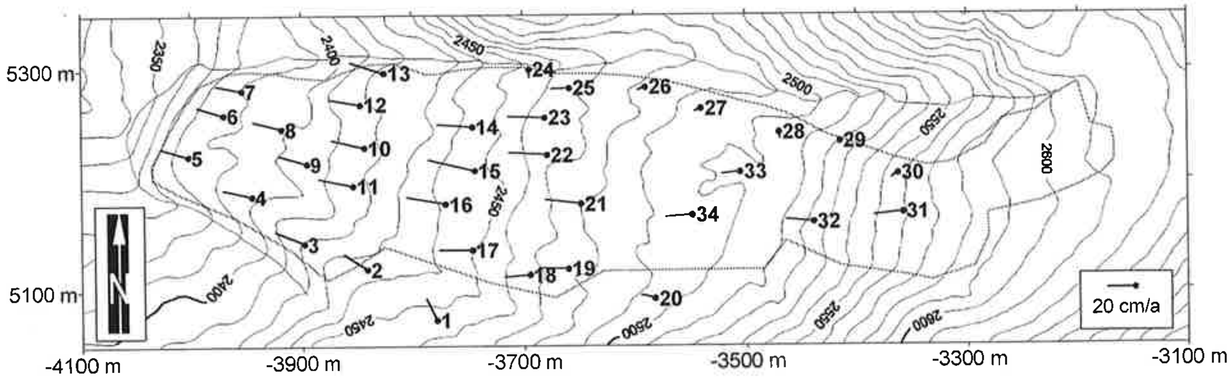

Fig. 1: Mean annual horizontal flow velocity of Doesen rock glacier, 1997-1998.

Annual geodetic observations are carried out in these areas in order to derive time-series of precise 3D flow vectors. Doesen rock glacier, which has been selected as a test site in the framework of a multidisciplinary research project in 1995, shows horizontal movements of about 20-30 cm a^{-1} (cp. Fig. 1). Hinterer Langtalsee rock glacier has been observed for three years and horizontal flow velocities of up to 150 cm a^{-1} have been determined. At Weissenkar rock glacier we have measured rather low flow velocities, i.e. less than 10 cm a^{-1}, since 1997. All results are presented numerically and graphically.

Session 4. IPA Task Force - Permafrost Distribution Modelling

Oral Presentations

Principles of permafrost and slope activity modelling.

Hoelzle, M., Etzelmüller, B., Mittaz, C. and Haeberli. W.

In recent years successful attempts have been made to develop and improve spatial modelling of mountain permafrost distribution. Work Package 4 of the PACE project (Permafrost and Climate in Europe) sought to provide the essential basis not only of present-day modelling capability, but also of future enhancements in modelling methodology. The present paper briefly outlines the currently available typology of models, which involve various levels of sophistication at different spatio-temporal scales. Appropriate models may be applied to a range of environmental issues in cold mountain areas, including engineering applications, climate-change scenarios, large-scale mapping, studies of surface processes or environmental concerns. Special emphasis is given here to aspects of energy exchange at the surface and within the active layer. Such energy fluxes remain poorly understood but play an essential role in process-oriented research and sensitivity studies with respect to complex interactions and feedbacks within the system. In contrast to relatively flat permafrost areas in polar and subpolar lowlands, circulation of water and air can cause important lateral fluxes of matter and energy within coarse blocks on steep slopes and result in highly variable and sometimes extreme thermal offsets between the ground surface and the permafrost table. Measuring and numerically modelling such fluxes together with coupling time-dependent surface and subsurface ground thermal conditions in characteristic materials (bedrock, ice-rich debris, fine-grained deposits) constitute the main challenge for research in the near future.

Statistical modelling of mountain permafrost distribution - local calibration and incorporation of remotely sensed data.

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Field mapping and prospecting of mountain permafrost is laborious and generally yields point information only. At the same time, knowledge of spatial patterns of permafrost distribution is often of considerable importance for engineering and research in cold mountain areas. A model that is based on elevation and a parameterisation of solar radiation during summer is presented here. It allows for estimation of permafrost distribution and can be calibrated locally, based on BTS measurements or even other indicators such as mapped features of permafrost creep. Local calibration makes this approach flexible and allows for its application in various mountain ranges. Model output consists of a continuous field of simulated BTS values that are subsequently divided into the classes "permafrost likely", "permafrost possible" and "no permafrost" in analogy to the rules established for BTS field measurements. Additionally, the simulated BTS values can be interpreted as a crude proxy for ground temperature regime and sensitivity to permafrost degradation. A map of vegetation abundance derived from atmospherically-topographically corrected satellite imagery was incorporated into this model to enhance the accuracy of the prediction.
Based on the same corrected satellite image, a map of albedo was derived and used to calculate net short-wave radiation, hoping to increase model accuracy. However, the statistical relationship with BTS did not improve. Probably, this is due to the correlation of short-wave solar radiation with net long-wave radiation and snow-melt patterns, both relations being differently influenced by the introduction of albedo.

Numerical simulation of current and projected permafrost parameters distribution in Russia.

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Anticipated warming of climate may seriously affect permafrost. The investigation of this problem is very important. Computer simulation of permafrost parameters spatial distribution is a tool for such investigation. In the present work the multilevel model of the heat transfer in the grounds was used taking into account water phase transformation, snow cover and vegetation effects. The model is constructed vertically on the staggered expanded grid. The near surface structure of the atmosphere is evaluated on base of Re-Analysis, monitoring and global climate modelling (GCM) data. The permafrost parameters were calculated at each node of the one degree gridded permafrost area in Russia. The possibility of regional interpretation of GCM data was investigated. The simulated fields of the thawing layer depth and temperature fields at various levels in the soil were analysed under the current climate conditions.
The 'vegetation- snow- soil ' model rather accurately reproduces the present day field of the temperature at the level of 10m in the permafrost regions of West Siberia. The geocryological 10m temperature data were used for comparison. The response of the permafrost parameters to the climate change was evaluated for various types of ground and vegetable cover. Computationally derived maps of current permafrost characteristics and of predicted characteristics were analysed. The difference between the thawing layer depth maps for various surface covers is highly pronounced. In some regions the thawing layer depth is more sensitive to the surface layer cover then to the climate warming. Various strategies of warming prediction are compared.
Firstly the surface temperature values were obtained as a result of MGO GCM calculations and were used as input parameters of 'vegetation –snow –soil ' model on the nodes of one-degree grid regularly located upon the Russia regions These results correspond to the CO_2 doubling in the atmosphere. Secondly the information about climatic parameters trends was used. This information was extracted from monitoring data and from the data simulated by means of transient GCM. The evaluations were done for various approaches of ground heat transfer scheme. The natural ground and surface characteristics distribution was incorporated in the model for West Siberia regions on base of geocryological map. The effect of phase moving in the annual temperature cycle under the influence of climate change was analysed on base of permafrost characteristics model data. The study demonstrates the ability of the simple approach to reproduce the active-layer spatial distributions and temperature fields inside the permafrost. The climate warming influence is evaluated by various methods and inter-comparison of the results is carried out. The possibilities of model improving are quite sufficient.

Extraction of periglacial features from high-resolution digital images

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Sorted periglacial features act as proxy data to identify frost susceptible ground and the appearance of these features can be used to detect solifluction processes. Debris flows and avalanche tracks can similarly be used to identify areas susceptible to rapid mass movement. These features have traditionally been mapped with satisfactory results by using manual interpretation of aerial photography or satellite-data combined with fieldwork. The traditional method is time-consuming, and it is strongly depend on the skills the investigator. New possibilities are opened through access to high-resolution satellite data and digital orthophotos suitable to map geomorphological features by means of semiautomatic and automatic techniques. There is an interesting research going on within photogrammetry and remote sensing to automate feature extraction from digital images (Sowmya and Trinder 2000). Some of these methods can clearly be adapted to geomorphological mapping. The object of this work is to test the potential of textural parameters and local threshold methods to identify sorted periglacial features in an area close to Juvvasshytta (61°40'N, 08°22'E, 1850 m a.s.l.) in northern Jotunheimen, central southern Norway. The methods can be used to extract other geomorphological features like debris flows and avalanche tracks as well. The test area is part of a field area of an EU project called PACE (Permafrost and Climate in Europe).
Test areas was selected out of an area of 19.2 km^2, which was previously mapped by traditional techniques in scale 1:10000. The test areas is characterised by a variety of sorted patterned ground features like circles, elongated circles, stripes (Figure 1), block tongues and areas of irregular shapes (Ødegård et al 1988). The

area also comprises continuous block fields, perennial snowfields, a lake and different man-made features. The data used are a 10-m resolution DTM, digital orthophotos resampled to spatial resolutions of 0.5 m, 1m, 2m and 4m, a digital representation of the originally analogue geomorphological map and field data. Patterned ground can be identified based on local measures of variation in reflectance. To obtain continuous areas of patterned and sort out man-made structures some post processing was needed. Still small areas of patterned ground and individual centres of fines were not detected. A second approach was tested based on a threshold computed from a local average, and a binary picture was thus produced to detect individual centres of fines. This technique is particularly powerful if the objective is to obtain quantitative measures of the shape and density of centres of fines.

Figure 1 Well developed sorted stripes. Rucksack in front as scale.

PERMEBAL: A mountain permafrost distribution model based on energy balance calculations

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Various efforts have been undertaken in recent years to improve spatial modeling of mountain permafrost distribution based on empirical and statistical data. However, modeling of spatial permafrost distribution under climatically disturbed conditions requires detailed knowledge of the energy exchange processes at the atmosphere/lithosphere interface and a better understanding of the processes of alpine permafrost formation or decay.
Within the PACE project, the computer model PERMEBAL simulating thermal conditions at depth based on an energy balance approach has been developed at the Department of Geography, University of Zurich. The model consists of two principal modules, an energy balance module and a thermal-offset module. The energy balance module simulates ground surface temperatures with the help of suitable parameterizations for all important energy fluxes and using simple meteodata, digital elevation models and information on surface characteristics as input. The thermal-offset module links these ground surface temperatures to thermal conditions at depth.
Such a process-based model does not only show where permafrost has to be expected and where not, but also explains why permafrost is present or absent, that is, which parameters are the critical ones. This enables the modeler to adapt the model to changed environmental conditions and thus to compute various effects from climate change scenarios. So far, the model PERMEBAL is mainly applied to an area of $16km^2$ around the Piz Corvatsch (Engadin, Switzerland). The model calculations are verified independently by carrying out energy balance measurements at a permafrost site in the investigated area (Mittaz et al., 2000). Furthermore the model was compared with the existing permafrost distribution models PERMAKART and PERMAMAP (Keller and Hoelzle, 1996) and with BTS-measurements.

Numerical simulations on the influence of snow cover on the occurrence of permafrost

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The impact of snow cover on permafrost can be significant due to the high albedo, relatively higher emmissivity, low thermal conductivity of snow, and latent heat of fusion of snowmelt. The net effect of snow cover on the ground thermal regime depends on the timing, duration, thickness, structure, and physical and thermal properties of snow cover. It has repeatedly reported that snow cover is a dominated factor determining the presence or absence of permafrost in the discontinuous and sporadic permafrost regions. For example, the temperature at snow-soil interface by the end of winter, the well-known BTS (bottom temperature of snow) method, has been used to detect the existence of permafrost in European alpine regions when the maximum snow depth is about 1.0 m or greater, while a critical snow thickness of about

50cm or greater could prevent permafrost development in eastern Hudson Bay, Canada. Further investigation on the issue of snow cover and ground thermal regime is definitely needed to improve our understanding of the physical processes involved.

The objective of this study is to investigate the impact of snow cover on presence or absence of permafrost in cold regions through numerical simulations. A one dimensional heat transfer model with phase change and snow cover routine is used to simulate energy exchange between deep soils and the atmosphere. The model has been validated against the in situ data in the Arctic and the results agree well with observations. The baseline model inputs are as follows: mean annual ground surface temperature is set at 0_C with amplitude of 20°C. Soil bulk density is set at 1400 kgm^{-3} with soil water content of 35% by mass. Snow density is 250 kgm^{-3} with its thermal conductivity of about 0.26 $Wm^{-1}K^{-1}$. The lower boundary is set at 75 m below the ground surface with constant heat flux boundary condition. Firstly, the model is run without snow cover until it reaches thermal equilibrium. Due to the effect of thermal offset, permafrost develops with the mean annual temperature at the permafrost surface of about -3.1_C, i.e., the thermal offset value for this case. Then, the model is run with snow cover until the model reaches thermal equilibrium. The maximum snow depth varies from 10 cm to 120 cm with an increment of 10 cm and the snow cover onset date varies from October 1 to late January of the following year with an increment of 15 days. The initial condition used for these runs is the equilibrium temperature profile obtained from model output with no snow cover.

The simulation results indicate that both snow depth and the onset date of snow cover establishment are important parameters for presence or absence of permafrost. For permafrost cases, early snow cover establishment can make permafrost disappear even though with a relatively thin snow cover, while permafrost may survive when snow cover starts after the middle of December even though snow thickness can reach to more than 1.0 m. This effect of snow cover on the ground thermal regime can be explained with reference to the pattern of seasonal temperature variation. Early snow cover establishment would enhance the insulating impact over the entire cold season, thus warming and eventually thawing permafrost. While the insulating effect would be reduced substantially when snow cover starts relatively late and snowmelt in spring is a huge heat sink, a very favorable combined condition for permafrost existence.

Natural rhythms and modelling of the cryosphere's evolution

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A study of the paleotemperature curves obtained by the different authors in different parts of a planet allowed the correlation between well-known natural rhythms and the periods of glaciations and permafrost development with consideration for the interglacial duration.

From them most popular are the orbital rhythms Milankovich (19-23, 41, 100 thousand years). They are well tracked, for example, on a curves δD_{ice}, $\delta^{18}O$, isotopic temperature, CO_2 from the Vostok (Antarctica) or Summit (Greenland) ice core to the past 2-4 glacial-interglacial cycles. Except for orbital rhythms exist galactic (230, 65-30, 1-5 Ma) both solar and circulating (9-11 thous.years, 100-2000 years).

We will utilize a complex of the programs to reconstruct a continuous course of air temperature on simple paleotemperature datings on the basis of harmonic analysis methods. Climatic rhythms are characterized by harmonics with particular parameters (periods, phases, and amplitudes), while the climatic trend accounts for the contribution of harmonics of higher rank.

Are obtained design paleotemperature curves for European Russia (64°N), Northeast of Russia (65°N), Southeast Chukotka (63°N), Antarctica (78°S) in Pleistocene.

It is interesting, that the periods and phases of elementary harmonics are close, and the amplitudes depend on a geographic position. The error of definition of temperature (σ) estimated as ±1.25-2.5°C.

For a Holocene paleotemperature curves are obtained for European Russia (64°N), Northeast Europe (68°N), Yamal (71°N), Taimir (72°N), etc. (σ= ±0.4-1.35°C).

The approach proposed allows the more perfect simulation of the evolution of the Earth's cryosphere and the forecast of permafrost conditions for different regions.

Mapping and distribution modeling of mountain permafrost in the Tien Shan

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Mapping of permafrost in the Tien Shan continues using two different approaches. One is like the traditional approach based on the dividing of mountain ranges into belts with different types of permafrost distribution. Sometimes this approach implies distinctions in altitudinal boundaries of permafrost of the northern and southern macroslopes. For determination of differences between the boundaries, the following premises were used:

- the difference in altitudes of a glaciers lobes positioned on northern and southern slopes in the Transili Alatau Range (N. Tien Shan) is 200-250 m (Catalogue of glaciers..., 1976);
- the difference in altitudes of the snow line between northern and southern slopes is constant and about 200-220 m (Seversky & Blagoveshchensky, 1983);
- the difference of 1.5-2° C in ground temperature between northern and southern slopes at the depth 15-20 m were measured at the altitude 3300 m a.s.l.

The Map of Permafrost Distribution in Central Northern Tien Shan has been compiled at 1:200,000 using these premises (Marchenko, 1999). But this approach does not allow allocating islands of permafrost inside the belts and is acceptable only for small-scale mapping.

The other approach for large-scale mapping uses modeling of the permafrost thermal state. Mapping and modeling permafrost distribution is carried out in several countries in Europe, e.g. for the Alps (Funk & Hoelzle, 1991; Keller, 1991). In Kazakhstan the Map of Permafrost, Glaciers and Periglacial Phenomena Distribution in the Bolshaya and Malaya Almatinka River Basins has been compiled based on GIS technology (ArcView). Our system includes topographical, geological, geomorphological, vegetation and snow cover layers. The topographical map has a scale of 1:50,000. Results of fieldwork during the last 25 years and surface analyses based on digital terrain model (DTM) were used. As a result of our work the map of ground temperature at the depth of zero annual amplitude was generated.

For a quantitative estimation of heat supply in mountain territories the conductive-convective model is suggested. The model has the possibility to compute the thermal state of blocks and psephitic porous sediment in which air circulates. This is very important because in the mountain territory the similar sediments are widely spread and have a significant cooling influence on underlying ground. Temperature observations in combination with simulations have shown that permafrost can be forming and existing inside and under such sediment when the positive mean annual air temperature is 1-2°C.

Snow and freezing in mountain regions

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The soil freezing model in mountains (of the North Caucasus region) has been developed that accounts the phase transition layer, variation of effective thermal conductivity of snow, change of snow density with thickness, variability of nivo-meteorological parameters, and soil properties. Characteristic of winters of the North Caucasus were based on analysis of instrumental observations of snow, temperature and humidity. The model snows the essential influence of effective thermal conductivity on soil freezing in mountains regions. Thus, the influence of thermophysical properties of snow on soil freezing can significantly exceed the influence of soil lithology and humidity. The influence of nivo-meteorological factors such as wind velocity and cloudiness on freezing is insignificant.

A numerical model on the permafrost aggradation/degradation during the last 120 kyrs in northern Germany

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Evidence of permafrost in Europe during the Weichselian is only recorded in near surface features (fossil ice cracks, pingos, palsas...), but little is known about its lateral distribution and its maximum depth extent. Therefore, an attempt was made to calculate permafrost aggradation/degradation on the basis of a newly constructed climate curve and a new numerical model on permafrost development, which specifically accounts for the release (uptake) of latent heat during freezing (thawing) of the sediments.
The climate curve was reconstructed from results of geological investigations, results of coleoptera and of botanical macrofossil analyses and evaluation of pollen diagrams from northern and central Germany and neighbouring countries. The climate curves give the mean annual temperature as function of time (120 - 0 kyrs before present), which were incorporated in the numerical model to drive the change in subsurface temperatures. As key factors controlling permafrost depth in Europe were identified terrestrial heat flow, thermal conductivity and porosity of the rocks. Calculated maximum permafrost thickness range between 100 m and 155 m in northern Germany during the peak of the last cold stage. Talik formation under lakes and rivers will be shown to be strongly dependent on river width, spacing of river arms and the climatic changes alike.

Climate impact on the thermal regime of Storglaciären, Northern Sweden

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The measurements of the temperature distribution within glaciers are used as proxy data for climate change within the project Climate Permafrost and Climate in Europe (PACE). Within the Swedish part of the project temperature distribution on 40 glaciers has been mapped and thermistor strings have been placed both in bedrock and in glacier ice.
Scandinavian glaciers are often referred to as polythermal. The thickness of the below freezing point part of the glaciers vary and is highly correlated to the rate of mass turn over. Dry conditions favour development of deep permafrost in glaciers and maritime climate favour temperate conditions. Maritime climate associates to high ablation rates and the high net accumulation and thus warm conditions.
Due to the strong climatic East-West gradient permafrost is more frequent along the eastern rim of the mountains than in the west. A normal thickness of the frost layer in the north east is 30-100 metres. This imply that 10-100% of the base of the glaciers is frozen to the ground during present climate. Approximately 50% of the glaciated area on the eastern side of the range is frozen to its ground. On the western side this number is smaller but still significant.
Spatial and thickness changes of the cold surface layer of Storglaciären has been recorded over a ten-year period. In 1989 the thickness of the dry, below freezing point, surface layer was mapped with a high frequency and high resolution radar system. At the time this was a new approach and the survey has since then been followed by several similar studies especially from Spitsbergen. Such data is useful in search for suitable ice coring sites, ice velocity surveys, ice sheet modelling in mountainous areas, permafrost studies etc. The thickness of the cold surface layer was in accordance with previous spot measurements of ice measurements and showed large spatial variability. The distribution and thickness of this cold layer on the ablation area shows similarities with the distribution of vertical movement. After 1989 the mass balance has been generally positive and the glacier has thickened by ~4 m in the terminus area. In spring 1999 the cold layer thickness was mapped again indicating measurable changes. In this paper we are presenting two detailed data sets sampled on Storglaciären and discuss differences in the light of mass balance and dynamic changes recorded during the past decade.

High resolution regional climate model validation and permafrost simulation for the East-European Russian Arctic

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A 15-year long, 16km horizontal resolution, present-day climate simulation has been conducted with the HIRHAM4 regional climate model. The model has been forced by ECMWF re-analyses at the lateral boundary and over sea by sea surface temperature and sea ice concentrations from the same source. The model domain is centred over the European part of Arctic Russia focusing on the Usa River Basin near the Ural Mountains. It is demonstrated that with this fine mesh, the model simulates the annual course and interannual variability in temperature and precipitation quite realistically. Furthermore the model captures the timing of permanent snow cover very accurately with less than one-week discrepancy in both autumn and spring. An interpretation of modelled sub-surface layer temperatures in terms of mean annual temperature and a 'frost index' reveals that the model captures present-day regional permafrost patterns to a high degree of accuracy.
The good interpretation of permafrost extension using the frost index in the high-resolution run is so encouraging that an effort to undertake a similar analysis for a global climate model has been initiated. Using the coupled model ECHAM4/OPYC two transient climate change experiments (using SRES scenario A2 and B2 respectively) have recently been conducted at the Danish Meteorological Institute. Results from a preliminary analysis of the simulated changes in global permafrost extension based on the frost index will also be presented.

Poster Presentations

SRAD - a spatially-distributed radiation balance model applied in geocryology

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Solar radiation is the main energy source both on the Earth's surface and in the atmosphere. Spatial variations will affect temperature, melting and thawing processes in the ground, or in snow and ice. Direct solar radiation is a function of latitude and time of year, and the local distribution is controlled by slope, aspect and topographic shadowing. In addition, factors such as ground albedo and cloud cover will influence the solar energy balance on the Earth's surface.
Several mathematical models have been developed for calculating the solar radiation over elevation models, for different applications and parameterisation schemes. The problem is to develop a program, which can both estimate the spatial distribution of radiation and can adjust for the different atmospheric buffer layers and other variables, that influence how much radiation really reaches the ground.
SRAD uses general radiation equations described by Gates (1980) to estimate the spatial distribution of solar radiation and energy balance. The program estimates the average radiation over a period of time, ranging from one day to a year for a digital terrain model. In addition the user can modify the estimated result by entering information on albedo, cloud or temperature to the program as locally specified parameters. SRAD estimates shortwave radiation, but has also implemented a simple model for calculating longwave radiation.
SRAD is a FORTRAN77 program, developed by Moore (1993) as part of the "Terrain analysis programs for environmental sciences" (TAPES) [Gallant, 1996 #612]. This poster summarises the principles and parameterisation schemes of the model, and presents sensitivity tests, validations and applications of the model in periglacial research, with an example from the Finse area, southern Norway.

Permafrost in Northern Sweden

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The Scandinavian mountains are particularly sensitive to climate warming since they are characterized by the presence of permafrost. About ten years ago late Prof. Anders Rapp initiated a project dealing with cold-based glaciers and permafrost issues. An investigation of Ekmanglaciären was carried out in April 1993 and the same year he began a study of landslides/debris flows which could have been triggered and caused by thawing permafrost. Among several sites he often used the slides on the south-facing slopes in Kukkesvagge as type locality for his research. This slides occurred in August 1985.
By studying sediment layers created by known mass-movements as in Kukkesvagge, the project is aiming at anlysing the process variation during the last ca 1000 years. Previous studies have shown that the frequency of rapid mass wasting processes have been increased during periods of climatic cold/wet conditions. These are thought to be triggered by intense rain-falls. By comparing paleoclimatic information with information from the sediment archives, we hope to find closer evidence for the relations between climate and geomorphic impact.
To study the thermal changes in the ground over the last decade and for future monitoring permafrost changes, one hundred metre and two fifteen metre bore holes were drilled close to Tarfala Research Station in April 2000. The initiative was part of the PACE programme. The hundred metre borehole was drilled at 1550m asl where the present annual air temperature is about –6 degrees. The permafrost depth is approximately 200 metres and the curve show a clear warming during the 20th century and in the last decade a slight cooling.

The occurrence of permafrost in the Polish part of the Tatra Mountains

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In summer 1995 the authors started the research on permafrost in Kozia Valley of the High Tatra Mts. The Kozia Valley lies at altitude of 1900 meters a.s.l. The mean annual temperature is below 0°C. The climate is there rather severe and it makes conditions favourable for permafrost to occur. Several methods were used in our studies. First, careful geomorphological and geological inspection of the slopes was made to select the most favourable places for further, physical investigations. In the period 1996-1997 the measurements were taken using the BTS method (Bottom Temperature of the winter Snow cover). The lowest temperatures were observed for the lower parts of the screes: about -10°C in 1996 and about -11°C in 1997. According to Haeberli [1973] the permafrost presence is highly probable when the BTS result is below -3°C. Temperature research was continued in September 1997 with the AGEMA Thermovision PRO 470 camera. The infrared image of the valleys shadowed (North facing) slopes indicated the existence of warm and cold zones. Lower parts of the screes and the valley bottom were a few degrees colder than upper parts. The maximum difference between the warm and cold zones was 7 °C. At the beginning of 1997 thermistor sensors were installed in the shadowed screes at the depth: 0 m, 0.5m and 1 m. Simultaneously started the measurements of the temperature of the water flowing from Kozia Valley.
Another method applied in studies was resistivity sounding. The presence of high resistance (hundreds thousands of Ωm) layer was detected at the depth of few meters on valleys slopes and, to some extent, in the valley bottom.
The results of the research indicate the existence of multi-annual, insular permafrost in the Tatra Mts.
In 1999 we started to monitor the permafrost with resistivity sounding method. First results indicate distinct changes in permafrost thickness during summer.

Modelling permafrost distribution in northern Sweden first results with PERMASIM - a radiation based model

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A mountain permafrost simulation model for northern Sweden was developed using the approach by Hoelzle (cf. Hoelzle et al. 1993, Hoelzle 1996) which is successfully used for the Swiss Alps and based on the relation between measurements of the bottom temperature of the winter snow cover (BTS) and climatic parameters.
The Kebnekaise/Tarfala-region in northern Sweden with an available set of BTS-measurements and results of other field investigations such as geoelectrical soundings and near surface temperature measurements (Kneisel 1999) confirming the occurrence of discontinuous permafrost was chosen as test area.
The programme PERMASIM is realised in Java. In a first step the potential direct solar radiation is calculated using a DTM as input data source. Then the permafrost distribution is estimated using a relation between BTS measurements, mean annual air temperature and the calculated direct solar radiation.
The results of the model indicate a lower limit of discontinuous permafrost roughly at 1000 m a.s.l. for northern exposures and 1400 m a.s.l. for southern exposures.
The first results of the spatial modelling provide general features of discontinuous permafrost occurrence which compare well with field investigations. Results from field measurements, however, show considerably more detail as well as local deviations from the model simulation.
It can be supposed, that the model can be improved by implementing further important factors such as the albedo for the calculation of the net shortwave radiation and a greater number of regularly distributed BTS-measurements in exposition and over a wider altitude range.

Use of the Solar Compass to Estimate the Presence of Permafrost

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In the 1970s, W. Haeberli developed a range of different methods to estimate the presence of permafrost in the area of the Flüelapass, Switzerland. These methods were based, on the one hand, on classifications dependent on the topologic and climatic terrain features, on the other hand, on bio-geographic indicators. The adequacy of these methods, which were now put down in a list of rules-of-thumb, were confirmed by an extensive number of tests of 700 BTS - measurements. The presence of permafrost in much lower situated shadow regions cannot be taken out with this method. These methods of estimation with the implementation of radiation calculation over a complex topography such as developed by Haeberli were recently applied in GIS-simulation in order to determine the spatial distribution of permafrost (Haeberli, W., Höelzle, M., 1996; Imhof, M., 1999). The development of simple measuring methods without the help of digital terrain models and GIS-simulations were neglected in recent years. In order to include radiation in the application of the above-mentioned rules-of-thumb, a method has been developed which enables us to estimate the radiation energy input with the solar compass. Thereby, the maximal possible sunshine input of each month can be determined at a certain spot in the terrain with the help of the solar compass. On the basis of this measurements and with the help of a new developed computer program, it is possible to determine the possible radiation energy input. "Field - measurements makes it possible to estimate the topologic elements such as inclination and exposition on a scale of about 10x10m. GIS-modeling usually is less precise. Due to these estimations in the terrain, more exact calculations of the radiation input result. Also soil albedo, which is responsible for the energy input into the ground, can – right on the spot - be determined more easily and more exact. Overall, this means that the energy input into the ground can be quantified more accurately than before.
All the calculations are carried out under the condition of a clear sky. The relationship between the presence of permafrost and radiation input on the basis of GIS-simulations as described by Höelzle, M., 1994, Schrott, L., 1994, and Krummenacher, B., 1998, can be confirmed with this new measurement method. In-situ measurements show that the modeled scales used for the energy input, which amount up to about 3 $GJm^{-2}a$ as the boundary value for the presence of permafrost on an altitude of ±2500 m a. s. l., can be confirmed. This newly developed measuring method, including the 10 rules-of-thumb, enables us to more accurately

estimate the presence of permafrost at a certain spot in the terrain. This can be done without the application of a digital elevation model, which reaches out to the horizon.

Regional modelling of present, past and future potential distribution of discontinuous permafrost based on a rock glacier inventory in the Bagnes-Hérémence area (Western Swiss Alps)

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A rock glacier inventory was carried out in the 200 km2 of the Bagnes-Hérémence area (Western Swiss Alps, 46°07N/7°19E) to investigate the spatial distribution of discontinuous permafrost. The data led to the local/regional redefinition of pre-existing distribution models and were also used to simulate present, past and future potential distribution of permafrost.
The study area is characterized by intra-alpine climatic conditions (1000 mm of annual rainfall at 2000 m a.s.l) and by a dominant metamorphic lithology (gneiss). 239 rock glaciers were indexed. A little more than half were regarded as active or inactive, the others being relict. The high number of inventoried formations allowed a statistical processing of the various measured parameters (altitude, orientation, surface, etc).
A model describing the altitudinal permafrost distribution according to the orientation was established to run a geographical information system (Idrisi). The comparative application of this model to the contiguous area of Entremont (e.g. Delaloye and Morand, 1998) shows certain disparities between the distribution of the rock glaciers and the simulated distribution of permafrost, underlining the need for using regional models.
According to the slow reaction of permafrost to a change in climatic conditions, we consider that the present distribution and characteristics of active/inactive rock glaciers (based on a single visual observation) rather corresponds to the Little Ice Age climate than to actual conditions. As mean annual air temperature has risen of about 1°C for the last 150 years, a strong imbalance exists near the lower limit of the permafrost belt. Considering an adiabatic thermal gradient of 0.56°C/100 m, a belt of 170 m should be concerned by melting conditions.
On the basis of the lower limit of relict rock glaciers and reconstructions of the glacial stages, the extension of permafrost and glaciers in Younger Dryas (Egesen stadial) was reconstructed for the Tortin area (Nendaz Valley). A distribution scenario was also carried out for a climatic warming of 1°C compared to the current conditions.

Modelling alpine permafrost distribution, Val de Réchy, Valais Alps (Switzerland).

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The spatial distribution of alpine permafrost is simulated in Upper Val de Réchy (south-western Swiss Alps, lat. 46°N), a small periglacial catchment area (6 km^2 between 2500 and 3000 m a.s.l), with the use of a GIS (Geographical Information System).
The objective is to compare two models based on different approaches with a set of 188 bottom temperatures of winter snowcover measurements (BTS) carried out between 1986 and 1996.
The first model needs four ground surface indicators (talus, bedrock outcrops, alpine meadow and lake) as factors to weight the permafrost distribution simulated by the topo-climatic model of Haerberli (1975).
The second one simulates the permafrost distribution as a function of mean annual air temperature (MAAT) and direct potential solar radiation (Hoelzle 1994; Delaloye and Morand 1998).
Both simulated distribution of permafrost show similar results and a good relation with the BTS mapping.
The second model was applied to simulate the spatial distribution of the permafrost facing a climatic modification and permit to identify areas sensitive to warmer conditions. An example is presented with an increased MAAT of +1°C.

Interaction between snowcover and permafrost in the alps: coupling of the snowpack model with a ground heat flux model.

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By coupling of a ground heat flux model with the so-called snowpack model, the interaction between snow cover and alpine permafrost will be studied: The coupling will serve to a numerical description of various snowpack evolution processes over permafrost and non-permafrost ground, leading to different behaviour of avalanche activity. Based on the coupled model also the biophysical factors at the ground surface will be studied. The modelling of ground heat fluxes will be done on different levels of complexity: These levels include rock ridge in the first simplest level, plain close-grained soils in the second level, steep close-grained soils in the third, and coarse-grained rock glacier surface in the fourth level. The model considers only simple heat flux in the first level, latent heat flux in the second, latent and lateral heat fluxes in the third and fourth level. The necessary level of precision of the model approach will be determined for the treatment of specific and fundamental questions concerning the interaction between snow cover and ground. Field measurements will be carried out at appropriate sites to verify model results.

Micro-scale mountain permafrost distribution in the Daisetsu Mountains, northern Japan

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Mountain permafrost exists in the Daisetsu Mountains, northern Japan (Fukuda and Kinoshita, 1974; Sone *et al.*, 1988). Its distribution is sporadic and restricted only in the summit areas as shown in the previous paper (Ishikawa and Hirakawa, 2000). In order to reveal the factors controlling this permafrost distribution, intensive field surveys of ground temperature measurements and DC resistivity imaging was conducted. Ground surface temperature monitoring indicated significant differences in the temporal regimes between the wind-blown and the snow accumulation grounds. The permafrost table is suggested to be laid in shallow depths beneath the wind-blown ground by DC resistivity imaging, where as in the deep depths beneath the snow accumulating ground where mean annual ground surface temperature is above 0°C. These results suggest that the snow cover during winter is the main factor for permafrost distribution in these mountains. Furthermore, two-dimensional transient heat transfer analysis is required for modelling such a complicated permafrost distribution and for simulating this permafrost dynamics due to climatic changes expected.

The possible occurrence of permafrost in Corral del Veleta (Sierra Nevada, Spain) according to thermal prospecting methods.

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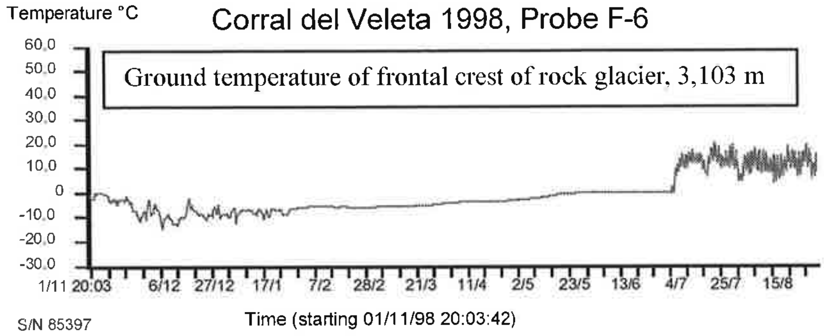
Long-term observations of the landforms and geomorphologic processes (Gómez *et al.*, 1996) and the results from geophysical prospecting based on resistivity tomography, refraction seismic, BTS measurements and shallow boreholes (Geotécnica del Sur, 1995, Terradat & ETH, 1998) done in the area of Corral del Veleta, located in the extreme western edge of Sierra Nevada on the Iberian Peninsula (37°03'24" N, 3°22'05" W) revealed that ice masses and/or permafrost exist in this enclave that is typical of Mediterranean mountainous regions. Observation and control of the geothermal behavior of the surface and subsurface (active layer) in Corral del Veleta were established in order to confirm the existence of any surviving ice nuclei and to determine their location and extent. Later, readings were taken of the nuclei's

seasonal temperature evolution to better understand the ground's energy balance, the physical mechanisms associated with the freeze-thaw cycle, and the thermal influence of snow cover. Likewise, the testing helped to evaluate the aggradation or degradation of frozen ground or permafrost at the base of Corral del Veleta.
Temperature variations in the ground surface layer (active layer) were systematically recorded throughout the year during 1998 and 1999. Data was provided by a network of six automatic and independent SAD Tinytalk-II -40º/75º probes (Ramos et al., 1998), that were installed at various sites at the base of Corral del Veleta. These probes measured the thermal evolution of the ground surface at the point of contact with the air or snow. Another device was used to record the evolution of the geothermal gradient in the subsurface layer at depths of -10cm and -50cm from the surface. Also, a fully-equipped weather station, that acted as a reference factor, was installed on one of the edges of Corral del Veleta.



Maps of superficial isotherms were developed with the aid of ArcView GIS software that used data obtained during this initial phase of observations on ground surface thermal evolution at the ground-snow interface. The maps show a spatial variation of temperatures at the base of Corral del Veleta and a clear indication of existing cold spots in the eastern sector. These spots correlate with landforms that are characteristic of a periglacial environment (rock glaciers, patterned ground, etc.) and of taluses that are extremely active. The amount of snow accumulation is a key factor in the thermal evolution of the ground surface, since the insulating effect of the snow allows temperatures to stabilize in the ground-snow interface during the winter and spring, which strongly influences geomorphologic processes.

Permafrost distribution in the Posets massif (Spanish Pyrenees)

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The Posets massif is located at Central Pyrenees, between the Cinqueta and Esera basins (Aragonese Pyrenees). It is the second higher massif in the Pyrenees, the Posets peak reaches 3.369 meters above sea level. The massif is formed of strongly folded Palaeozoic shales and schists and the granitic rocks of Maladeta batholith. The landforms are shaped by glacial and periglacial phenomena. The more characteristic features are glacial cirques and troughs, lacustrine basins and crest and ridges are, next to periglacial landforms (debris lobes, solifluction lobes, debris talus and cones, and rock glaciers. Present day there are three glaciers, Posets glacier, La Paúl glacier and Llardana glacier. All of them are little cirque glaciers with beveled fronts separated of Little Ice Age moraines. On slopes, troughs and basins the periglacial processes are actives. There also are two rock glaciers, Posets rock glacier and Gemelos rock glacier (Agudo et al. 1989; Serrano y Agudo, 1998; Serrano et al. 1997).
Various methods such as direct current (DC resistivity) sounding, geomorphological mapping, BTS measurements and continuous measurements at the ground surface have been used since 1998. This is a comparative study, applied in a concrete massif, related to the active rock glacier analysis in all Pyrenees range.
In the Posets massif the periglacial processes distribution are established, linked to permafrost presence or gravity fluxes. The continuous permafrost are present up to 2.850-2900 meters on all slopes and orientations. Up to 2.500 meters sporadic permafrost in favourable orientations and topographies is located and discontinuous permafrost are generalised up to 2750 metres.

The map of cryogenic processes intensification in the North and its ecological application

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The map of cryogenic processes intensification under mechanical impacts (scale 1:10000000), the first map with permafrost content, is included into Ecological Atlas of Russia, which is being designed at geographical department of Moscow University. The map demonstrates the level of intensity and the types of destructive cryogenic processes, shaping the ecological situation. The mechanical impacts include the destruction of vegetation even to the point of its degradation; the variation in thickness, density and albedo of snowcover; the change of ground water regime and that of surface drainage; the change of structure and quality of ground. This leads to the disturbance of heat- and water- exchange on the surface of soil and activity of cryogenic processes. The situation is estimated for the representative man-induced impacts in Russia. The area of landscape with anthropogenic cryogenic processes is estimated first of all. In addition to that the dynamics of processes, the degree of modification in natural relief, the possibility of processes damping as a result of natural condition are also estimated. The territories with different rate of danger in respect of cryogenic processes activity - catastrophic, strong, medium, moderate, weak, - are distinguished on the map within permafrost zone of Russia. The weak activity of processes means that they occupied no more than 10% of total area of specific landscape, the moderate activity - up to 50%, the medium - about 50%, the strong - more than 50%, the catastrophic - more then 90%. The assessment of cryogenic processes intensity is specific for plains and mountains. Plain landscapes are estimated as a whole, whereas it is necessary to assess mountain and valley landscapes separately when assessing mountain territory. The first reason is that the permafrost and landscape conditions of watersheds, mountain slopes and valleys are different; besides the man-induced changes are more intensive in valleys than they are in mountains. The assessment of cryogenic processes intensity is based primarily on the analysis of the following natural factors: cryogenic structure (or ice-content) of frozen ground, permafrost temperature within the depth of annual temperature fluctuation (10-25 m). These properties are highly definite and they have been proved repeatedly in the course of the assessment. Massive ice (ice wedges, massive ice bed, pingo ice) are the most favourable factor of processes expansion. The hazard of cryogenic processes becomes less intensive, hen the permafrost mean annual temperature decreases. In contrast there is a high probability of the processes amplification if temperatures are close to 0^{o}C. The area of permafrost has a direct relationship to the assessment of processes intensity. In the direction from the South to the North the hazard of cryogenic processes becomes greater as the, share of permafrost area in the total territory of a landscape grows. Particular groups of cryogenic processes, triggered by mechanical disturbances, are indicated within territories with specific types of forecast dangers. 11 groups of cryogenic processes, constituted by a composition of eight most ecologically dangerous ones are singled out. Namely these processes are: thermokarst, thermo-erosion, frost cracking, frost heave, solifluction, stone stream. It is these processes which complicate environmental protection, including re-cultivation.

Session 5. Hazards, Geotechniques and Geophysics in Permafrost Regions.

Oral Presentations

The assessment of potential geotechnical hazards associated with mountain permafrost in a warming global climate.

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European mountain permafrost is generally only a few degrees below zero Celsius, and may therefore be highly sensitive to climate change. Permafrost degradation may lead to thaw settlement and reduction in the stability of mountain slopes. Engineering projects within the high mountain zone require careful investigations of potential permafrost-related hazards. This paper summarises a staged approach to such investigations. Phase 1 involves walkover site survey supported by a desk study to define potential permafrost hazard zones. Data from permafrost distribution maps, topographic and geological maps are integrated, preferably using GIS methodology. If permafrost is possible and is judged to pose a significant threat to the development, Phase 2 investigations are recommended whereby field thermal measurements, drilling of exploratory boreholes, and geophysical surveys are undertaken to clarify permafrost characteristics. The resulting data set should form an important component in subsequent engineering design. On a larger scale, a similar approach should be adopted as part of land-use use planning within the mountain permafrost zone.

Assessing the impact of possible future permafrost degradation on urban and industrial infrastructure in the East-European Russian Arctic using a GIS approach

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Global climate change is expected to be most severe in high latitudes. This study focuses on the Usa Basin in the East-European Russian Arctic (roughly 65-68° N and 56-65° E). Permafrost in this area is mostly discontinuous and relatively 'warm', making it highly sensitive to climatic changes. Assessing the impact of possible future permafrost degradation on infrastructure (buildings, pipelines and (rail)roads) is relevant at this moment, considering the large-scale industrialization taking place in the area.
High-risk areas are analyzed by comparing a permafrost map with a map of the infrastructure in the Usa Basin. The permafrost map is based on characteristics like ground temperature, active layer and seasonal freezing, obtained from reference boreholes. The infrastructure map shows the distribution of the different types of infrastructure such as built-up areas, powerlines, pipelines and (rail)roads. Both maps are digital and by means of an overlay in a Geographical Information System (GIS), conclusions can be drawn about the possible high-risk areas for infrastructure in the Usa Basin under conditions of climate change. Future permafrost conditions in the area (over a period of 70-100 years) are derived from a transient permafrost model that utilizes the climate trend derived from a General Circulation Model (the Hadley Centre 750 ppm stabilization run) superimposed by a past climate record from the study area to account for very high natural variability.
Finally, an overview will be given of current adaptation strategies and techniques for preventing and repairing damaged infrastructure due to permafrost degradation in Russia. Also an inventory will be presented of other possible techniques resulting from engineering experiences of countries like Canada and Alaska.
This study was supported by a grant from the European Commission (Contract Nr. INTAS OPEN 97-10984).

Permafrost degradation and environmental hazards under global climate change.

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Scenarios of climate change derived from GCMs predict an increase of approximately 1°C in the global-mean air temperature by the mid-21st century, with much greater warming(2-3°C) in high-latitude regions. Permafrost models can be used to evaluate the effects of climate change on the ground surface temperature and the depth of seasonal thawing. Results from such a model predict 1.5 - 2.5°C warming of the ground temperature and 30%-50% increase of the seasonal thaw depth over the next 50 years. Changes of the ground thermal regime in permafrost regions will intensify thermokarst, active-layer detachment slides and solifluction. Climate projections for the first half of the 21st century indicate that warming of the upper ground layer may cause 30% to 60% loss of the bearing capacity, which can exceed the safety factor incorporated in the design of pile foundations. Deeper seasonal thawing of ice-rich permafrost may result in uneven ground settlement and cause severe damage of structures built on permafrost.

A hazard index was developed to regionalize degrading permafrost with respect to potential environmental hazards associated with thaw consolidation, instability of pile foundations, and mass movements. The hazard index was constructed using data on ground-ice content and projected changes of ground temperature and seasonal thaw depth under future climatic conditions. Hemispheric-scale maps of the hazard index indicate that elements of the infrastructure are at high risk in several parts of the circum-Arctic permafrost region. Special efforts may be required to prevent damage to existing infrastructure under the warmer climate in the first half of the 21st century.

Potential geocryological environmental hazards can be studied effectively using the Arctic-oriented information system "GeoInf," which was specifically designed to account for the various impacts of climate change in the permafrost regions of the northern hemisphere. The system includes climatic and permafrost databases, several scenarios of climate change, climate-driven permafrost models of different complexity, and tools for data analysis and visualization. The system facilitates statistical analysis of empirical records of permafrost and climatic parameters, and uses embedded models and scenarios of climate change to predict the distribution of near-surface permafrost, ground temperature, depth of seasonal thawing, and mapping of the hazard index for both modern and projected climate. Data can be represented as hemispheric maps or exported in standardized formats. Several tests indicated that the results predicted by GeoInf are in good agreement with the empirical permafrost data. In particular, the calculated distribution of near-surface permafrost in the northern hemisphere is in a good agreement with a recent empirical map of permafrost and ground ice conditions, including regional details.

Work of the pile foundations in thawing water impregnated ground in conditions of the development of negative friction forces and seismic effects.

Torgashov, V.
(Chita Department of Permafrost Institute, of Siberian Division of the Russian Academy of Sciences)

The engineering geocryological performance of a site is given in brief, on which were erected two multi-storeyed large-panel residential houses. The buildings were erected on pile foundations with use of permafrost ground on principle II (with the assumption of thawing frozen ground during operation of the building). Full-scale research of the joint work of the thawing base and pile foundations, with a monolithic tape, by pile cap were conducted. The foundations were executed with an uniserial disposition composite on the length of piles with depth immersing from 14.0m up to 19.0m.

The bearing capacity of the base of the piles is determined (by settlement measurement and results of static tests). The factors are established, under which there was irregular settling of piles, causing strain of the building. Comparative analysis of the network of elements of the system (thawing bases – pile foundation – building) of a two, multi-storeyed, large-panel, residential houses are undertaken, essential distinctions between the elements are revealed. Measures undertaken on each building for the purpose of restoring their stability and reliably are illustrated, and an evaluation of the efficiency of these measures is provided.

Calculation of the influence of cryogenic processes in soils while evaluating the stability of buildings

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While designing and constructing buildings for different purposes, arises the necessity of solving engineering problems, connected with the influence of disposed to freezing heaving soils upon foundations and other underground constructions. Such influences are caused by the development of cryogenic and postcryogenic processes, affecting the modifications of the building qualities of soils and the nature of interaction between foundation and building. The evaluation of stability and reliability of building under the considered conditions is connected with the necessity of defining both the value of deformation and intensity of freezing heaving of soils when being frozen through, as well as the characteristics of their strengthening attributes in the following process of defrosting.
On account of long-lasting field experiments, laboratory and theoretical investigations, the methods of forecasting the degree of frost-risk of the soils in building and constructing were elaborated. It is suggested that the intensity (heaving coefficient) and the value of freezing heaving of the soils should be determined on the basis of empirical dependence, taking into account form and condition of the soil, the speed and depth of freezing and the location of underground water level. On account of this dependence it is also possible to define the value of unit pressure of freezing heaving depending on the degree of limitation (constraint) of heaving deformation.
The regularity of moisture migration to the frozen layer subject to it's stressed state, water conductive qualities of the soil, gradient of humidity, the location of underground water level, the time and the speed of freezing was established. Approximately the winter water accumulation in the frozen layer of the soil can be defined on the basis of value of freezing heaving coefficient, determined according to stated above empirical formula.
The method of evaluation of the modification of the frozen soil solidity during the process of defrosting was established. The marginal resistance of the soil to the slide is highly dependent upon the value of migrating water accumulation while freezing. The restoration of the solidity of the soil up to it's initial (before freezing) level occurs in the process of consolidation of the defrosting soil. The degree of the solidity restoration during the certain period of consolidation can be calculated. On the account of the established regularities of forming strengthening qualities of the defrosting soil, the method was established aimed to define the value of the angle of internal friction and unit cohesion of the soil, which allows to calculate the marginal critical pressure, calculated resistance of the soil, and also to define the pressure on the barriers (retaining walls) and evaluate stability of soil massif in the slope while defrosting.

Application of freezing indices for design and maintenance of buried water pipes in mountain permafrost areas

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About 15% of the mountain railway infrastructure in Switzerland are located in the mountain permafrost area. In the last couple of years a lot of water pipes were constructed in high mountain areas. The seasonal frost or permafrost causes damages to some of these water pipes. At totally 11 locations temperatures were measured in different depths. Using linear extrapolation the seasonal frost penetration was estimated. The maximal measured depth of frost outside the permafrost area is 3.2 m. The mean delay time of the temperature minimum at the surface to the underground is 48 days. Using the equation used by Martin Hoelzle to predict permafrost a new freezing index is defined. The basic idea is to use the vertical distance from the permafrost limit as an indicator to predict the frost penetration. It seems to be possible to estimate the frost depth on the base of the new defined freezing index with an R^2-value of 0.8. Regarding the small number of temperature measurements this value has to be handled with care. Nevertheless it is possible to draw up a map in the GIS application FREEZEMAP according to the mentioned frost index which shows the frost penetration with an estimated precision of less then 50 cm.

The remote investigation of cryogenic objects with have been using microwave radiometric complex.

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The complex has been used in experiments on the study of processes occurring in soils while their freezing and thawing by remote measurements of radiobrightness temperature in a specified direction. Regime observations have been conducted at natural objects. Prolonged experiments have been done in inter-season. Extreme continental climate of regions where investigations took place imposed certain requirements on scientific equipment. The developed complex satisfies requirements of work in field conditions, possesses the temperature and temporal stability (the drift of output signal under the change of the operating environment temperature is practically unavailable), provides a high absolute precision of measurements.
High technical properties of the radiometric complex of devices have been made possible due to using in it a new principle of operation. Modification of the zero receive method with length modulation of the comparison signal has been used in radiometers.
The concept of the zero receive method is not new. M. Ryle and D.D. Vonberg used the zero receive method in the creation of automatic system for measuring the sun radiation (1950). In 1974 a group of American scientists (Hardy W.N., Gray K.W., Love A.W.) suggested another realization of this method – to adjust not power but duration of the comparison signal. This allowed to simplify construction of the input high-frequency radiometer unit and raise linearity of transmitting characteristics of the radiometer. However, length modulation has involved difficulties in processing signals after square-law detection when the envelope of modulation signals has been distinguished. The use of classic operations of phase-lock detection, filtration, integration for detecting voltage levels in different instants of antenna connecting and matched load resulted in this case in greater errors than in a conventional chopper radiometer. Therefore, length modulation has not received wide acceptance.
Authors of the paper suggested modification of the zero receive method with length modulation of the reference signal. Originality is in the uses of signals' processing after a square-law detector on a very unique scheme. A new algorithm of the radiometer operation has caused a total change and simplification of the low frequency measuring tract. The absence of transforming the modulation signal train form (antenna and references) into voltage levels for their consequent comparison has significantly reduced (one order of magnitude) an error of the device operation. After strengthening in a low frequency tract the signal arrives at the voltage comparator through dividing condenser. The condenser excludes de voltage in the signal, the comparator produces synchronous comparison of input voltage with a zero level. The output signal of the comparator analyzes a digital control block.
Construction of the complex incorporates two blocks – microwave and processing. Microwave block is set squarely on the antenna. It consists of two receivers for wave lengths 18 and 2.3 cm and detachable input devices. Fluctuation sensitivity of receivers at signal accumulation time 1 sec. is 0.05 and 0.1 K. Modulation of reference and measuring signals is done in input devices. The complex has five detachable input microwave devices differed by a range of measurements, sensitivity, stability.
The report is executed at support of the Russian Fund of Fundamental Researches.

Applicability of frequency- and time-domain electromagnetic methods for mountain permafrost studies

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The electromagnetic instruments EM-31, GEM-300 and PROTEM have been tested at various field sites during the PACE (Permafrost and Climate in Europe) project. In this paper the applicability of the different methods for permafrost studies in mountainous regions is evaluated and the results are compared with borehole data.
The EM-31 showed a great applicability for mapping of shallow permafrost occurrences and active layer studies on various permafrost environments. The surroundings of PACE boreholes were investigated for near-surface heterogeneities. Absolute conductivity values could not be determined due to the high-resistive

environment, but results are shown as relative conductivity variations along the survey lines. Sensitivity studies concerning snow cover and instrument drift were performed.
The multi-frequency instrument GEM-300 was compared to the EM-31 and showed good agreement between the results for similar induction numbers (relation between transmitter-receiver spacing, frequency and conductivity). However, care has to be taken in choosing the appropriate frequency in GEM-300 surveys, as the instrument response depends on the frequency as well as on the ground resistivity. For high-resistive materials (e.g. rock glaciers with a high ice content) high frequencies (19975 Hz with the GEM-300 or the single frequency 9800 Hz EM-31) are appropriate. In relatively low-resistive material, resistivity variations with depth may lead to different responses for different frequencies. The time-domain system PROTEM was used to determine the depth of the permafrost base at various mountain permafrost sites. The exploration depth in this study ranged between 100 and 300m, depending on the upper layer resistivity. The results were especially encouraging for sites with large contrast between the resistivity of the frozen and unfrozen layer (e.g. rock glaciers). Estimated permafrost thicknesses are in good agreement with borehole data.

Two new boreholes through the Murtèl-Corvatsch rock glacier, Upper Engadin, Switzerland

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In 1987 the first scientific cored borehole was drilled through an Alpine rock glacier (e.g. Haeberli et al., 1998). Meanwhile, the Murtèl-Corvatsch rock glacier is one of the best investigated creeping permafrost bodies. A number of studies provided information about different aspects: distortion of the borehole, analysis of the drilling core, snow cover characteristics, energy balance, temperatures in the borehole and at the surface, geodetically and photogrammetrically determined creep behaviour, hydrology, isotopic analysis of melt water and a number of surface geophysical surveys.
However, determination of factors of safety and geotechnical ground parameters has not been part of the investigations so far. To understand the thermo-mechanical behaviour, a combination of field and laboratory tests is necessary. The interdisciplinary ETH-Project "Unstable Alpine Permafrost – a potentially important natural hazard" involves the three institutes Geotechnics , Geophysics and VAW. In 1999, when four 70m deep boreholes were drilled through Muragl rock glacier (Musil et al., 1999), only a few cores could be saved due to various reasons. Therefore, it was decided to drill additional cores at Murtèl-Corvatsch in 2000.
A chilled air drilling system with a triple tube drill rig was used in order to core undisturbed samples. The new boreholes reached depths of 51.9m (1/2000) and 63.2m (2/2000), respectively. They are located at 16m and 33m upslope from the borehole 2/1987. Internal structues were compared to the reflection horizons of the GPR survey (Vonder Mühll et al., in press).
In contrast to 2/1987, major problems with the borehole stability occurred at different depths. Not only in the lower part, where a talik in known to exist, drilling difficulties were encountered. Below the shear horizon mainly large boulders partly with a lot of air voids are present. Some arching effects might have formed distinct stress passes within the ground were the material is compact and the borehole wall was stable. On the other hand, regions seem to exist, where nearly no compaction occurred and the ice-gravel-mixture is in a very lose, granule state with no real overburden pressure.
In addition, free water was found within the ice in borehole 1/2000 at 27.0m, which indicates, that at temperatures closely below 0°C, water lenses might be present and as a consequence, influence the creep behaviour of the rock glacier. Even though the bedrock was assumed in a depth of about 45m, there were still lose blocks, voids and gravel all the way down to a depth of 63.2m.
In total, some 40m of frozen cores were got for laboratory testing. Determination of in situ strength and stiffness using a pressuremeter has been performed (Arenson and Springman, 2000). Moreover, instruments for long-term monitoring of deformations and temperatures have been installed.

Temperature regime and permeability of a tailing deposit on permafrost in Bjørndalen, Spitsbergen

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For the last 30 years large deposits of material from the construction of Coal Mine no. 3 (gruve 3) have been placed on permafrost in Bjørndalen. The main fill is approximately 20 metres high and during the summer season, acid seepage from the fill causes environmental problems and destruction of the vegetative cover downstream from the fill.
Y-shaped ditches have been dug on the downstream side of the fill, but have failed to eliminate the problem. Acid seepage is also a problem for other mine tailings on Svalbard.
The main objective of the research presented in this paper, was to gain a better understanding of the physical processes involved in water seepage through "modern" man-made fills in permafrost areas. This has been obtained by:

- analysis of the hydrological regime in the area surrounding the fill,
- measurements and modeling of the thermal regime in the fill,
- measurements and estimates of the permeability of the fill and spatial and time dependent modeling of seepage through the fill.

Based on the improved physical understanding of the thermal regime, permeability and seepage patterns remedial actions are suggested in order to reduce the problem with acid seepage from man-made mine tailings on Svalbard.

Ground Penetrating Radar (GPR) investigations in a discontinuous permafrost environment, Greenland

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Permafrost is an important factor when considering hydrologic studies in arctic regions. More precisely, the depth, the thickness and the discontinuity of the permafrost are key parameters in determining and mapping suprapermafrost and subpermafrost groundwater.
We used ground-penetrating radar (GPR) in an attempt to map the permafrost parameters, the areas of frozen and unfrozen materials and the bedrock interface in Greenland. The survey area is located in Sisimiut, just north of the Arctic Circle on the West Coast of Greenland. The environment is arctic with discontinuous permafrost, and the investigated area includes an 18m deep freshwater lake, which serves as the sole water supply for the town (about 6000 people). However, because surface water has to be treated bacteriologically, a groundwater pumping well is desirable. Therefore, the aim of this study is to locate subpermafrost groundwater and to follow the seasonal changes in the permafrost under the lake area.
For a better interpretation of the GPR data, information on the electromagnetic properties of the local geology is of great importance. This was achieved by making TDR measurements (Time Domain Reflectometry) on geological samples taken from the site. Thus we obtained values for both the permittivity and the electric conductivity as a function of temperature of the water and its surroundings. These measurements made it possible to estimate the radar wave velocities in and the depths to the permafrost, the thawed zones and the water.
The GPR profiles were carried out across the lake both in the late summer and in the early spring with 50, 100 and 200 MHz antennas, giving different resolutions and penetration depths. Though the radargrams were quite complex due to multiples, scattering losses and snow cover on the ground during the winter, clear differences in the seasonal extent of the permafrost are seen. All together the GPR method appears to be a very efficient tool in mapping the unfrozen and the frozen areas of the arctic environment.

New geophysical methods of investigating the nature and distribution of mountain permafrost with special reference to radiometry techniques.

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A series of geophysical surveys were undertaken within the PACE Geophysical Work-Package. Various methods were applied including refraction seismic, DC resistivity, ground penetrating radar (GPR), electro-magnetic induction, radiometry and Bottom Temperature of Snow cover (BTS). The focus of the surveys was to determine internal structures and distribution of mountain permafrost. The present paper gives a preliminary overview of progress. The two-dimensional DC resistivity tomography combines the geoelectrical sounding and mapping and makes it possible to model internal structures. This method was applied at all PACE drill sites. Electromagnetic induction methods (described in detail elsewhere in this volume) showed good results, in particular the EM-31 for determining the permafrost distribution and the PROTEM to assess the overall permafrost thickness. A major new development discussed here is the use of passive microwave (11.4 GHz), for air-born remote measurement of the Bottom Temperature of the Snow cover (BTS). Manual BTS measurements agreed very well with the BTS determined by radiometry. To reduce ambiguity, several geophysical methods should be deployed at the same locality. As a further step, such measurements could be interpreted using joint inversions.

Geotechnical centrifuge modelling of mass movement processes associated with thawing permafrost soils

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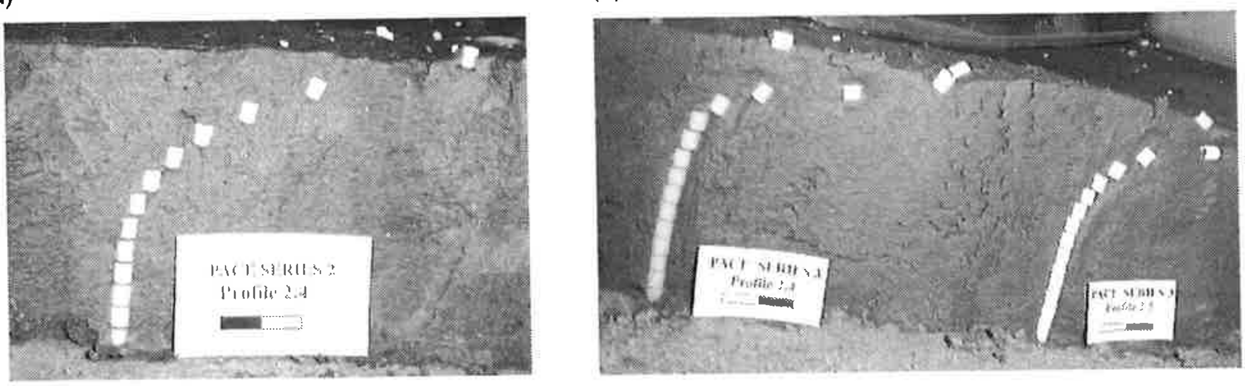
This paper presents initial results from scaled geotechnical centrifuge modelling of cryogenic slope processes. The basis for physical modelling is that geometric and dynamic similarity between model and prototype (full-scale equivalent) allows the response of the prototype to be interpolated from the observed response of the model. Centrifuge modelling of the thaw consolidation process involves no scaling conflicts, so the technique offers great potential for cryogenic process studies. Four experiments are described in which 1/10 scale planar slope models were constructed from a silty soil at gradients of 12°, 18° and 24°. Models were frozen on the laboratory floor, and thawed in the centrifuge at 10 gravities. Frost heave, thaw settlement, soil temperature and pore water pressures were recorded. In each experiment, ten columns of 5 mm long plastic cylinders inserted through the soil profile, allowed surface soil displacements to be determined, and indicated displacement profiles with depth at the end of each experiment (Fig. 1).

Figure 1. Soil displacement profiles (a) 12° slope, four cycles of freeze-thaw; (b) 18° slope, two cycles of freeze-thaw.

(a) (b)



The 12° model was subjected to four cycles of freezing and thawing, simulating four annual active-layer freeze-thaw cycles. During each thaw phase, gelifluction occurred, and average model-scale surface displacements were 18.7 mm per cycle (equivalent to 187 mm/cycle at prototype scale). In the 18° model, gelifluction rates were higher, with average surface displacements of 65.1 mm/cycle at model scale, 651 mm/cycle at prototype scale.

Peculiarities of cryomorphogenesis on the slopes of the Russian western Arctic sector

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Evolution of the western sector of the Arctic during the Quaternary predetermined the peculiarities of their geological and geomorphological structure, formation and evolution of cryolithozone and specific features of cryomorphogenesis. Stability of slopes in these regions both in natural conditions and under economic development depends upon these factors. Coastal areas of the Arctic are characterized by the existence of the complex of glaciomarine and marine sediments dated from the Late Pleistocene and Holocene. These sediments form a successive series of terrace-like levels. Specific character of cryomorphogenesis in these areas is conditioned primarily by lithology of relief-forming sediments and climatic conditions. The extent of cryogenic processes governing the slope stability also depends primarily upon sediment composition. In general, we can conclude that geosystems, including those on slopes, composed primarily of sand and loamy sand sediments are more stable to technogenic processes in comparison to those composed of clayey and loamy sediments. Specific character of cryomorphogenesis on the slopes of the western Russian Arctic is considered here for two territories in the north of Russia situated in similar geological and geomorphologic conditions, namely Kolguev Island (Barents Sea) and Yamal Peninsula (Kara Sea). In principle, slopes are unstable systems unfavourable for technogenic development. This is especially true for the slopes of the Arctic where the slopes are in the borders of the permafrost and, therefore, subjected to all negative consequences of ground changes under any thermal variations in the system ground-atmosphere. Ground composition of accumulative plains on the Arctic coast of Russia is a leading factor of landscape formation in similar geomorphological and climatic conditions. However, even in the Arctic and Subarctic, specific character of cryomorphogenesis connected with the geological and geomorphologic structure of any territory during the Quaternary makes it possible to reveal the more or less stable slopes. This fact permits an advance prediction of formation and development of any zonal (frost) processes and phenomena on slopes and selection of methods of their economic development minimising negative consequences of anthropogenic impact. Engineering geological properties of grounds used as basements for various constructions depend primarily by specific features of their composition and structure. In arctic areas, besides water physical properties, thermal regime of perennially frozen grounds, their salinity and the presence or absence of ground ice of various genesis have a great influence on ground resistance to engineering constructions.

Permafrost in the Mattertal, Swiss Alps; monitoring, degradation and geotechnical consequences.

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Prospecting, mapping and monitoring of mountain permafrost is of interest for geomorphologists as well as engineering geologists. The paper summarises the permafrost research done in the Mattertal, Wallis, Swiss Alps during the past 15 years. In the research area permafrost occurs to a vast extent and merits special attention as Zermatt is one of the prime tourist sites in the Alps.

A great number of field observations connected with the existence or non-existence of permafrost (especially a great number of active and relict rock glaciers, or perennial snow-patches) form the base for automated mapping of potential permafrost areas. These models were verified in the field. The measurement of the basal temperature of the snow cover (BTS) offers the opportunity to map mountain permafrost at the end of the winter at a large number of points in a short time. The BTS value gives an indication not only to the probability of permafrost existence but also to the mean annual ground temperature. This allows a very rough estimate of the probable permafrost thickness. A summary of laws governing the permafrost distribution is given.

The combination of ground temperatures only slightly below zero, high ice contents and steep slopes, makes mountain permafrost vulnerable to even small climate changes. Slow melting of deeper subsurface materials may provoke instabilities of steeper slopes in general. This may result in increased landslide activities that can hit areas that have never been submitted to this danger during postglacial times. Where buildings and other installations are underlain by permafrost, their foundations may directly be affected by ground thawing.

Important information is supplied by construction activities. These include roads, railways, cable car stations, ski runs, communication towers, avalanche protection installations hotels and supply lines (e.g. water and sewage). In the Gornergrat/Stockhorn area, the permafrost thickness increases from about 50 meters, Gornergrat (3100 m) to probably more than 200 meters at the Stockhorn monitoring site (3400 m a.s.l.). In the Kleinmatterhorn area, a thickness of more than 300 meters at 3820 m a.s.l. may be expected. However, problems with permafrost degradation may arise at tourist installations when questionable construction design exists or careless operation with heating happens. In the Seetalhorn/Grächen area, a permafrost thickness of more than 100 meters is expected at an altitude of 2860 meters. Several tourist transport facilities have been built on ice-coated, loose material. For safety reasons, these sites are regularly inspected concerning stability problems due to permafrost creep and degradation.

Whereas great progress was achieved in the understanding of the spatial distribution of mountain permafrost, relatively little is known about its changes over time. Here the permafrost monitoring network of the PACE-project will form a good base to study the permafrost behaviour under changing climatic conditions. A permafrost monitoring site has been developed on the Stockhorn with drillings of 100 meters and 20 meters, respectively.

An investigation of the effect of global warming on rock slope stability using the technique of centrifuge modelling

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Charles Harris, School of Earth Sciences, Cardiff University

The presence of ice in discontinuities can contribute to maintaining the stability of rock slopes (e.g. Bjerrum and Jørsbad, 1968). Because the strength of ice is a function of temperature, weakening of ice bonded joints is likely as rock temperatures rise. Such slopes may, therefore, be sensitive to changes in the thermal environment, for example the impact of climate change. Centrifuge modelling allows studies of the mechanisms associated with the stability of frozen rock slopes to be investigated under highly controlled boundary conditions and provides the opportunity to explore consequences of changes in thermal regime. As part of the EU PACE programme, scaled models of suitable prototype slopes were constructed and then permitted to thaw during centrifuge operation. The data, from the experiments, has been used to assess performance prior to failure and identify trigger mechanisms.

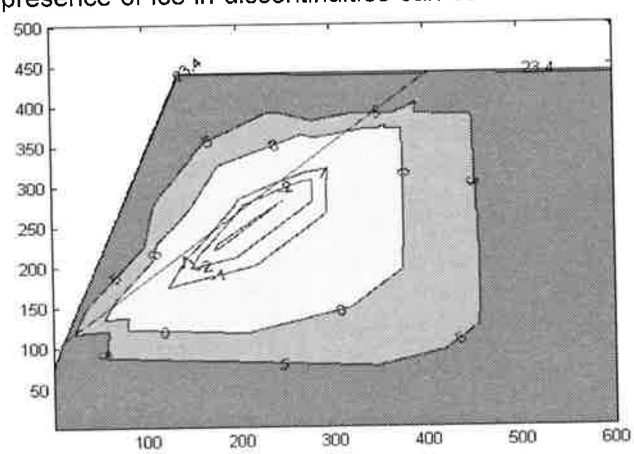

Fig. 1 Isotherms at failure

Direct shear box tests were conducted to investigate the strength of ice filled rock joints. This revealed that the stiffness and strength of an ice filled joint is a function of both normal stress and temperature (Davies et al 2000). Comparison of these data with the results of similar experiments conducted on unfrozen joints indicates that at low temperatures and normal stresses the strength of an ice filled joint can be significantly higher than that of an unfrozen joint. However, in the absence of sufficient closure pressure, the strength of an ice filled joint can be significantly less than that of an unfrozen joint. This implies that if the stability of a slope is maintained by ice filled joints its factor of safety will reduce with temperature rise. This hypothesis suggests that a jointed rock slope that is stable when there is no ice in the joints and is also stable when ice in the joints is at low temperatures will become unstable as the ice warms. Results from the model tests have confirmed this hypothesis. This is demonstrated in Fig. 1, which shows isotherms at the moment of failure in an experiment modelling a 40 m high slope that is stable in the unfrozen state, at which stage temperatures were below zero along 74% of the discontinuity.

Poster Presentations

Some regularities of development negative friction forces on a lateral surface of deep-lying foundations

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Experimental and theoretical research negative friction, acting on the deep-lying foundations in thawing soils, are conducted. The experience in full-scale and laboratory conditions were carried out. The comparison calculation and experimental values of negative friction forces, obtained in full-scale conditions is given. It is found that in the majority of cases mean values of negative friction specific forces f_n, calculated according to CRP in 1.5-2.1 times higher than experimental values.
Negative friction forces substantially depend on the ratio of the pile cross section sizes and the leading bore diameter. Nine stages of interaction of system elements «pile-soil» have been established, every stage being analyzed. Some peculiarities of thermo-mechanical interaction of piles with thawing soils are stated.

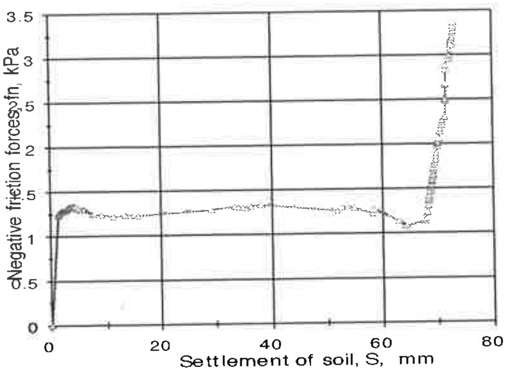

Fig. 1. Dependence of negative friction forces, developing on lateral area of pile model SRS, from setting of thawing soil

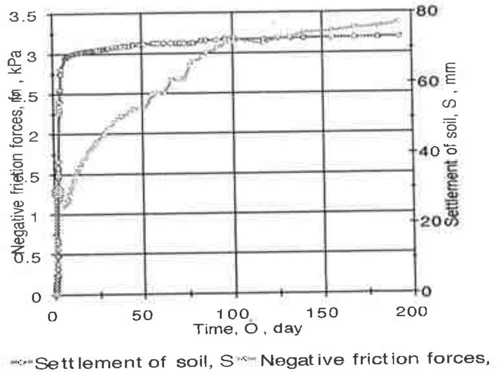

Fig. 2. The time change of setting of thawing soil and the time change of negative friction forces

Table 5. Comparison of the results of determining of negative friction forces, obtained by an experimental method in full-scale conditions and by a calculation method according to CRP

Number of test	Number of tested pile	Specific significance of negative friction forces, MPa, obtained :		Error of calculated method of the definition of negative friction forces, %
		By results of tests $f_{n,test}$	By calculation under the formula ÑRP 2.02.04-88, $f_{n,calc}$	
1	1	0.0193	0.036	86.5
2	1	0.0201	0.036	71.9
11	2	0.017	0.032	111.8
1	3	0.038	0.060	57.9

Permafrost monitoring of the structure foundations of the gas regions of the northern part of the Western Siberia

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Main gas provinces of Siberian are situated in the permafrost zone, that demands to make regular frost monitoring by the foundations of the main objects. Such system of monitoring is established in Jamburg in the northern part of West Siberia. Geocryology monitoring on the inhabited and industrial areas take place in the period of the engineering preparation of the squares for building up, building and exploitation of the buildings and structures. Special attention to the condition of permafrost ground complexes is allotted in the areas of development dangerous engineering geocryology processes, object deformation or special works to strengthen foundations are conducted. In this report are given the results of the field observations, calculations, theoretical researches of the conditions of the main structures, objects deformed under breaking geocryology and geoecological conditions. Differences in the stability of objects, maintained in the permafrost zone on the different types of foundations are proclaimed and connection with negative technogenetic influences is established. System of observations and calculations for prognosis of situation is given. Also in this report are offered methods to increase stability and safety exploitation of the buildings and structures in the permafrost zone.

Interrelation between frozen soil and rock moduli of deformation obtained under various regimes of mechanical stresses.

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The frozen soils and rocks as heterogeneous and multiphase elastic-viscous media are deformed differently under mechanical stresses-σ in dynamic (periodical) regime and in static load tests. This is reflected in different values of dynamic E_d and static $E_s = f(\sigma)$ moduli of elasticity and in its grow with the temperature decreases. The applied soil mechanics use also a modulus of total deformation $E_{def} = f(\varepsilon)$ taking into account in addition a quasiplastisity of frozen grounds. The determination of the E_s and E_{def} values is much more complicated as compare the acoustic tests. Nevertheless, in accordance with physical model of frozen soil (Frolov 1998, 1999) the deformations under various stress regimes are conditioned by the same physical subsystems of medium influences the response on stress hence the values of the moduli E_d, E_s and E_{def} ,which considerably depend on the state and composition of inter-grain zones of frozen soils and crack zones of frozen rocks. This indicate on the possibility to establish the correlation between dynamic (real elastic) parameters E_d, stress wave velocities V_p or V_s and E_s , E_{def}. The correlation of such kind obtained for frozen soils and rocks as the result of analysis and generalization of the data of laboratory and field studies are presented and discussed. The obtained interrelations make it possible to evaluate the E_c and E_{def} values of frozen media using acoustic and seismic techniques.

Technocryogenesis as a leading exogenic process in industrial centres of permafrost zone

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Natural complexes in the permafrost zone are extremely unstable under technogenic influence. The tendency to the degradation of permafrost observed in large cities of cryolithozone results in the

development of dangerous cryogenic and glacial (in mountain and piedmont regions) processes. Basic reasons causing changes of permafrost conditions are as follows: changes to the natural landscape had introduced various anthropogenic infringements during construction; imperfect methods of engineering preparation of development sites; heat flow into the ground, especially during the installation of pile foundations; numerous infringements during the operation of ventilated cellars and other cooling geotechnical systems; mechanized redistribution of snow cover; arrangement of underground collectors for engineering communications; changes in thermal physical properties of the ground. Thermocarst, unpredictable increasing of the ground temperature of frozen bases during the construction, solifluction, technogenic rock glaciers, thermal erosion as well as other negative processes developed under technogenic impact cause critical situations. All these dangerous engineering-cryogenic processes may be united in the term "technocryogenesis". Technocryogenesis is a specific exogenic process developing on urbanised territories of cryolithozone. It appears as a result interaction between technogenic loading and geocryological conditions. This process is irreversible and manifests itself in the formation of special natural-territorial geocryological complexes. Modern geocryological and geoecological situation in largest industrial centres of Northern Russia is analysed in the report, the results of influence of technocryogenesis on permafrost are presented, proposals on the stabilisation of situation as well as application of effective measures on geocryological conditions management are given.

Distribution and geotechnical implications of permafrost in the Zugspitze area (Bavarian Alps)

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In the Zugspitze area (Bavarian Alps, Germany) permafrost conditions are present in limestone bedrock and in regolith. Distribution is strongly dependent on topography in the east-west oriented mountain crest with steep north and south facing slopes. Numerous constructions mainly for tourist purposes (cable car and recreation buildings, ski lift masts, rack railway tunnel, tunnel with supply facilities) are situated in the area and several of them are placed on permafrost underground. Results from a temperature measurement programme and modelling with PERMAKART/PERMAMAP (ETH/University Zürich) carried out within the EU-project PACE (Permafrost and Climate in Europe) show that for some of these constructions the effects of permafrost melting have to be considered in terms of stability of the foundations.
Actual permafrost conditions are found in the bedrock of the east-west oriented Zugspitze crest, but measurements and modelling show the lower limit of continuous permafrost in the south facing slope to be located close to the summit crest. Permanent surface and subsurface measurements carried out with miniature dataloggers in several sites (2780-2950 m a.s.l.) display a sporadic occurrence of permafrost in this south facing part depending on micro-relief and snow distribution. Monitored BTS temperatures are between -3.5 and -1.5°C and only in one site subsurface temperature (1 m depth) is lower than surface temperature during winter. In the north-facing slope permafrost is obvious e.g. due to prevailing ice on surface and in joints. Permafrost in this summit crest area seems to be more or less in equilibrium with actual climatic conditions.
In the base parts of the south facing slope and in the adjacent cirque area (Zugspitzplatt) with small retreating glaciers ground ice is found in regolith and moraine material. Modelling results stress that this area is well below permafrost limit. BTS measurements on the Zugspitzplatt (2500-2650 m a.s.l.) display temperatures of -2.4 to 0°C with a mean of 1.2°C. Hence, the observed ground ice is assumed to exist only as relic ice, i.e. as ice-cored moraines or relic permafrost and therefore, melting is in progress but is retarded due to thick isolating regolith covers. Actually, melting of the ground ice accompanied by subsidence has been observed in several sites.
As results of the investigation programme and the analysis of constructions main risks which have to be considered related to permafrost are (1) the possible failures of foundations and rockfalls in the bedrock summit area and (2) the subsidence of foundations in the regolith/moraine area.
The permafrost distribution has several implications for the constructions in the Zugspitze area. Since the summit crest displays the permafrost limit stability evaluations for the constructions in this area have to consider the possible melting of ice within the bedrock caused by climate warming. Stability of the foundations as well as stability of rock walls in this area probably will be affected by a shifting of the permafrost limit. Constructions in the Zugspitzplatt are already affected by the melting ground ice and stabilising measures have to be evaluated for several foundations where subsidence is likely to occur.

The mass movement-permafrost couple: deep seated gravitational deformations and landslides in the Alta Valtellina (Lombardia, Northern Italy) influenced by the raising elevation of permafrost.

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One of the key issues in order to understand the hazards due to deep-seated gravitational deformations (DSGD) and mass movements is the influence of different mechanisms. We started a project in the area of Valtellina to evaluate the relative weighting of the different morphogenetic factors that contribute in past and present to the recent geological evolution of the valleys. The reconstruction of the late glacial and holocene landscapes should allow to quantify the evolutionary trends and relative interactions by tectonics, fluvial dynamics, glacial and gravitational processes as well as anthropogenic impacts during historical times.
In this regard, one most important and discussed factor that can influence the stability of high mountain slopes is permafrost (Haeberli et al., 1997). For instance, the observation of permafrost in the upper part of the Val Pola landslide support the idea that variations in the state of permafrost can play a significant role in similar catastrophic landslides in the Valtellina (Dramis et al., 1995).
In principle we try to answer if the landslides and DSGD can be reactivated or increase their action in the future in connection with the raising elevation of permafrost by the following approach:
A detailed map of a test area of the Upper Valtellina has been compiled using field mapping, interpretation of aerial photographs and historical data. It considers the distribution of the quaternary and mass movement phenomena like DSGD, rock falls, debris flows and debris slides. This map performed with GIS software allows the integration of other data like stratigraphies, dating results, mesostructural analyses and historical data, to reconstruct the recent landscape evolution since the Upper Pleistocene. In a second step this map will be combined with Landsat TM images which clearly represent zones of permafrost Guglielmin, 1997) in order to get a better picture of the permafrost influence on lanslide phenomena. This test can be used as calibration for the greater region of Valtellina to quantify how many DSGD and landslides are influenced by the raising permafrost conditions.

Development of deformations of buildings and constructions under changing geocryological conditions

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Observations conducted in the 90-s provided evidence of increasing number of deformed structures. It has been determined that thawing of perennially frozen soils enclosing end-bearing piles leads to a drastic decrease in piles stability owing to the action of bending moments and shearing forces. Consequently, permafrost warming and thawing phenomena manifestations vary which results in different foundation displacements causing structure deformations. Furthermore, different loads on particular supports enhance differentiation of foundation dislocations. Currently about 25 % of large structures in Norilsk are situated on foundations beds with disturbed frost conditions and about 250 buildings has been deformed. For the last 5 years foundation beds with technogenetically minimized bearing capacity have numbered 5 times as great as for the 50 previous years. It has been established that a general tendency in big cities of the region is towards permafrost degradation. Yet local permafrost warming up and thawing manifest themselves more pronouncedly and have more adverse economical and environmental impact than general warming up with a stable temperature balance. A thorough examination of the current construction norms and specification has revealed that the most commonly used pile types in Norilsk region (0,4x0,4 m and less) have not been specified by the state construction standards. Violations of maintenance rules for geotechnic systems (service cellars, collectors etc.) and distinctive features of structures heat release result in thawing of frozen layers. Non-uniform thawing soil settlement, presence of frozen lenses and rise of ground water enhance local variations of unfavorable impacts on deep emplaced piles.

Defrosting of permafrost with using of jet grouting method

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With using of icy permafrost as a base of buildings and structures, the deformations of that base arise often under its defrosting and following soil consolidation due to civil-engineering loads. An artificial freezing of soils at wintertime is the most widespread method of a base bearing capacity maintenance. But for permafrost of temperature more then - 1°C this method can be not sufficient effective. Because it makes a sense to consider an expediency of an artificial controlling process of frozen soils reformation, that is theirs artificial defrosting with following artificial consolidation. The described below process of an artificial soils defrosting simulates natural processes, but it allows accelerating of ones in thousands times as rate. For this aim the jet grouting method is used. The operations sequence is following. At the first stage holes drilling is executed according to given graticule. Later a jet monitor with washing-out nozzles is sunk into the hole. The nozzles are fixed in different directions according to given angle, for example 180o with each other. Later pressured water, compressed air and a sand pulp of high consistency are feed to the monitor and one is lifted slowly. In the process of this operations the narrow slots of average width of 100 - 150mm are originated by water jets in an air stream, for whole thickness of defrosted massive, with filling those slots by sand. In coarse of the technological process a washed-out soil is carried away through the hole with wastewater and foul air. In the result of sequential execution of above-mentioned operations the massive of permafrost soil is divided to blocks of square or polygonal form by drainage slots, which are filled by sand. At the second stage of the works a trench is excavated at the depth, which is traded off a crossing of this trench with the drainage slots. A warmed up by sun water from shallow pond is feed into the mentioned trench. At the third stage well pointing is executed from opportunity side from the network of drainage slots and it causes a defrosting of frozen soil blocks. All three stages are executed in synchronism. A presence of drainage slots network with draw-down under way after soil defrosting completion and too a load from base's soils layer, which is disposed upper of elevation of permafrost, muss promote to advantage of active consolidation of defrost soils. This is especially effectively in those causes when we are concerned with weak clayey soils or with silt.

The interaction of linear technogenic systems and permafrost rock on the economical developed territories of the cryolithozone

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At the moment the science notes the important role of transport communications and other linear constructions in the alteration of the cryolithological situation, what demands new approach to this problem. Unlike other anthropogenic influences (global, local, specific etc.), the linear technogenic systems form the extensive but comparatively narrow zones of important influence on the environment and, after all, on its landscape permafrost and ecological components. It demands special approach to research and monitoring. Changes in geocryolithological conditions occur differently depending on the technogenic influence type. It should be emphasized that by the construction and exploitation of linear structures the dangerous cryogenic processes, resulting in the destruction of linear systems and alteration of regional geocryolithological situation, usually arise. Such deformations are studied on the Urengoy gas fields, in the Norilsk industrial and in the other regions in the north of Russia. In the report the reasons of the aggravation of permafrost situation by the construction and exploitation of linear objects are analyzed, the specific examples of dangerous process development are cited, the forecast of changes in geocryolithological conditions (also taking into account the different climatic scenarios and technogenic influences) are worked out and the suggestions on situation stabilization are given.

About the mechanism of creep of high-temperature" frozen soils under external loads

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Institute of Environmental Geoscience of Russian Academy of Sciences

In works of the authors the new scientific field is developed. Creep of frozen soils under external loads at high negative temperatures is considered as a result of processes developing at the level of particles of soil. First of all the process of water movement and consolidation is considered at negative temperatures. The contact interaction of mineral particles and ice, melting of ice was originally taken into account in view of densities of ice and water, infiltration of water in pores and to the surface of soil.
The numerical calculation of contact interaction of mineral particles with ice was carried out both the classical method of Hertz and the method of homogenization of the physical characteristics of components of frozen soil. Thus the task of the mechanics of discrete environment was united with the thermodynamic Clausius - Clapeyron equation. The areas of the thaw ice and channels between particles were simulated by a grid with the elementary objects - crosspieces either conducting, or blocking. The conditions of occurrence of a cluster, i.e. a system of conducting elements connecting any surfaces in soil were obtained. The formula for a total flow of water to the surface of the sample allowing predicting of the part of deformation was received. The equation is connected to the local phase transfer "ice - water" and water movement to the surface of the sample.
The further analysis shows that the mechanism of consolidation of frozen soils essentially differs from the mechanism of consolidation of thawed soils. There are areas of the lowered pressure in frozen soil on ways of water flow, and there are no that areas in thawed soils. In frozen soils the areas of the lowered pressure are areas of repeated freezing; due to that the flow of water has faltering character: beginning is in the area of the raised pressure, and stop is in the area of the lowered pressure. Between the elementary acts of absorption and allocation of heat a balance is established. The same balance is established in experiences on passage of a firm body through ice. The offered model in a combination to the above-stated methods can be used for a quantitative assessment of water flow to periphery part of the sample, to the pores and to the ice lenses with the subsequent freezing.

Assessment of working shallow foundation from the influence of frost heaving forces.

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Dr. J.A. Ivin, Chita Technical University (Russia)

The most effective and easy method of building construction is to erect them on shallow foundations. Shallow foundations are pawned in later seasonal freezing and so are subjected to tangential and normal frost heaving forces. Tangent forces are formed and act along the lateral surface of foundation, but normal-perpendicular sole of foundation. However simple summation of these forces does not reflect the real picture of interaction of shallow foundations with freezing swelling soils, as by non-simultaneous action of these forces, and by the different mechanical nature of the interaction between the body and the foundation.
For development of the method of calculation shallow foundations we carried out field and laboratory experimental researches. Studies were conducted on two experimental ranges in regions with different climatic conditions: The researches were carried out on two experimental ranges in regions with various climatic conditions: in the European part of Russia and in Southern Transbaikalia. Each author carried out independent researches, and propounded problem was studied from different sides. In this work is done attempt to unite the carried out researches and to present a considered problem on more high level, than in separately taken our works.
The carried out researches have shown that at the calculation is impossible to use a simple summation of tangent and normal frost heaving forces. Joint action of tangent and normal frost heaving forces should be corrected by the parameter _ which depends on freezing basis conditions. The technique estimation of up-heaving loaded foundation in view of forces action and values of pressing foundation on frost soil. is offered. For increase of reliability work shallow foundations are conducted preventing measure. In given work two preventing measure – defensive screen from the polymeric film and inside sandy pillows are considered. The researches temperature and moisture condition freezing soils are given.

The results of researches allow to decide some problems arising at designing shallow foundations and give direction for the further research.

Researches of a microstructure frozen ground as one of major directions in study of cryolithosphere

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The researches of a microstructure frozen ground now are one of major directions in study frozen deposits of cryolithosphere. The basis of these researches was incorporated in 50 years P.A. Shumsky in institute of Permafrost Academy of Science of USSR, in 60 years and until now they in Russia will be carried out, mainly, at the Moscow university. At the end of 60th years in research of a microstructure by the author for the first time was applied scanning electronic microscope. To the present time the significant material reflecting features of morphology of a skeleton, inclusions of ice, not frozen water and new growth in the frozen ground of various genesis is saved. Is shown, that the particles of a skeleton of frozen ground, tested cryogenic influence have specific features - cracks and fragments, connected with destruction by their ice at numerous freezing. Other feature is connected with cryogenic aggregation and iron-clay pellicles in a surface of particles. The types of ice- cement in sand and clay deposits are determined and the connection between conditions of freezing. and its structure is found. It is revealed, that a genetic difference between ice - cement and segregate ice does not exist, last is formed at increase of volume of ice - cement and its structural parameters have the same dependencies on conditions of freezing of adjournment. Is found out, that during cryogenic transformations in the frozen ground are formed authigenic minerals of various structure being the important criteria of genesis of frozen deposits. The close connection of character of a microstructure of frozen deposits with types of their formation - epigenetic, syngenetic and cryoeluvium - is established.

Determination of long-term strength and strain of frozen soils under freezing temperature by time analogy methods

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Our research show that time-analogy methods may be used for prediction of long-term strength and strain of frozen soils. The essence of these methods is that they accelerate strain and reduce stress by factors which affect these processes. Such factors are higher temperature, load, load rates designated physical properties of soils. The using of time-analogy methods give possibility to receive strength and strain on the period near one hundred years on the basis of short-term experiments.
The different time-analogy methods (temperature-, stress-, concentration time-analogy) was mastered for different kinds of tests (uniaxial and triaxial compression, tension, shift, penetration of spherical punch) and different kinds of soils (sand, loam, clay, saline soils).
The received results of predictional long-term strength and strain gives on this paper for different frozen soils on wide diapason of temperature. This data are good material for analysis quantitative and qualitative changes of mechanical properties of frozen soils under rise of temperature, increases of load, increases saline, ice concentrations.

Frozen heaving of large dispersed soiled system.

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In the report general concepts and determinations for large dispersed soil systems are given, results of field and laboratory researches its frost danger are brought. Influence of the various factors to dynamics and laws of development of heaving of large dispersed soil systems, mechanisms of moisture transfer on a cryogenic structure and heaving is considered. In work is shown, that statement about the unfrozen danger of large dispersed soil systems is not always carried out.

Thus, field and laboratory experimental researches of heaving of LDSS (large dispersed soil systems) have shown, that:

- the highest significance's of speed of heaving of LDSS are marked in December – January;
- the most frost danger is the layer of LDSS equal 50-70 % of capacity of seasonal freezing soils;
- at availability of conditions for prevailing development of injectional and vacuum-migration mechanisms of training ice formations in LDSS irrespective of the contents of LDC (large dispersed component) and of dispersivity of FDC (fine dispersed components) can be extremely frost danger;
- influence of the contents of LDC on frost danger of LDSS should consider in a complex with other factors, determining optimal conditions of development of frost heaving: by a mechanism of formation ice inclusions, by speed of freezing, by natural moisture before the beginning of freezing, by gradients of temperatures at freezing of LDSS;
- in field and laboratory conditions in case of prevailing significance of migrational-segregation mechanism of formation of ice inclusions, frost danger of LDSS is practical always increased at a increase of the contents and dispersivity of FDC;
- increase of significance of gradients of temperatures from 3,3 °C/m up to 33,3 °C/m essentially reduces the frost danger of LDSS, and it is displayed the most appreciably at the contents of LDC less than 50 %;
- frost danger of loamy LDSS at the similar contents of LDC essentially higher than frost danger of sandy loam LDSS;
- the significance of frost danger for LDSS, received in field and laboratory conditions as a whole differed on 10-20 %, that permits to recommend a laboratory method of researches, developed by us for mass determinations of significance of frost danger of LDSS.

The report is executed at support of the Russian Fund of Fundamental Researches

Stability of underground cables under influence of frosty ground cracking.

Zheleznyak, Y.

The exploitation of underground cables in cryolite zone is an engineering task of serious difficulty. It is mainly connected with the negative cryogen influence of season freezing and defrosting ground on cables. There is first of all cracking. Such influences can cause mechanical damages to the cable : in the form of a break. There are results of experimental observation of formation and evolution of cryogen cracks in the ground, thermic processes accompanying them in the report. An original method of calculation of the cable stability under the influence of frosty ground cracking is given in the report, The report presents effective devices and methods for protecting the underground cables from breaking by frosty cracks. These methods are patented by me same time ago.

Influence on the freezing performances of drilling slurry by additive

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It is necessary to mix with an amount of additive to drilling slurry in order to meet with demand of the technical craft and suit to changes of stratum and climate. This result in transformations of mechanical and rheological characteristic accompanies with the change of thermal performance directly. There are four additive of Na(OH)¡¢Na2CO3¡¢CMC¡¢and CaCl2, which is often used in ground freezing engineering project. A series of experiments were carried out according to different additive and various amount. This article presents the research on influence of additive concerned the icing-point and heat conductivity of drilling slurry, which is helpful to design and construction.

The cryoecological assessment of tundra geosystems under anthropogenic impacts

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The integral evaluation of anthropogenic impacts risk for the environment is based on the assessment of landscape stability and ecological value. A new method for revealing the condition of local geosystems by means of criteria of ecological risk has been proposed. To calculate this criteria (by the equation of plural regression) the main biotic and cryogenetic are used, which have to promote the activity of cryogenic processes under mechanical disturbances of surface-cover and have been reflected bioresources value. The author proposes the leading criteria for assessment the Ust-Port test-object (south tundra zone). In this region the main cryogenic parameters consist of traditional indexes (the annual temperature, the depth of active layer, ice content) and some new ones - protector parameter corresponding the influence of both-heat isolation of moss-lichen cover and consolidation features of plants roots. The set of biotic parameters consists of traditional self-recovery and parameter of bioresources value of landscapes, including in particular, the index of deer capacity of pastures. According to the value of integral criteria of ecological risk all geosystems of test-object are ranged into three stages of sensitivity to disturbance: high, middle, low. For example, the highest risk of mastering in south tundra zone depends on ice content of permafrost, large protecting role of plant cover and its low recovery, high indexes of deer capacity.

Session 6. Antarctica.

Oral Presentations

Age of Antarctic permafrost

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Antarctic permafrost, have not received as much study as has been devoted to the ice, though that permafrost is more stable, older and informative than ice sheet. The permafrost studies can give the new principal data for Cenozoic paleoreconstructions. In Dry Valleys coarse-grained frozen sands the unfrozen water values there are so small that the instrumental methods fail to record them. There is an obvious absence of liquid water and water-bearing horizons, and the domination of the active processes of sublimation that excludes any downward infiltration. The *pH* is alkaline and *Eh* vary +260 to +480, that together with the absence of biogenic methane indicate conditions not as anaerobic as in Arctic. The total content of organic carbon is close to zero (0-0.1%). Na^+ ions are dominant, against of the equal presence of basic anions, and the dry residue reflects the fresh genesis of the soils. They are firmly cemented into a massive cryogenic structure up to 20 m depth and contain an unexpected high (25 to 50%) iciness values. These data changed the concepts that ground ice is unstable and of "dry Antarctic Permafrost", and help to explain its development in polar deserts (McKay think that some mechanism is recharging the ground ice from atmosphere).

The most important role for reconstruction have the permafrost age. Numerous publications indicates that Antarctic Cryosphere began to form dozens million years ago. According mostly sprigged point of Denton school the history of continent was detected by stability of Ice Sheet even during the warming in early Pliocene. The new point (Webb, Barrett) is that this warming reduce 2/3 volume of Ice Sheet. New and traditional views, best reviewed by Wilson, discuss only the ice - most mobile part of Cryosphere. The oldest glacial ice, 400000 years, is found at Vostok Station. The conditions for ice degradation (the geostatic pressure, interaction ocean - continent; etc) are not enough for thawing of most stable component of Cryosphere - permafrost, which history here is not investigate. The maximal (-18°C) permafrost temperature in Dry Valleys, is registered at low levels near the coast and decreases in accordance with the drop in air temperatures when moving inland and toward higher altitudes, reaching the lowest on the Earth, -24 to -27°C. The permafrost degradation were possible if temperatures increase up to 20°C. Because no evidences of such sharp increasing, it is possible that permafrost has existed in South Hemisphere greater than the duration of North Hemisphere by a factor of ten (Arctic oldest permafrost date back to 3 Myr) and that during most time of late Cenozoic our planet exist with only one cold Pole in South Hemisphere.

It also means that against the Arctic permafrost, which age is only approximate extraterrestrial model, the Antarctic permafrost age may be somewhat closer to Mars that could have a significant impact on the possibility for life preservation. If life ever existed on other planets, then by analogy with Earth, it might have been preserved and could be found at depths within permafrost. The discovery of viable cells within the oldest Antarctic permafrost will be important for exobiology. The limiting age, if one exists, within the most ancient permafrost, where the viable organisms were no longer present, could be established as the age limit for life preservation within permafrost. We found inhibited frozen layers in Arena and Beacon Valleys, where Sugden $^{40}Ar/^{39}Ar$ dates on ash layers suggest that permafrost below these layers may be 4.5-8.1 Myr old and in the glacial soil cores of Sirius Group on Mt. Feather, which age, according Marchant, dates back to 15 Myr or more. The main goal now is to find the oldest permafrost that is not easy, because its degradation were possible under the sea water or thick of glacial, and keeping in mind only 2% of ice-free areas. But the sites where it probably could be done are clean fixed: the uplands or their analogous like Mt. Fleming for epicryogenic pre-Cenozoic non-metamorphic deposits, and closed depressions like Don Huan Pont for syncryogenic ones, formed by weathering.

Frost Mounds, Northern Victoria Land, Antarctica

Hugh French
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Frozen ground phenomena in the vicinity of Terra Nova Bay (Latitude 74_30' S), Northern Victoria Land include large scale thermal-contraction-crack polygons, 15-20 m in diameter, and small frost mounds, 1-5 m high. The frost mounds occur in association with perennially frozen lakes. They are thought to be related to seasonal frost and icing-blister activity, caused by the episodic injection of free water from below. Limited quantities of unfrozen water must accumulate each year beneath the perennially frozen lake cover. Hydraulic pressures must develop that are sufficient to cause upward injection of free water. Isotopic and water chemistry data are presented. Debris on some of the lake-ice surfaces is best explained in terms of seasonal basal ice accretion beneath the lake ice cover. The relative roles of basal ice accretion, lake ice ablation (sublimation) and free water injection need further investigation.
Research is being conducted in collaboration with Mauro Guglielmin (Milan), under the auspices of the Italian Antarctic Research Program (PNRA) (Project 2a.13, Professor F. Dramis, University of Rome 3).

Observations on the periglacial dynamics of the south slope of Johnsons ridge, Livingston Island, South Shetlands

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The Johnsons ridge (336 m ASL) is a paleonunatak located in the northern limit of Hurd Peninsula in the South coast of Livingston Island (62°39'S 60°21'W). It is constituted by the Miers Bluff formation, a turbiditic sequence affected by low-grade metamorphism, which is represented in the Johnsons Dock by series of shales and fine sandstones (Arche *et al.*, 1992). The climate is cold oceanic with frequent summer rainfall and moderate annual thermal amplitude. Measurements from the Polish station Arctowski in King George Island indicate a mean annual temperature of *ca.* –2°C at sea level with mean-monthly values above 0°C from December to March and a mean annual precipitation of *ca.* 500mm (following the data from the Department of Antarctic Biology PAS). The occurrence of mean temperatures above freezing during the summer months results in snowmelt, freeze-thaw cycles and the existence of an active layer (Serrano & López-Martinez, 2000).
The research was conducted on the South slope of the Johnsons ridge. It is a slope with a relief of 300 m starting at the sea-level in Johnsons Dock, a small bay some 800 m long and 500 m wide. The retreating Johnsons lobe, a tidewater glacier flowing from the Hurd ice cap, glacierizes most of the lower section of the slope. Only the western part of the slope is completely ice-free. There, the surficial features still reflect very clearly the effects of the glacial morphogenesis and till and lateral moraines prevail. These are being remobilised contemporaneously by fall and gelifluction, the later originating stone lobes.
The periglacial trimline at *ca.* 150 m ASL is sharp and above it a very dynamic slope is to be found. It is formed by a composite rock-step with a free-face overlying it. The rockwall is very active and produces dominant high frequency and low magnitude rockfalls that originated an accumulation of debris and blocks in the step. During fieldwork, the authors observed the occurrence of several small debris-falls, also evident by the large number of rockfalls that accumulate on the glacier surface. Below the rockwall a talus exists. It presents signs of remobilisation of sediment by debris-flows in some sites. The area below the talus is characterised by an accumulation of blocks that extends down to the trimline. In this sector the authors identified: near the talus-foot the occurrence of several arcuate forms interpreted as protalus ramparts; sectors with boulder lobes (very frequent in the Hurd Peninsula); sorted circles in low energy sites near the trimline; and lobate forms interpreted as talus rockglaciers. These are particularly interesting for in the Hurd Peninsula only one rock glacier has been described and studied before. Their proximity to the Spanish Antarctic Station 'Juan Carlos I' offers excellent studying and monitoring perspectives.
Special emphasis is given to the talus rockglaciers and their implications and a detailed geomorphological map of the Johnsons Dock is presented.

Thermal regimes of tors on Ellesmere Island, Canada (80°N) and Victoria Land, East Antarctica (75°S)

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The thermal regime of near-vertical rock surfaces at high latitudes was examined in both hemispheres. Hourly temperatures were measured at depths of 15, 50 and 100 mm around a sandstone tor for a complete year (1992-1993) on Ellesmere Island. Similar measurements were made around and on top of two tors, one in granite and the other in basalt, in Victoria Land. Temperatures were recorded at depths of 5 and 15 mm at 1-minute intervals for the month of November 1999, and at 15 and 50 mm at hourly intervals for more than 3 months (November 1999 to February 2000). The northern hemisphere data showed that the late-winter (April and May) was the period of most profound solar heating for the south-facing side of the tor. Temperatures reached about 25°C above the ambient air temperature. Cloudier conditions and an incomplete snow cover meant that solar heating in the autumn was much less significant. In the Antarctic, maximum differences between air and rock at 15 mm depth over the late-winter and summer exceeded 30°C for both rock types. Rock temperature cycling through 0°C while air temperatures remaining below zero occurred frequently in both regions. Field observations in Antarctica showed that some of these temperature cycles could be effective for freeze-thaw weathering, despite the general aridity, because blowing snow can melt on irradiated surfaces, percolate into pre-existing cracks and fissures and then refreeze in the shade. The potential for thermal shock on the Antarctic tors appeared limited as at a depth of 5 mm, the threshold temperature change of 2°C min^{-1} was exceeded only twice on the west side and once on top of the granite tor, and not at all on the basalt tor.

Establishing base-line monitoring of permafrost in the Ross Sea region of Antarctica

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Areas with permafrost are thought to be particularly sensitive to global climate change (Paetzold *et al.* 2000). It is considered important that suitable long-term monitoring programs are established to quantify any climate changes and to determine the effects on the local environment and potential global impacts. This paper reports the preliminary work undertaken to establish base-line monitoring in the Ross Sea region of Antarctica.
The USDA has installed soil climate stations in the Arctic and on the Tibet Plateau to establish base-line information to help evaluate global climate change (Paetzold *et al.* 2000). A further three climate stations were established in the Ross Sea region of Antarctica in January 1999 located near Scott Base, Marble Point, and Bull Pass in the Wright Valley. Dataloggers were used to query the instruments and record the data on an hourly basis. Volumetric soil moisture content was monitored using frequency-domain type soil moisture sensors (Vitel Hydra Type A) and soil and air temperatures were monitored using thermistors (Campbell model 107). Atmospheric variables, including relative humidity, windspeed and direction, and solar radiation were also recorded. The climate data are to be made available via the internet.
In the coastal areas of the Ross Sea region much of the permafrost is ice-cored and there is potential for marked surface subsidence in response to any warming and consequent permafrost melt-out. With the advent of differential GPS (Global Positioning Systems) it has become possible to undertake accurate (+/- 2 cm), replicable, measurements of surface topography. In December 1999 an initial effort was made to establish detailed topographic monitoring in the vicinity of the three climate station monitoring sites. A Trimble 4000Ssi RTK GPS unit was used to measure topographic spot-heights giving x-y-z coordinates. Over 500 points were recorded in the vicinity of the climate stations. The time available limited the amount of data that was collected. The equipment performed well in the Antarctic environment with adequate satellite coverage at all times. The data were referenced to existing Antarctic survey marks and will be stored and made available on the internet. It is intended that the current base-line data set be expanded over time with inclusion of sites from a wider range of climate zones and extension in the detail of the topographic survey.

Thermal characteristics of permafrost in Seymour Island and James Ross Island, Antarctic Peninsula

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Permafrost occurs in ice-free areas of Seymour Island and James Ross Island, situated at 64° S on the east coast of the Antarctic Peninsula. In Seymour Island the temperature records at 10, 50, 100, 200, 300, 400, 600, 800cm depths were obtained on Meseta terrace of 200m a.s.l. from March1999 to March 2000. Superficial mean annual ground temperature was ca.-7°C. The temperatures at the depths of 10 and 50cm sometimes crossed the freezing point from December to March. The thickness of the active layer was ca.65cm. At greater depths, temperature variations became progressively more symmetrical, and below 4m closely resemble sin curves. The depth of zero amplitude was estimated to be 17m by using the heat conduction equation with a sinusoidal surface temperature variation. Ice-wedge polygons are observed in the island. It is concluded that permafrost develops continuously in Seymour Island.
In the east coast of Lachman Crag, James Ross Island, ground temperatures were measured at 5, 50,130,180,230cm depth. Mean annual ground temperature near ground surface was ca.-3 °C. The thickness of the active layer was ca.130cm. The temperatures of 5 and 50cm deep rose above the freezing point in October - November, and fell below 0 °C in March. The depth of zero amplitude was estimated to be 7m. Periglacial landforms and phenomena such as ice-wedge polygons, solifluction lobes, rock glaciers and patterned ground are well observed in the island. It is concluded that permafrost develops continuously - discontinuously in James Ross Island.

Permafrost distribution in the area of the Spanish Antarctic Station (Livingston island): ground temperatures during 1995.

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During the end of the summer of 1995, automatic data loggers were installed in the vicinity of the Spanish Antarctic Station in order to study the thermal regimes near the soil surface. The monitoring of the temperatures in sites with different topographic characteristics, soil structure and snow accumulation, allows to study the migration of the freezing front and to correlate it with the geographical variables. A statistical study of the data and it's integration in a Geographical Information System allowed the mapping of the soil surface temperatures (Romanovky *et al.*, 1997). The correlation of these maps with the distinct radiation models developed in the framework of the research conducted in the area, provide significant information in what respects to the assessment of permafrost distribution (Waelbroeck., 1993).

Permafrost monitoring Antarctic Network in Northern Victoria Land (Antarctica): preliminary results

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Since 1997 IPA recommended to start a circum-antarctic permafrost monitoring network to allow comparison with the CALM and other monitored permafrost boreholes within different scientific frameworks in Europe (PACE), Russia and North America.
Actually, the Italian research group on Antarctic permafrost is carrying out the monitoring of the active layer and upper permafrost zone temperature and other important climatic elements (i.e. air temperature, incoming radiation, wind speed and direction, snow cover thickness, snow temperature) in Northern Victoria Land since 1996. At the moment, three different ice-free areas, located from 200 m to 1,100 m a.s.l. around the Italian station at Terra Nova Bay are recording hourly data of ground temperature at different depths ranging between the surface and -8.3 m. In 1999 also a 15.5 m deep borehole was drilled in granite bedrock, at 80 m

a.s.l. Another 7.9 m deep borehole was drilled at Lachman site (James Ross Island) within Tertiary exposed bedrock, in co-operation with the Instituto Antarctico Argentino and the Hokkaido Institute of Low Temperature. In this paper we present the first three years of data recorded in Boulder Clay Glacier 74°44'45"S - 164°01'17"E) and the first thermal profiles of the 15.5 m deep borehole. At Boulder Clay, in the period December 1996 - October 1999, the air temperature ranged between 14.5 and °C -35°C (with a MAAT of -15.2°C), while the ground surface temperature ranged between 3.7°C and -35.3°C (with a MAGT) of -17.2°C. The ground surface temperature is well correlated with the air temperature (Ts = -2.82+0.920954 Ta; R2 = 0.874) while the incoming radiation does not seem to make much effect on the ground temperature at this site. It is remarkable that, during the observation period, the active layer thickness has progressively increased, with a faster rate after the extremely warm summer of 1998. The good relationship between air and ground temperature seems to exclude any important role of snow cover. From the other hand, some experimental simulations carried out on the field showed that, under a constant snow cover of 10 cm, the ground temperature was 3.5 °C lower than the natural one. Therefore, it can be assumed that, during the monitoring interval, the site was never covered by an effective snow layer, possibly because of the local occurrence of strong winds. The first thermal profiles seem to locate the ZAA between -13 and -14 m, with a slight change of slope towards warmer temperature in the lower part of the curve. However, the correct interpretation of the borehole in terms of paleoclimatic reconstruction needs more measurements. Basing on the heat conduction theory and assuming that the thermal properties of the rock are constant with the depth, the permafrost thickness at the site should be around 800 m.

Poster Presentations

Geomorphic responses to climate change in the Antarctic: science questions and possible approach

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Concerns about the impacts of climate change on northern high latitude/altitude environments have triggered widespread research interest and much work is ongoing to investigate and understand responses in landscape dynamics. Southern Hemisphere high latitude environments equally possess large and ecologically important and sensitive areas of permafrost and periglacial terrain, but are very poorly understood. To date, research activity aimed at understanding geomorphic responses to climate change in these terrains has been minimal and has been conducted in an uncoordinated way. This paper addresses the science questions for the Antarctic and defines a framework within which such activity could be developed within an international context.

Antarctic geomorphic responses to climate change require a rational understanding of the forcing action of the critical environmental controls (esp. temperature, moisture, radiation) on process in a quantitative manner. Equally, as many geomorphic processes are sensitive to only small changes in such environmental conditions, the physical effects (morphology) of such processes are likely to provide important signals of climate change.

Second, the Antarctic environment provides a record of recent past environmental change that forms the backdrop against which current and projected change should be viewed. The abiotic environment, and particularly its landform associations, provides important clues to the recent landscape evolution of the study areas. As better understanding develops, such landforms may offer quantitative assessment of past environmental conditions.

As various international programmes, including GTOS/GTN-P, RISCC and the IPA/SHWG home in on these issues, it is proposed that a co-ordinated and systematic approach be adopted to these questions. The specific objectives emerging from the above questions are identified and a strategy to answer them proposed.

Present-Day Soil Frost Activity on Marion Island, maritime sub-Antarctic

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Marion Island (46°54'S, 32°45'E, 290km^2) is one of a few small islands in the Southern Ocean and a rich location for geomorphological research on climate change. Marion consists of a shield volcano rising to 1230m asl. and has an extremely oceanic climate. Almost entirely glaciated during the last Glacial it still has a few small permanent ice bodies near its summit. Periglacial morphology include extensive solifluction lobes and terraces, blockfields and –streams, mostly developed on glacial till during the early Holocene and are now relict (Boelhouwers and Holness, 1998). Currently active morphology includes small solifluction forms and patterned ground and are widespread on the island.

Objective of this study is to establish quantitative relationships between morphology/sedimentology of currently active soil frost forms, the processes involved and their associated ground climate and materials controls. This is supported by two years of field observations by one of the authors (S.H.).

Morphology/sedimentology data on patterned ground show a steady increase in lateral and vertical sorting, but no change in particle size, with altitude. Process activity is here shown in the form of dowel heave indicating a close correlation between effective depth of frost heave and depth of vertical sorting.

Clast movement data, ground thermal profiles and frost susceptibility data quantify the effectiveness of needle-ice and ice-lens induced frost creep. Needle-ice activity dominates up to 300m asl, with ice lens growth under diurnal frost becoming increasingly important above these altitudes. This pattern correlates strongly with a change in ratio of coarse versus fine stripe width in sorted stripes. Above 800m asl mild seasonal frost dominates with snow limiting frost action and creating isothermal conditions in winter around –1 to –2oC, down to at least 40cm depth. Moisture and particle size distribution forms no limit to frost activity on the island.

Overall results allow for a first zonation of the Marion Island frost environment. Further work on establishing statistical correlation between morphological and climatic parameters is now underway, while future work will attempt physical modeling and application towards palaeoenvironmental reconstructions.

The necessity for high-frequency rock temperature data for rock weathering studies: Antarctic and northern examples.

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To a very large extent our perceptions of rock weathering in cold regions are the product of untested assumptions coupled with the artefacts of our methods of temperature monitoring (Hall and Andre, In Press; Hall, *et al,* In Press). Two attributes have worked to produce a poor scientific approach to rock weathering among geomorphologists. First, the assumption of process(es) and hence a frequency of temperature observation suited to that assumption coupled with, secondly, the logistical and technical constraints of data acquisition in cold regions. Most available rock temperature data are at a frequency that (a) is not suitable for the deduction of some processes, (b) produces a false "image" of the weathering regime, and (c) becomes a self-fulfilling prophecy of the initial assumption due to inadequate data. Rock temperature data collected at one-minute intervals for extended periods (3 months to over one year) at various depths within rocks, including on different aspects, has opened a whole new perception of bedrock weathering. Thermal stress fatigue and thermal shock can, based on one-minute data, be shown to occur and to, particularly in the Antarctic context, be major contributors to rock breakdown. This is all the more so as water, rather than temperature, is the limiting factor with respect to weathering in the Antarctic (Balke, *et al.,* 1991). It will also be shown that at high latitudes weathering regimes vary greatly both spatially and temporally, with, for example, the poleward exposure being warmer and experiencing less freezing events than the equator-facing exposure for part of the year. Such findings may have major ramifications in terms of understanding landform development through time. Lastly, while contemporary discourse has moved from diurnal freeze-thaw events to the annual freeze-thaw cycle as being of the greatest geomorphic effect, recent data have shown that this may be, in part, an artefact of available data. Using one-minute data recording it has been found that frequent exotherms, indicative of water freezing, can be identified in the field. The question remains, as it does for the annual cycle, of their effectiveness in any given situation, but, nevertheless, there is unequivocal evidence that diurnal freeze-thaw *does* take place. Thus, the argument is made that, for any meaningful investigation of weathering, it is necessary to obtain thermal data at a high frequency.

RiSCC (Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems), a new international research programme.

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RiSCC (Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems) was conceived two years ago during the VIIth International Biology Symposium of the Scientific Committee for Antarctic Research (SCAR) in Christchurch, New Zealand. During the last biennial meeting of the SCAR delegates in Tokyo (July 2000) the science plan and the implementation plan were approved and RiSCC is by now an offical SCAR program.
RiSCC aims to understand the interactions between biodiversity, functioning and climate of Antarctic terrestrial and limnetic ecosystems, and to predict regional sensitivity to the impacts of climate change by:
1. identifying and quantifying differences in environments and biodiversity within and between ecosystems;
2. understanding the potential for ecosystem processes to respond to changes in climate;
3. partitioning the effects of climate change among the key components of the ecosystems;
4. using new and existing data to provide a synthesis of the likely effects of climate change on Antarctic terrestrial and limnetic ecosystems to contribute to their management and conservation;
5. orienting the research to achieve links with other international programmes seeking to understand the implications of global changes.

Three research lines have been developed. Research will be performed on:

- Species richness and functional group diversity
- Organism and community functioning
- Phenotypic plasticity and genetic variation

In order to achieve its goals, RiSCC defined an Antarctic Environmental Gradient along which this research will be executed. Prime component of the research is a thorough understanding of the environment along the gradient. This makes that RiSCC and the IPA should collaborate in their research in the Antarctic, as some of the data to be gathered will be of importance for the research executed in both programmes.

Snow metamorphic evolution in a permafrost site near Terra Nova Bay Station, Victoria Land, Antarctica

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During the XIV and XVI expedition of PNRA (National Antarctic Research Program) stratigraphic and thermal analysis of snow cover were carried out almost daily in a site near the Italian Station of Terra Nova Bay. The ground is made by grüs rich in mirabilite, with a permafrost active layer 8 – 10 cm thick. That has a deep influence on the metamorphic evolution of the snow which stay above and makes strong difference respect to sites at the same altitude, but on rocky or glacial ground.
The very low permafrost albedo allowed the solar radiation absorption; so melting processes interest all the profile much more quickly than in the other site: that happened in 1998 starting from early December, in 2000 starting from 25 December.
Anyway the permafrost presence helps the persistence of the snow cover for much more time than the rocky ground; that also allows the formation of polycrystals rounded by melting and refreezing (6mf) with exceptional size (diameter more than 10 mm). The soluble salts in the active layer modify strongly the thermal profile, by causing a melting of the basal layer also during the periods when the most of the profile has temperatures less then 0°C (see fig.1).
Then the typical profile of the beginning of the summer season is made by a superficial part characterized by melting processes (and sublimation when the catabatic wind flows), which are function of the part of solar radiation strongest absorption; below that, there is a strong thermal gradient which allows the growth of faceted crystals or depth hoar. But at the base of the snow cover there are again melting processes with the formation of melted snow and basal ice (see fig.2).
Meanwhile the summer season is advancing, the lower superficial percolation limit gradually lowers, until it reaches the basal melting zone; from this moment the metamorphic processes are reduced simply to daily melting and refreezing processes, by which the already quoted growing of big dimension polycrystals are caused. As regards permafrost dynamics, what above described implicates the presence of liquid water in

the active layer during all the summer season, also when the thermal profile of the snow cover is largely lower than 0°C.

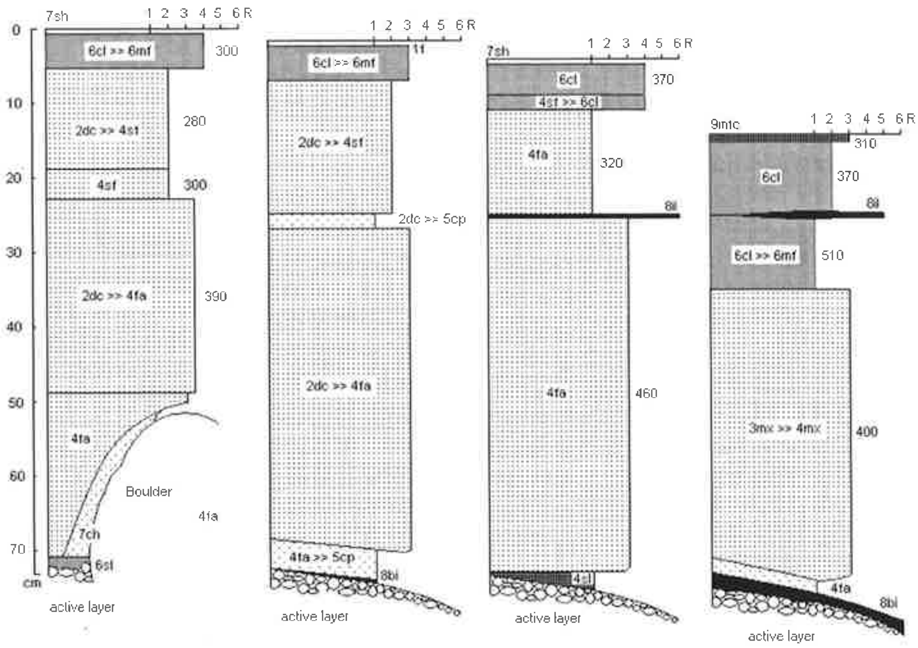

Fig. 1 – Stratigraphic variations during the measurement period. From left to right: 11, 14, 20, 27 December 2000.

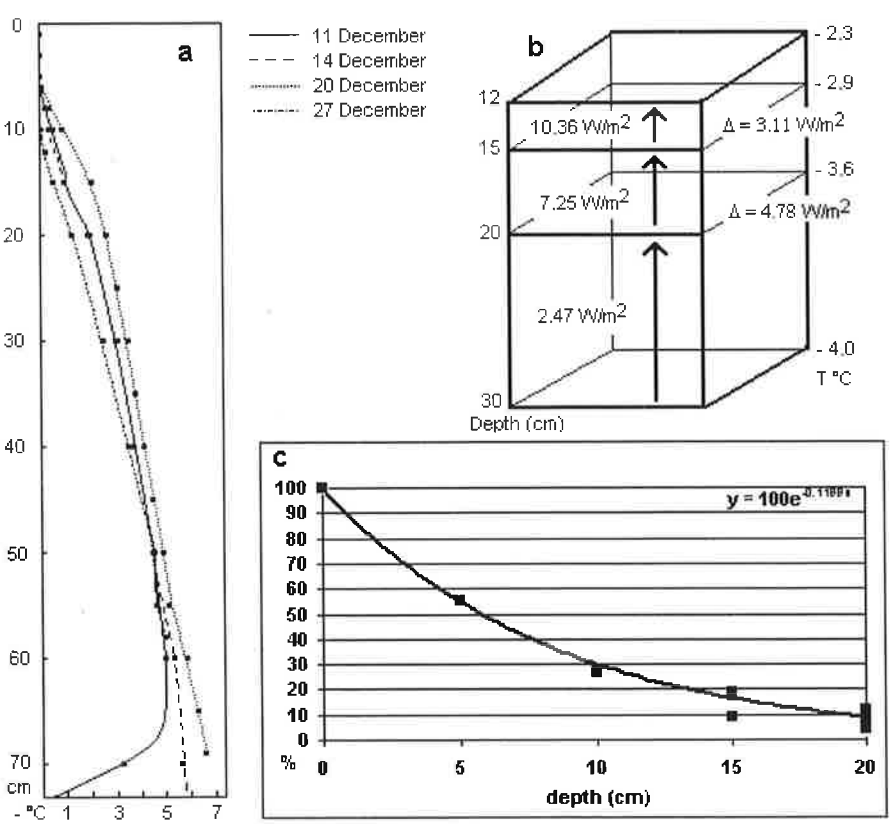

Fig. 2 – Thermal profiles (a), thermal exchanges by conduction between 12 e 30 cm deep (b), and per cent reduction of the radiation entering between 0 e 20 cm (c).

Ice wedges in the Terra Nova Bay Region, (Antarctica). Distribution and morphological features

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Field researches aiming at the individuation of ice wedges have been carried on during two Italian expeditions in Antarctica, which took place in the area of Terra Nova Bay – Northern Victoria Land – in the austral summers of 1998-1999 and 2000-2001.. The area taken into consideration is one of the widest defrosted regions in East Antarctica, with the exceptions of the Dry Valleys and the area of McMurdo. In the whole investigated area the polygonal soils, which constitute superficial expression of ice wedges, form the most widespread among the periglacial forms.
The ice wedges examined and located between 15 and 2000 m a.s.l., are found in deposits of the Holocene, the Late Wisconsin and also of unknown age and of various origin: glacial and littoral deposits, volcanics and surface regolithes. On the basis of their morphological and structural features (shape and vertical foliation), it can be stated that they are epigenetic, although some evidence, surveyed at two sites 30 km far from one another, indicate that some of them may have been undergone rejuvenation processes.
The ice wedges investigated extend in depth from 50-60 cm to over 150 cm. In all of the wedges observed, the outer lateral transition to the permafrost is marked by glassy clear ice, whereas air bubbles increase in the ice, revea1ing visible vertical strips, moving from the edges towards the central part of the wedges. The presence of central fissures that have gaps of 5-6 mm filled with hoarfrost and snow in some sites indicates that the polygons are related to thermal contraction cracking of frozen ground during the winter. While the position of some wedges relative to the frost table indicate that they are probably inactive. Further indications either of this aspect or for the rejuvenation is expected from the results of the crystallographic and isotope analyses that will be performed on the ice samples, and particularly from the ^{3}H analysis results.
Sand wedges measuring 30 -50 cm in width and 70-100 cm depth were found beneath the furrows of polygonal soils in some sections made in the interior zones. Though still on the basis of preliminary data, it is possible to state that the variety of moisture conditions affects the distribution of ice wedge and sand wedge polygons. The humidity level is definitely higher in the coastal sectors compared to the interior sectors and this has probably contributed to the different development and distributions of ice and sand wedges.
The results of the fieldwork indicated that ice wedges and sand wedges are present and widespread landforms with characteristics similar to those located in the Dry Valley and in the McMurdo Sound area.

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Oral Presentations

Permafrost properties and landforms in emerged marine sediments of Nunavik: a source of basic knowledge on permafrost formation in Quaternary marine sediments.

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Twenty holes were drilled through the permafrost in July 2000 near Umiujaq in Nunavik (the Inuit territory of northern Québec) in order to obtain cores and to install geophysical instrumentation in the permafrost. The aims of the project are:

1- To observe the cryostratigraphy in permafrost that aggraded in marine sediments following land emergence (from isostatic rebound) and interpret the sequences of ground ice layers and sediments in term of the processes of permafrost formation.

2- To obtain samples of ice and trapped gases for chemical and isotopic analysis.

3- To obtain temperature records along thermistor arrays that provide three dimensional temperature fields in permafrost and obtain groundwater pressure measurements at the base of permafrost in order to calibrate heat and mass transfer models of permafrost growth and regime.

4- To provide open access holes for determination of geophysical properties, namely acoustic and electromagnetic properties of the permafrost and for long term monitoring of those internal properties in parallel with climate-induced thermal changes.

5- To interpret and model the process of formation of palsas and like permafrost mounds.

6- As the recent emergence of these marine sediments is a possible analogue for early Glacial emergence of marine sediments in other Arctic regions, provide some potential explanations of permafrost characteristics and features now found in seabottom conditions.

Three sites were drilled and instrumented:

1- A (mineral) palsa consisting of a circular mound 50 m in diameter and 3 m high. The surface is pitted with mudboils. Ice lenses up to 50 cm thick were found down to the depth of 11.5 m in homogenous marine silts.

2- A permafrost mound 14 m high that probably formed when permafrost invaded a spur between two pre-existing gullies. The sediments consist of silt with scattered boulders and some sandy layers. Near permafrost base, about 21 m deep, the soils grades into stratified sand. The ground ice consists of lenses and reticulated ice.

3- A 2,5 m high sandy mound. The drilling revealed thick ice beds (up to 35 cm) at depths from 5 m to 14 m in silty layers and at the stratigraphic contacts between sand and silt layers. The permafrost grew in a sequence of glaciomarine sediments.

The morphological analysis of those landforms and the permafrost characteristics will be illustrated. The planned monitoring program is open for discussion.

Subsea permafrost in the Laptev Sea/Siberia and associated permafrost (?) features at the sea floor. Potential analogues from the emerging Hudson Bay region.

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Seismic refraction experiments and marine geologic sampling have revealed the existence of extensive subsea permafrost in the Laptev Sea, Siberia. The permafrost has formed during cold stages, when the worldwide drop of sea level caused the Laptev Sea shelf to fall dry. Numerical modelling suggests the development of 400 m to 800 m thick permafrost during cold stages, which degrades only slowly during marine transgression associated with interglacial stages. A numerical model on the likely internal temperature regime of the permafrost layer during glacial and interglacial stages will be presented.

Numerous crater-like features, tentatively identified as "pock marks" were observed on the sea floor of the Laptev Sea. Several explanations for the origin of these features are under discussion: pingo scars, gas blowout craters, iceberg scouring or drowned remnants of minerogenic palsas.
The Universite Laval and BGR cooperate in an extensive study to investigate the thermodynamic processes active in developing minerogenic palsas located near the emerging (glacial rebound) eastern shoreline of the Hudson Bay. The field situation along the shoreline of the Hudson Bay is considered as a modern analog of the situation that prevailed during the last marine regression at the Laptev Sea. Ultimately, the structure of modern palsas will be compared with those of the "pock marks" in the Laptev Sea.

Temperature measurements and their variations on the permafrost bearing Lapev Sea shelf, Siberia.

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Oceanographically the Paltev Sea is a very shallow marine shelf and it is the drainage area of the big Siberian rivers Lena, Yana and Kathang. Tectonically the area undergoes a differentiated subsidence due to the initiation of a rifting system. Simultaneously eustatic sea level rise introduces a major transgression of marine environment onto a formerly terrestrial area.
Due to the terrestrial evolution of the Laptev Sea shelf is stable, increasing or retreating is a question of recent investigations. Results from research cruises within the framework of the Russian-German joint project Laptev Sea 2000 reveal new insights into the oceanography of Laptev Sea.
Freshwater input leads to a stable thermohaline layering and thermal decoupling of surface and bottom water. Thus, three major factors are ruling the stability of permafrost beneath the Laptev Sea: a) oceanographic input from the Atlantic and Northern Polar Ocean, b) river run-off during the summer season and c) geothermal heat flow, which is severely modulated by tectonic activity.
Temperature measurements in time and space are presented here to illustrate the temperature variations as a boundary condition for the stability of the permafrost. Understanding the stability of submarine permafrost is essential for the prediction of risks. Especially the Laptev Sea is a source of methane gas, which could be trapped by a continuous permafrost cover. Release of huge amounts of gas has a possible impact on climate. A spontaneous gas release along pathways through the frozen soil is a potential risk for any human activity in the area.

Influence of salt transportation process on subaquatic permafrost dynamic in the course of the Holocene transgression

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During last decades on arctic seas shelves large-scale geological investigations, associated with oil and gas research, were carried out. Presence of subaquatic permafrost was authentically established during this works. Problems of interaction of shelf permafrost and near-bottom seawater are covered by numerous works. However, only energetical aspect of interaction was taken into account in these works. In our opinion, taking into account the process of salt transportation can lead to significant correction of results. Therefore, accordingly to data of drilling on some sites in Barents Sea and subsequent laboratory researches, salinity of porous liquid is decreasing from approximately 35‰ in the top of profile down to 5 – 10‰ in the bottom of the profile of the Quaternary sediments. Under our judgment, it specifies presence of diffusion salt transportation in frozen and thawed (cooled) rocks. Authors have attempted to take into account influence of above mentioned processes on thawing of Barents Sea shelf rocks during Holocene transgression.
The solution of the system of differential equations of heat conduction, pressure conduction and diffusion for frozen and thawed zones with interconnected conditions at the front of thawing is considered.
Results of modeling on proposed model (with close-to-zero diffusivity) and well-known "TEPLO" (WARM) program, showed good matching.
Modeling was taken for four boreholes in Southeast part of Barents Sea. Authors had data on lithological structure of their profiles, temperature and salinity profiles. On the surface (sea bottom) temperature and salinity, characteristic for the Southeast of Barents Sea, were set. Surface temperature was in the range of

(0.0°C – 1.0°C), surface salinity was taken as 35 – 36‰. Phase structure, temperature of freezing (melting), thermophysical and mass exchange properties were selected as characteristic for rocks in the profile.
Calculations on this model showed that salt transportation processes could significantly (1.5 times) increase depth of thawing, in comparison to the model, taking into account only thermal interaction. Results of comparison of temperature and salinity profiles and position of the permafrost roof, obtained by the modeling, and experimentally gained during field researches have shown good matching (comparison was taken out for four boreholes).
Conclusion: it is necessary to take into account processes of salt transportation in numerous cases of modeling of shelf permafrost dynamic.

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Frozen saline soils of the Arctic coast: their origin and properties

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The conditions of formation of the frozen saline soils of the Arctic coast as a special phenomenon of the sedimentary process in cryolithozone distinguished by frozen status and degree of differentiation of sedimentary substance are revealed. The main kinds of the frozen saline deposits are allocated, a classification of types of salinization of permafrost is developed, and their distribution in the world is established. The salts contained in porous solutions are partially taken out and are mainly redistributed in soils during freezing of deposits. The generalization of the available data has shown that the sea type of salinity is characteristic for Canada and Alaska, and the sea and mixed type is more characteristic for the Arctic coast of Russia.

The description of features of structure and physical properties of frozen saline soils is executed; is shown, that they represent the special class of cryogenic sedimentary formations having a combination of attributes of frozen and unfrozen soils. The porous solution of frozen saline soils of marine origin is close to composition of sea water, and such a frozen saline soils are wide distributed in the Arctic coast of Eurasia and America; their salinization basically is within the limits of 0.05-2 % and is increased to the north; active layer, as a rule, is not salted. Cryogenic structure of the frozen saline soils is characterized by various cryogenic textures with the prevalence of ice lenses that do not contain salts. The temperatures of freezing and phase structure of water depend on a degree of salinization, salt composition and other factors.
The basic laws of change of structure of the frozen saline soils are revealed at external influences. The data on transfer of salts and water, and transformation of cryogenic structure of the frozen saline soils for the first time are received at long-term (up to 15 years) influence of gradients of temperature and salinization. The migration of salts in frozen soils at influence of a gradient of salinization at the constant temperature, and also at influence of a gradient of temperature occurs at the large values of these gradients.
Strength properties of the frozen saline soils of various structure and composition are established. Is shown that the frozen saline soils have low strength that quickly decreases with increase of time of load. The important role of ice inclusions, which, as a rule, make frozen saline soils more resistant, is established.

Drainage direction of superpermafrost waters and denudation of permafrost sediments at the coastal cliffs

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The complex studies of destruction of permafrost deposits on the coastal cliffs are carried out since 1992 at coast of the East Siberian Sea, Small Chukocha Cape. The secondary frozen taberal deposits of Alas seria are the typical sediments in the region. They have rather low ice content (no more 50% vol. usually). The taberal deposits content the small thickness post-Holocene ice wedges. We studied the alas surface morphology at the coastal band. The peculiarities of coastal cliff were described too. The direction of superpermafrost water flow was determined by the observation in the shallow drill holes. Also the slope of alas surface was measured at the site with different conditions.
Two types of sites were selected at the base of peculiarities of the coastal line. The curved form of the coastline characterizes the first type of sites. The slope of cliff is practically vertical here (falling 75-80 degree). The width of a beach at the cliff basis is lower 3-4 m. The concave form of coastline is characterized for the sites of second type. The coastal band of alas surface is destroyed by thermoerosion here in a width 15-20m. There are many of thermoerosion depressions at the thawing ice wedges. At the surface of the second type sites. The coastal cliff has a falling about 55-60 degrees, and is covered erosive depression. The beach of width 50-70 m takes place at the basis of cliff.
The superpermafrost water flow is filtrated to the lake in 1.7 kilometers from cliff at the sites of first type. At the sites of second type, the superpermafrost water horizon is drained by the coastal cliff. The data of measurements of slope of alas surface confirm that direction of transfer of superpermafrost water is different at the sites of different types.
The mentioned peculiarities of a shore at the sites drained by cliff (concave coastal line, slanting slope of cliff, deluvial accumulation, fast thermodenudation) are explained by the erosion activity of the superpermafost waters filtrated from the alas surface.

Shore face of the Arctic seas - a natural laboratory for marine permafrost dynamics

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The subsea permafrost on the Arctic shelf is still imperfectly understood especially in Eurasia. The large-scale geocryological investigations are needed to utilise the natural resources of the Arctic shelf and to forecast the changes of Arctic environment. Severe climatic conditions and high costs hamper these investigations. Therefore the mathematical modelling of subsea permafrost dynamics is widely used for compilation of the forecast permafrost maps. A large amount of modelling is curried out taking into account conductive heat exchange and dependence of freezing point on the salinity of sea water and pore solution. It is impossible to verify results of this modelling in the most regions because of the lack of boreholes on the shelf. However the scant factual data obtained by drilling show that the diversity of geocryological conditions on the Arctic shelf can not be explained by conductive heat exchange only. It is found that a large role in the subsea permafrost dynamics play the convective heat exchange and the mass exchange in the form of diffusion and convective transport of salts in pore solution. Both free and forced convection may take place in the pores of thawed and ice-bearing subsea permafrost. The free convection is caused by gradients of pore solution concentration and temperature. The growth of fast ice on shallows, the nonuniform freezing and thawing of sediments under the sea floor, the near bottom currents and sea turbulence may initiate the forced convection.

Elaboration of mathematical model taking into account all physical and chemical processes participating in permafrost dynamics is an extremely complicated task which is not handled yet. The latest theoretical works demonstrate a considerable progress, explain some results of field investigations, suggest various hypotheses but do not solve the problem as a whole. The difficulties are caused not only by complicity of the problem itself but may be to a greater extent by poor understanding of subsea permafrost properties and physical and chemical processes controlling permafrost dynamics. Therefore it is necessary to concentrate the efforts of international permafrost science community on the large-scale investigations of subsea permafrost in situ.

The degradation is absolutely prevailing modern process of subsea permafrost dynamics. The underwater slope of thermoabrasion shores is the best place for the field investigations. The last glacio-eustatic transgression ceased in the middle of the Holocene and therefore the relative sea level remains stable in many areas of the Arctic during last 5-6 thousand years. The prevailing rates of thermoabrasion shore retreat are in the range of 2-6 m/year. It means that in the second half of the Holocene the sea inundated a long shore stripe of the land at least 10-36 km wide. The shore line displacements were measured during last 50 years. The largest rate 16 m/year is observed on Cape Halkett in Beaufort Sea Alaska. The shore retreated here for 800 m during 50 years. The position of some thermoabrasion shore sections in various areas of the Arctic was documented several times during the last half a century. The distance of a few hundred metres from the shore on these sections represents a relatively reliable scale for the sea bottom inundation time. Thus investigations along the shore face profile will allow to trace the changes of subsea permafrost in time. The results of these investigations have to be used as a base and for calibration of the mathematical models. The evident advantage of investigations in the coastal zone as compared with open sea investigations is relative simplicity and low costs.

Coastal erosion of ice-rich, permafrost-dominated coastlines in the Laptev Sea Region

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Shore dynamics directly reflecting the complicated land-ocean interactions play an important role in the balance of sediments, organic carbon and nutrients in the Arctic Basin. Sediment input to the Arctic shelf resulting from erosion of ice-rich, permafrost-dominated coastlines may be equal to or greater than input from river discharge.

In order to demonstrate the significance of coastal erosion for the sediment budget of the Laptev Sea, here we present new data on the coastal erosion sediment input.

Field investigations carried out during the expeditions LENA 99 and LENA 2000 focussed on several key sections of the coasts, situated in various environments and consisted of three main parts:

- Geodetic measurements were performed on land to obtain the modern position of the shores.
- Shoreface profile measurements were carried out from the shoreline across the outer boundary of the shoreface.
- For shallow seismic profiling a sediment echo sounder was used.

Numerous aerial photographs and topographic maps were considered for study of the Laptev Sea coastal dynamics by remote methods.

The average shoreline and cliff top retreat rate for all Laptev Sea coastal sites, which consist of ice-rich sediments, is approximately 2-2.5 m • year^{-1}. The maximum rate of coastal erosion was observed on the

Northern Cape of Muostakh Island: 650 m during 48 years or 13.5 m • $year^{-1}$. The obtained data indicate that the sediment input to the Laptev Sea by rivers and shores is of the same order but probably coastal erosion sediment input is considerably larger than riverine sediment discharge.

Poster Presentations

Dynamic of Barents Sea shelf permafrost development during middle Pleistocene – Holocene

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The authors, based on data on Barents and Kara seas shelf permafrost structure and distribution, have conducted modeling of dynamics of subaquatic permafrost during transgressive-regressive cycles of the middle Pleistocene – Holocene for Southeast region of Barents sea.
Calculations were carried out for two sites in Southeast part. The first site, "Varandey", has sea depth approximately 20 meters, and average seabed temperature 0,5° C. The thermal flux for this site is 45 – 60 mWt/m^2. The second site, "Karskie Vorota" (Kara Gates), has sea depth approximately 70 meters, and average seabed temperature 0,0° C. Salinity of seawater is approximately 35-36‰. The thermal flux for this site is 55 – 60 mWt/m^2.
Calculations covered a temporal interval of 250 thousand years (up to the present time). Paleoclimatic and paleogeographic scenarios, lythological and thermophysical properties of the rocks, and thermal flow from the depth, were taken into account. The distribution of temperatures on a profile on a beginning of Samarovsko-Tazovskaya regression (initial moment of calculations) was taken into consideration also, it was supposed, that on that moment the shelf rocks were thawed. Paleoclimatic and paleogeographic scenarios supposed that sites were subsequently exposed to the surface and flooded by seawater some times. Two paleoclimatic, "warm" and "cold", were considered. For each site, durations of subaquatic and subaeral periods were calculated, based on their bathymetric position and considered scenarios. Calculated periods were corresponded with surface temperatures for each transgression and regression period.
The following results were obtained:
Layers of permafrost with thickness up to 550 meters were formed during regressive stages. These stages were generally degraded during consequent transgressions.
Calculations showed presence of massifs of subaquatic permafrost with thickness 100 – 200 meters, that was confirmed by fact sheet.
Existing permafrost can be both in non-stationary and in stationary conditions.
The results of calculations have shown a possibility of existence of subaquatic permafrost, generated and developed during regressions and transgressions of the middle Pleistocene - Holocene in a Southeast part of the Barents sea shelf, that is corresponding with the fact sheet and allows to use a selected technique of modeling hereafter.

Onshore and Offshore Permafrost and Gas Hydrate Stability Zone on Shelf and Coastal Plains, Laptev Sea Region, Russia

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The paper is compiled as a review of scientific investigations carried out in the frame of the joint Russian–German projects "Laptev Sea System" & "System Laptev Sea 2000".
On the base of field data and mathematical simulations a wide distribution of the offshore, ice-bonded permafrost on the Laptev Sea shelf is shown (Romanovskii et al, 1998). The seabed relic permafrost underlies most of the Laptev Shelf. Up to isobath 40-45 permafrost is continuous, to isobath 70-80 m it is discontinuous and to the upper boundary of the continental slopes permafrost exists only as islands. Terrestrial permafrost is continuous with thicknesses from 400 up to 700 m depending on the latitudinal

position, geological condition and geothermal heat flow- q_{gt} value. Variations of q_{gt} are from 40 to 80 mW/m.sq. in tectonic blocks. In fault zones qgt probably exceeds 100 mW/m.sq.
The main natural events in the region during Pleistocene-Holocene were: - long-term climatic fluctuation,- glacioeustatic transgression and regression which led to a periodical submergence and emergence of the sea shelf, -accumulation on the lowlands and exposed shelf ice-rich syncryogenic deposits- Ice Complex (IC), and -destruction of the latter by thermokarst process and shore thermoerosion. Thermokarst on the base of IC started approximately 12.8 Kyr B.P. on both lowland and exposed shelf. The duration of thaw lakes formation in dependence from IC thickness were from 2-3 Kyr up to 10 Kyr. Most of the lake taliks are closed. Thaw lakes with a bottom below sea level transformed into thermokarst lagoons during the transgression. It leads to an enlarging shore line, intensification of shore thermoerosion, and to an increasing rate of shelf submerging (Romanovskii et al, 2000).
Permafrost aggradation on the shelf takes place during regression. Submergence by sea water with mainly negative temperature causes permafrost degradation: gradual temperature increase and thawing preliminary from permafrost bottom under the influence of q_{gt}. Permafrost thickness decreases with increasing q_{gt}. The impact of q_{gt} during the period of aggradation is less than in the degradation period.
Simulations of permafrost thickness and of gas hydrate stability zone-GHSZ evolution during 4 climatic and glacioeustatic cycles have been performed for the shelf and arctic lowlands. Calculation was made for different q_{gt}, sea water depth and latitudinal position. Records of modeling show that ice-bonded continuous permafrost and GHSZ constantly exists in lowlands and inner parts of the shelf and to the isobath 40-45 m since not less than 400 Kyr. In the zone between isobath 40 and 60 m total thaw of offshore permafrost and a decomposition of hydrate of gases in sites with high values of q_{gt} (60-70 mW/m.sq) take place during sea transgression. Offshore permafrost in this zone transforms into discontinuous relic. From isobath 60 m and deeper ice-bonded permafrost thawed completely. It is possible to suppose that below the permafrost foot in lowlands and inner parts of the shelf a long-term conservation of underground gases took place often in form of gas hydrates. An emission of gases is possible only through fault zones with high values of q_{gt} and open taliks.

Late Quaternary sedimentation history of the Lena Delta

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The Lena River draining to the Siberian Arctic is considered to be the main sediment source for the Laptev Sea. Nevertheless, for the delta of the Lena River occupying an area of 28000 km^2 there are many unsolved questions concerning the environmental and sedimentation history, genesis and ages of deposits, permafrost distribution, and climatic records in the area.
In the eastern part of the delta (first terrace), where modern sedimentation takes place, mineralogy and geochemistry of permafrost sequences indicate a general development from river bedload to suspension load bedding. The hydrochemistry of the permafrost documents that Holocene conditions of accumulation and deposition are controlled merely by fluvial processes and any marine influence on modern delta sedimentation can be excluded.
The western Lena Delta deposits (second terrace) show a sedimentary nature indicating pure bedload sedimentation. According to OSL age determinations the deposits represent a fluvial stage of late Glacial age (14500 to 10900 a BP).
At Lake Nikolay, the largest lake in the Lena Delta, lake sediment profiling using a radio-echo sound (RES) system and a sediment echo sounder has been carried out in order to understand the origin and age of the numerous lakes located in the sandy second terrace. Both, basins filled with lake sediments and frozen areas, could be surveyed. AMS datings of lake and permafrost sediments reveal an age of about 7000 a BP for Lake Nikolay. This may coincide with the regional Holocene climatic optimum resulting in thermokarst processes, which promoted lake development in the sandy environment.

Photographs, back cover, clockwise from top right

The arid mountain periglacial zone of the Sierra Nevada, Spain

Permafrost map based on numerical modelling, Jotunheimen, Norway

Resistivity survey of mountain permafrost, Schilthorn, Switzerland

Coral del Valeta and Valeta Peak, site of the southernmost PACE borehole, Sierra Nevada, Spain

Tarfala, Sweden, site of the Swedish PACE monitoring borehole

Photographs, front cover, clockwise from top right

Drilling in frozen bedrock, Murtèl-Corvatsch, Switzerland

PACE monitoring borehole, Stelvio Pass, Italy

Mountain permafrost zone, Engadine, Switzerland

Drilling the northernmost PACE borehole, Janssonhaugen, Svalbard