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Chapter 1

Scientific Programme

Steering and Organizing Committees

Steering Committee	Local Organizing Committee
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Vonder Mühl, Daniel (Basel, Switzerland)	

Welcome from the Organizer

As Chair of the Steering Committee for the 2nd European Conference on Permafrost I should like to extend a warm welcome to all delegates. This Second European Conference has been organised primarily through the European Science Foundation Network PACE21, which was established in 2002 to convene a series of workshops and conferences concerned with permafrost and its response to climate change. In addition, representatives of the International Permafrost Association have served on the 2nd EUCOP steering committee to provide a non-European input to conference planning. The First European Conference on Permafrost, held in Rome in 2001, marked the completion of the EU “Permafrost and Climate in Europe” (PACE) Project. Since then, Europe has hosted the 8th International Conference on Permafrost in Zurich, Switzerland in July 2003, and this has certainly stimulated wider interest in frozen ground research, reflected in the diversity of sessions scheduled for the present conference.

The Steering Committee wishes to thank the local organising committee, under the chairmanship of Hans Hubberten, for their work and commitment in organising the 2nd European Conference on Permafrost, and

the sponsors (see the back cover of this volume) for their valuable support. Particular thanks are also due to Dr. Thomas Kumke who has taken the lead in compiling the present volume of Abstracts.

Many permafrost regions are undergoing rapid environmental changes in response to our changing climate system, and in turn, these regions have been shown to critically affect global atmospheric circulation. In addition, terrestrial permafrost environments are providing valuable analogues in understanding the evolution of other planets. The significance of the polar regions has been recognised by the designation of 2007-8 as the International Polar Year by ICSU and the WMO, making the 2nd European Conference on Permafrost a timely meeting for scientists seeking to emphasise the importance of permafrost in the research programme of IPY.

Conference Themes

Conference Theme	Organized in association with
(1) Permafrost Records of Past Climate and Environments	IPA Antarctic Permafrost WG
(2) Permafrost Affected Soils, Microbiology and Trace Gas Releases	IPA Cryosol WG
(3) Periglacial Landforms and Cryogenic Processes	IPA WG on Periglacial Processes and Environment
(4) Permafrost as Analog for Extraterrestrial Systems	
(5) Hydrology and Sediment Fluxes in Permafrost Regions	ESF project SEDIFLUX
(6) Mineralogy, Geochemistry and Isotopes in Permafrost Research	IPA WG on Isotope and Geochemistry of Permafrost
(7) Permafrost Monitoring and Modelling in the Context of Global Change	
(8) Coastal and Offshore Permafrost	IPA WG on Coastal and Offshore Permafrost, IPA-IASC project Arctic Coastal Dynamics (ACD)
(9) Permafrost Engineering, Land Use Planning, Hazard and Risk Assessment in the Context of Global Change	IPA WG Permafrost Engineering, IPA WG on Glaciers and Permafrost Hazard in High Mountains, IGU Commission on Cold Regions Environment

Excursions

Tour to Telegrafenberg

Leader: Diedrich Fritzsche, Potsdam

It will be an easy walk through the Telegrafenberg area for about one hour of duration on Sunday. The park landscape and architecture of a unique collection of scientific facilities whose construction began in the 1870's and continue up to today will be the topics of this tour. The Telegrafenberg is named after a station of an optical telegraph line built to link Berlin with Koblenz via Potsdam. Research has a long tradition here and is characterised by activities in the fields of astrophysics, geodetic surveying and gravitation research. When the first special astrophysical observatory in the world was founded in 1874 it was the birth of the research site on Telegrafenberg hill. In 1881 Albert Michelson carried out his famous experiment for the first time in Potsdam in the main building of the astrophysical observatory. In 1924 the solar observatory in the Einstein tower on Telegrafenberg hill was completed which was to provide evidence for the predicted effects resulting from Einstein's general theory of relativity. In the 1890's the Royal Prussian Geodetic Institute moved from Berlin to Potsdam and the meteorological-geomagnetic observatory was founded on the Telegrafenberg. Among other activities, both institutes carried out the preparation and support operations for many expeditions to the Arctic and Antarctic.

Tour to “Grottensaal” (cave hall)

Leader: Diedrich Fritzsche, Potsdam

The New Palace is the largest 18th century structure in Park Sanssouci. It was built from 1763 to 1769 according to the plans of Johann Gottfried Büring, Heinrich Ludwig Manger and Carl von Gontard and served Frederick the Great as a palace for his guests. Out of the two hundred palatial rooms some sixty can be viewed. The “Grottensaal” is one of the most spectacular rooms of the palace. It is a richly decorated hall imitating a natural cave. It forms the background for the display of the unique collection of the Prussian kings, consisting of almost 20,000 samples of minerals, rocks, fossils and shells and initially assembled by Frederick the Great between 1765 and 1768. The duration of this tour is about two hours.

Tour to historical Potsdam (City)

Leader: Hans-J. Paech, Potsdam

A pedestrian tour (about 5 km in three hours) through the historical city centre focuses on Potsdam's heritage from the Electorate Brandenburg (17th century), and Prussian kingdom (18th and 19th century), set within a picturesque Pleistocene landscape. For centuries the Old Market with the city palace (Stadtschloss), Nicolai Church and the ancient city hall - remained the city's historical centre. However, during the war the outstanding buildings were damaged or later removed. There is today only a single original element, the Marstall - the Royal Stables. In 2002 the Fortunaportal - Gate of Fortune - was re-constructed in its historic position. Then, the tour familiarizes with Garrison Church (in re-building), New Market, City Canal and streets within the first (1720 to 1733) and second (1733 to 1742) baroque city expansion. It includes the famous Dutch quarter.

Tour to historical Potsdam (Palaces)

Leader: Hans-J. Paech, Potsdam

A pedestrian tour (about 4 km) through the Royal Parks of Sanssouci (since 1990 part of the world culture heritage by UNESCO) including Sanssouci Park proper, Rehgarten, Marlygarten, Potentestück and the palaces, Neues Palais, Orangerie, Belvedere, Charlottenhof, propervine palace Sanssouci set within a Pleistocene landscape. Potsdam's most popular sight is the SchloßSanssouci palace located in the park to which it gives its name. Here Frederick II (later the Great) could stay without worries (hence the name sans souci, Sanssouci palace, which means without worry in French). The Marlygarten was originally an orchard near Potsdam.

Tour to Rüdersdorf

Leader: Gerda Schirrmeister and Johannes H. Schroeder

This one day bus trip leads to the key-locality for the European glaciation theory by Otto Torrell (1875). The large quarry of Rüdersdorf opens a 250 m thick sequence of rocks of Middle Triassic age; it is surrounded by glacial sediments covering almost the entire state of Brandenburg. For more than 270 years Rüdersdorf has been site and subject of geoscience research. The results obtained have bearings beyond the local and regional frame, particularly with respect to glacial processes, Quaternary and Triassic stratigraphy, geothermics, salt tectonics and gas storage in salt. As far back as the thirteenth century, exploitation of the limestone for building materials (such as broken and dimension stones, later quick lime and cement) has been documented. After the German reunification the cement factory has been completely modernized and presently is producing by most stringent ecological and environmental standards. The tour includes visits to the opencast-mine, the cement factory and historical monuments of exploitation. The trip takes about 10 hours from Potsdam and back to Potsdam.

Preliminary Timetable

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8:30-8:45		Key Note talk	Key Note talk	Key Note talk	Excursion
8:45-9:00		Hoelzle	Murton	Hayley	
9:00-9:15	OPENING	Session 7	Session 3	Session 9	
9:15-9:30				parallel	
9:30-9:45	Key Note talk			Session 6	
9:45-10:00	Rivkina				
10:00-10:15	Session 2				
10:15-10:30					
10:30-10:45					
10:45-11:00					
11:00-11:15	COFFEE	COFFEE	COFFEE	COFFEE	
11:15-11:30					
11:30-11:45	Session 2	Session 7	Session 3	Session 9	
11:45-12:00				parallel	
12:00-12:15				Session 1	
12:15-12:30					
12:30-12:45					
12:45-13:00					
13:00-13:15					
13:15-13:30	LUNCH	LUNCH	LUNCH	LUNCH	
13:30-13:45					
13:45-14:00					
14:00-14:15					
14:15-14:30					
14:30-14:45	Session 8	Session 7	Excursion Meeting IPA Council	Session 1	
14:45-15:00	parallel			parallel	
15:00-15:15	Session 4			Session 5	
15:15-15:30					
15:30-15:45					
15:45-16:00					
16:00-16:15					
16:15-16:30	Poster Introduction	Poster Introduction			
16:30-16:45	POSTER SESSION	POSTER SESSION			
16:45-17:00					
17:00-19:00					

Chapter 2

Session 1 - Permafrost Records of Past Climate and Environments

Session Conveners: Bernhard Diekmann, Julian Murton

Ground ice conditions in Salluit, Canada: The legacy of post-glacial land emergence and Holocene climate changes

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key words: relative sea level fall, aggradational ice, saline permafrost, Holocene climate variations

In order to assess the terrain sensitivity in the coastal Inuit town of Salluit in Nunavik (Northern Québec, MAAT = -8°C), 26 cores were drilled in the permafrost, several kilometres of seismic and ground penetrating radar lines were surveyed, and three multi-sensor cone penetration tests were run. All the data were compiled in a high precision digital 3D elevation and geological model and a large scale ground-ice map was produced. As Salluit lies on the shore of a fjord that was submerged by the post-glacial marine transgression at deglaciation time (8 ka ago), the dominant Quaternary sediment is thick, fossiliferous, marine silt. Post-glacial land uplift is still going on at an estimated rate of about 4 to 5 mm yr⁻¹. The tidal range is 5 m. In the tidal zone, near the high water line, where shore ice freezes to the bottom, the sediments have temperatures below 0°C but are unfrozen. From the high tide line to an elevation of about 11 m a.s.l., volumetric ice content in the permafrost is about 30% and consists mostly of lenses 1 to 5 cm thick. Pore water salinity in the sediments between the ice lenses is in average 20 g L⁻¹ with peak values of 42 g L⁻¹ at depths between 6 and 8 m. At elevations higher than 11 m, an ice-rich layer (volumetric content over 90%) that can be up to 2.6 m thick underlies the permafrost table. Chunks of organic soil were occasionally found in this ice-rich layer, suggesting past variations of active-layer depth. The saline permafrost is found underneath. Our interpretation is that when the ground emerged from the tidal influence, ground freezing and permafrost aggradation expelled salt downward, creating intra-permafrost saline layers. Low elevation sites did not have sufficient time yet to build up an ice-rich layer. Sites that emerged a longer time ago developed an aggradational ice-rich layer below the permafrost table. The aggradation of new ice near the surface in the past was probably helped by upfreezing in the active layer during transitions from warm to cold periods (for instance, a ¹⁴C date of 360 BP in one core suggests incorporation of the organic chunk in the permafrost during the Little Ice Age). Other ice-rich soils are colluviums (slopewash deposits) that were deposited on lower slopes since at least 2200 BP, slowly building up syngenetic permafrost on thicknesses up to 4.5 m in waterlogged soils.

Palynology and stable isotopes of ice wedges - proxies for continentality?

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key words: palynology, stable isotopes, ice wedges, Holocene, Late Pleistocene

Ice wedges are well-known as a source of information about winter temperatures, which may be estimated by stable oxygen and hydrogen isotope methods. Being composed of numerous ice veins, ice wedges are predominantly vertically oriented ice bodies, whose chronology is difficult to decipher. They are enclosed by horizontally layered permanently frozen sediment. Ice wedges may contain particles of both mineral and organic origin (e.g. pollen, plant remains, lemming droppings). Identifiable pollen and macrofossils can be used not only for ^{14}C dating of ice wedges, but also for climate reconstructions (e.g. July temperatures, precipitation, runoff). In this study, palynological analysis has been used to investigate samples obtained from 4 ice wedges and surrounding sediments from the Mamontovy Khayata site. The site is located on the Laptev Sea coast of the Bykovsky Peninsula between $71^{\circ} 40'$ to $71^{\circ} 80'$ N and 129° to $129^{\circ} 30'$ E. Coastal and thermokarst erosion has created up to 40 m high coastal cliffs, trending NNW-SSE, and extending intermittently for about 2 km.

The samples from the oldest studied ice wedge were ^{14}C dated to ca. 42 ka BP. The ice wedge pollen data are very similar to the pollen records from the surrounding sediments dated to the same time interval. The difference is the relatively higher amounts of Asteraceae and Caryophyllaceae pollen as well as green algae colonies (*Pediastrum* and *Botryococcus*) in the ice. Poaceae and Cyperaceae communities with Asteraceae, Cichoriaceae, Caryophyllaceae and some other herbs dominated around the site ca. 45 to 42 ka. Climate was relatively warm and wet. The stable isotope record of this ice wedge shows relatively warm winter temperatures (reflected in $\delta^{18}\text{O}$ of about -30‰) during this time in comparison to other Late Pleistocene intervals.

The pollen contents in the samples from an ice wedge ^{14}C -dated to ca. 13.5 to 14 ka BP are also very similar to the pollen spectra from surrounding deposits of similar age, but the ice wedge spectra contains significantly higher amounts of *Betula* sect. *Nanae*, *Artemisia*, and Rosaceae pollen. Relatively high amounts of *Betula* sect. *Nanae* and Ericales pollen point to a wetter and warmer climate in that time. The ice wedge is also characterized by a heavier (or warmer) $\delta^{18}\text{O}$ about -28.5‰.

Generally, the Holocene ice wedge samples from the Mamontovy Khayata site have very low pollen contents and are not useful for pollen-based paleoenvironmental reconstructions. Only one undated Holocene sample ($\delta^{18}\text{O}$ about -26‰ reflecting warmest winter conditions) from the same wedge is rich in pollen. *Betula* sect. *Nanae*, *Artemisia*, and Rosaceae pollen. Relatively high amounts of *Betula* sect. *Nanae*, *Alnus fruticosa* and Ericales pollen dominate the spectrum. Such pollen content is typical for the spectra ^{14}C -dated from ca 8.5 to 7 ka BP in the Bykovsky Peninsula area. Climate conditions during this interval were the most favourable for ca. last 60 ka in the region.

The study shows that pollen from Siberian high Arctic ice wedges may be used for environmental reconstructions. The ^{14}C -dated ice wedge pollen spectra can also be used for quantitative climate reconstructions. This will give a chance for direct comparison of pollen-inferred climate variables (summer) with ice wedge isotope curves (winter) and, thus, derive a new proxy for continentality. This approach may also enable us to use the pollen for a relative chronology of the ice wedge ice as well as a direct linkage between the chronologies of ice wedges and the surrounding deposits.

Ice sheet-permafrost interactions through a glacial cycle

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key words: ice sheet, Earth stresses, permafrost, deformation, groundwater

Field experimental results from the margin of an Icelandic glacier show the relationships between glacier flow, proglacial ground freezing and hydrological regime. A model of these relationships is presented and applied to a high resolution model of the evolution of the European ice sheet and permafrost development through the last glacial cycle. The model is forced by a climate function derived from correlation between the Greenland ice sheet climate record and palaeoclimatic data from Europe. It is used to reconstruct the extent, thickness and dynamics of the ice sheet and subglacial and proglacial permafrost. The evolution of the subglacial and sub-permafrost hydrological system is reconstructed through the cycle, and the earth stresses that are generated. It has important implications for the evolution of the northern European groundwater system and its geochemistry and the geological structures of the European sub-surface.

Modelling of permafrost penetration, permafrost properties and their impact on ground water circulation pattern; Meuse/Haute-Marne underground laboratory site, Eastern France

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key words: natural proxies, paleopermafrost modelling, hydrological modelling, waste burial

In France, one of the direct climatic consequences of long term climate changes is permafrost that could develop during glacial periods. Such a question is studied by Andra in the framework of the geological long life nuclear waste repository project for it has consequences both on hydrogeology and surface environments.

For that purpose a permafrost model is applied to the Andra underground research laboratory site, excavated in a Jurassic argillite formation, 500 m deep, in Bure, northeast of France. This model is established together with long term (up to one million years) climate, geomorphologic and surface environment evolution scenarios, to take into account the changes that might occur in the future.

In a first approach, a thermal modelling of permafrost penetration has been performed with the LCPC Gelsol program, based on two paleoclimate approaches (vegetation and cryosols) and the in situ rock properties. This modelling has been completed through mapping of the permafrost extent stages along the whole Last Glacial based upon cryosols data. The mapping has been performed at two scales: the Paris Basin and the regional scale taking in account the relief.

A second approach is based on a simplified thermal modelling throughout a “complete glacial” applied to the site geological characteristics (Jurassic limestones and marls formations) to understand frost dynamics and development to take in account for hydrogeological modelling. A conceptual model for frost penetration in the weakly fractured limestones and in the marls has been proposed to control the evolution of the permeability of these rocks, taking in account the water salinity, the overburden pressure and the potential depth reached by the zero isotherm in the first model. The probability of gas hydrate formation is very low.

The forcing imposed by the development of ice in vertical fissures at depth, has been applied to the ground-water circulation pattern aiming at predicting the possible modifications in the streamlines in the vicinity of the underground research laboratory.

The conclusion of this work shows that the potential penetration of the 0°C isotherm is circa 300 m at the LGM, with some ice in the vertical fissures up to 100 m in depth. The high viscosity of water below that depth limits water circulation.

Detecting frost-wedge pseudomorphs using electromagnetic induction

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key words: frost-wedge pseudomorphs, electromagnetic induction, EC-profile ratio

The aim of this study was to locate near-surface Pleistocene frost-wedge pseudomorphs based on electromagnetic induction. Frost-wedge pseudomorphs are sedimentary structures representing the imprint of former frost-fissure wedges, which are important in the reconstruction of former permafrost environments. Mostly, aerial photographs are used to detect wedge casts, but also geophysical methods, such as electrical resistivity, have been used. As a response to the disadvantages of these methods, we propose a non-invasive, non-destructive methodology based on electromagnetic induction (EMI).

At a test site in Flanders (Belgium), a polygonal pattern of frost-wedges was temporarily exposed by construction works. Here we measured the soil apparent electrical conductivity (ECa) using the EMI sensor EM38DD. These measurements were taken every 0.5 m along parallel lines 0.5 m apart. The EM38DD measures simultaneously in the vertical (EC_v) and horizontal orientation (EC_h), each with a different depth response curve. A profile ratio (PR) was calculated as EC_h/EC_v reflecting best the differences between wedge and host material (15% difference in PR between wedge and host). These differences were attributed to textural differences: the host material contained 12.8% clay compared to 7.9% in the wedges. The PR map clearly revealed the polygonal pattern of the frost-wedge pseudomorphs. This PR map was used in a fuzzy k-means classification creating two zones: one representing the frost-wedge pseudomorphs and the other the host material. This result was compared to a digitized detailed drawing of the position of the wedges in the field. A cross tabulation yielded an overall accuracy of the ECa map of 80.9%. The Kappa value was 0.53, indicating that the classification represented a moderate agreement with the observed polygonal pattern. So the EM38DD proved to be able to locate frost-wedge pseudomorphs. Important was the dual dipole character of the EM38DD since the ratio between the two observations, rather than one of them, was found to be useful in locating the polygonal pattern of the pseudomorphs. However, it should be mentioned that only pseudomorphs wider than 30 cm could be located.

It can be concluded that EMI is a reliable method to locate near surface frost-wedge pseudomorphs based on textural differences between wedge fillings and host materials. Essential, however, is to have information obtained in different orientations to allow the construction of a PR. New perspectives on the detection of frost-wedge pseudomorphs under field conditions are offered with this method.

Episodic permafrost development in northern Germany during the Pleistocene - a first, preliminary approach

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key words: permafrost, Northern Germany, Pleistocene, Weichselian

Recent advances in climate research have considerably improved our understanding of the climate variations in central Europe during the Weichselian to the point, where we can retrace with reasonably good confidence the changes in mean annual air temperatures since Eemian times. The availability of proxy data from pre-Eemian subaerial deposits tends to be too spotty to enable us to reconstruct with confidence a continuous record of the regional climate for the whole Pleistocene, in particular prior to the times of the major glaciation advances from the north. To assess the likely duration and maximum depth of the occurrence of permafrost in northern Germany throughout the Pleistocene, the following approximation was chosen. The oxygen isotope record from marine sites (e.g. ODP site 677) offers very extensive proxy records for the climatic fluctuations, which in broad terms are considered to reflect the global climatic variations in the Pleistocene. We have used a previously presented reconstruction of the mean annual ground temperatures (MAGT) of the last 120 ka for northern Germany as calibration tool to reconstruct from marine proxy data a first, preliminary MAGT-record for northern Germany for the Pleistocene. Based on this curve, the maximum depth of permafrost and duration of permafrost episodes were calculated. The resulting image appears to reflect well our perceptions of the sequence of cold stages in northern Germany as they were derived in the last decades from the analysis of land deposits and the fossil record contained therein.

Lake records of environmental changes and palaeoclimate in Eastern Siberia

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key words: Siberia, Yakutia, lakes, palaeolimnology, palaeoclimate

Palaeoenvironmental reconstructions using land, sea, and ice records provide the basis for understanding the main forces that controlled the climate system in the past. The knowledge of these processes will help to improve predictions of climate-related environmental changes in the future. Research work during the last decades highlighted the role of the northern high-latitude regions around the North Atlantic and the Arctic seas for global climate variability. The climatic influence arising from the vast periglacial regions of eastern Eurasia is poorly understood. Those regions were only affected by regional mountain glaciations, are covered by taiga and tundra vegetation and are characterized by deep-reaching frozen ground. In particular, Yakutia in the northeastern part of Eurasia represents one of Earth's most extreme climate regions with semiarid continental climate and coldest winter temperatures in the northern hemisphere. The landscape of Yakutia is occupied by widespread lake districts. Dominant lake types mainly comprise thermokarst and alass lakes, fluvial oxbow lakes, and lakes of proglacial origin in the foreland of the Verkhoyansk Mountains. Lacustrine sediment records of these lakes provide the basis for palaeolimnological reconstructions of former environmental and climate conditions of the periglacial realm in eastern Siberia. The goal of studies is the recognition of past responses and influences on the global climate system, arising from Earth's permafrost-dominated areas that dominate about 25% of the terrestrial surface. The findings will complete and broaden our palaeoclimatic informations inferred from both ice-core records and marine sediment archives and allow to understand the complex climate system of the Arctic.

By using sedimentological, geochemical, and micropalaeontological methods as well as multivariate statistics, an interdisciplinary approach is followed to characterize the dynamics of lacustrine systems in connection with the climate-related development of the periglacial landscape in Yakutia. A first step is the ecological and geological classification of lake systems. Another important objective is the inference of quantitative palaeoclimate-related variables by the establishment of a calibration dataset for deriving quantitative transfer functions from aquatic organisms and pollen assemblages in modern lake sediments. The application of transfer functions on fossil bioindicators is aimed for the reconstruction of palaeoecological conditions, for example the spatial and temporal displacements of vegetation zones or changes in lake-water temperatures and nutrient concentrations. Reconstructions of the depositional lake environment will give insights into the glacial dynamics of the mountain areas and yield lake status records of the lowlands related to natural and human-induced changes in hydrology. The final objective is to provide proxy data sets to the global network of palaeoclimatic data, used for the validation of existing climate models and new high-resolution modelling experiments. In this contribution, we will show first findings of ongoing palaeolimnological research in Yakutia.

Deep groups of sand veins in aeolian sand-sheet deposits at Sint-Niklaas (Flanders, Belgium) and their palaeoenvironmental implications

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key words: sand veins, thermal contraction cracking, permafrost, Belgium, Late Glacial

Groups of sand veins, containing ~ 3 to 50 sand veins, enveloping wedge-shaped bodies up to 1.0 m wide at the top and extending to (more than) 4.0 m in aeolian and fluvio-aeolian sand - silt deposits have been observed at Sint-Niklaas (51° 09' 54" N, 4° 08' 31" E), located in the northwestern European sand belt. Individual groups, 2 to 14 m (mean: ~ 10 m) apart and showing lateral continuity may suggest a polygonal arrangement. The structures may be considered as an early stage in the formation of large epigenetic sand and composite wedges typical for continuous permafrost environments. Each sand vein represents a cast of a thermal contraction crack infilled with sand, sand-ice or ice. The structures most likely formed during the coldest spells of the Late Glacial (probably Greenland Stadial 1 or Younger Dryas) based on their stratigraphical position. It is suggested that permafrost conditions most likely occurred during the Younger Dryas. Defining a more precise palaeoenvironmental significance is more difficult as the structures may have been formed in a continuous permafrost environment, or as a result of infrequent cracking in a discontinuous permafrost environment. Although discontinuous permafrost conditions with mean annual air temperatures (MAAT) between -1.5 to -4.5°C are very likely as suggested by the literature, the occurrence of continuous permafrost conditions for a relatively short period cannot be discounted.

Evolution of lake basins in arctic Alaska: a revision of the “Thaw-Lake Cycle”

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key words: permafrost, landscape, evolution, lakes, ground ice

While numerous concepts of a “thaw-lake cycle” have been developed to explain the abundance of lakes and basins in northern Alaska, they vary in their explanations of lake formation, the role ice aggradation and degradation, and the process by which the surface returns to near-original conditions to complete the cycle. Lack of data on topographic changes, soil stratigraphy, and ice volumes necessary to evaluate the

physical processes involved has prevented the development of a consensus on the “thaw-lake cycle”. During fieldwork on the central Beaufort Coastal Plain in 2001 to 2002, we collected data to help quantify the “thaw-lake cycle”, based on interpretation of airphotos and analysis of topographic profiles, soil stratigraphy, nature and abundance of ground ice, and radiocarbon dating. Our analyses of the nature and patterns of soil and ground-ice development, however, revealed numerous processes that were inconsistent with the “thaw-lake cycle”. First, potential thaw-settlement (0.1 to 1.2 m) of terrain units were insufficient to allow development of lakes and basins that were often 3 to 5 m below the adjacent terrain. Second, expansion of initial thermokarst pits related to ice-wedge degradation into larger ponds was not evident, instead pits were found to stabilize and revegetate without pond expansion. Third, ice-aggradation in most lacustrine deposits was insufficient to uplift surfaces to original heights. Fourth, shoreline profiles of large lakes usually had gently sloping, wave-cut, sandy margins that were consistent with mechanical erosion, but not thermokarst. Finally, rates of land lost to shoreline erosion were too slow ($<0.017\%$ of landscape yr^{-1}) to have allowed multiple “cycles” during the Holocene. The concept that thaw lakes continually migrate across the coastal plain and that soils go through a cycle from upland surfaces, to thaw lakes, and then back to conditions similar to the original is not consistent with our data. Our analyses revealed that the process of lake-basin development is more complex and less cyclic than previous investigators believed. Accordingly, we developed an alternative model of lake-basin evolution that applies to most of the Beaufort Coastal Plain, which is underlain by extensive sand sheets. This includes:

1. initial flooding of low-lying areas during early Holocene to form primary lakes;
2. lateral expansion and sorting and redistribution of lacustrine sediments to create silty centers and sandy margins;
3. lake drainage during mid-Holocene from expansion of the drainage network;
4. greater ice aggradation and surface heave in centers than in margins, causing water to impound in newly developed low-lying margins;
5. infilling of ponds along the margins and occasional formation of secondary thaw lakes in the centers;
6. basin stabilization during late Holocene.

This sequential evolution of unique circumstances formed the conditions for the development of persistent large primary lakes, infilling secondary ponds along the sandy margins of the drained-lake basins, and occasional secondary thaw lakes in the ice-rich silty centers within the large basins that are widespread across the modern landscape. While we recognize that true thaw lakes have developed in areas with thick, extremely ice-rich, silty deposits, such as loess (lower Brooks Foothills), abandoned floodplains (Colville Delta), or marine silt (narrow region between Barrow and Cape Halkett), these areas are limited in extent in arctic Alaska.

High arctic environments and climate during the Saalian and Eemian climate phases in Siberia: plant macrofossils from permafrost records at the Laptev Sea coast as palaeoecological indicators

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key words: plant macrofossils, arctic Siberia, Eemian interglacial, Saalian cold stage, palaeoenvironments

Plant macroremains from permafrost deposits, outcropping at the Laptev Sea coast of Bol'shoy Lyakhovsky Island reflect palaeoenvironmental conditions in arctic Siberia during the Saalian cold stage and the Eemian interglacial.

All studied Saalian macrofossil records show very low species diversity, reflecting a narrow range of available habitats. The only aquatic plant, proved for that time, is *Chara* sp. Among terrestrial wetland plants, *Eriophorum scheuchzeri*, *E. angustifolium*, *Caltha palustris*, and *Carex bigelowii* indicate conditions comparable to modern tundra in that area. At exposed sites, arctic pioneer communities with *Papaver* sect. *Scapiflora*, *Cerastium* sp., *Minuartia rubella*, *Draba* sp., *Taraxacum ceratophorum* existed, reflecting intense deflation and thin snow cover. The upland vegetation included a few steppe species such as *Alyssum obovatum*, indicating, to a certain degree, arid conditions, which are confirmed by the finding of the halophytes *Puccinellia* sp. and *Chenopodium* sp.

In contrast to Saalian records, the Eemian species spectra are highly diverse and indicate the coexistence of various plant communities such as aquatics with *Callitriche hermaphroditica*, *Batrachium* sp., *Potamogeton vaginatus*, *Sparganium* spp., *Myriophyllum spicatum*, riparian and wetland vegetation with *Comarum palustre*, *Eriophorum angustifolium*, *Carex bigelowii*, erect shrub tundra with *Alnus fruticosa*, *Ledum palustre*, *Betula nana*, *Empetrum* sp., and *Vaccinium vitis-idaea*, arctic upland vegetation with *Kobresia myosuroides*, *Dryas*, *Artemisia* sp., *Papaver* sect. *Scapiflora*, *Minuartia rubella*, *Draba* sp., and even xerothermic vegetation with *Rumex acetosella*, *Carex duriuscula*, *Potentilla arenosa*, and *Potentilla stipularis*. The occurrence of the boreal/subarctic shrubs *Alnus fruticosa*, *Ledum palustre*, and *Betula nana* and, in particular, the evidence of the temperate and boreal aquatics *Callitriche hermaphroditica*, *Potamogeton vaginatus*, and *Myriophyllum spicatum* indicate mean summer temperatures as high as 12°C at the study site during the last interglacial, thus 8°C higher than today.

Late Pleistocene loess-soil-cryogenic formation of East European plain (by the Suvorotino and the Gololobovo cuts example)

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key words: loess, permafrost, Pleistocene, cryogenesis, weathering

The East-European plain loess formations containing fossil interglacial soils include several well-developed palaeocryogenic strata dating from late Pleistocene (the Smolensk, Vladimir and Yaroslav strata). The strata are presented completely in both the Suvorotino (in Vladimir Opolye region) and the Gololobovo (Podolsk-Kolomna Opolye region) cuts. The Smolensk stratum lies on the contact of the Early Valdai loesses and the Mezin soil complex (90 to nearly 100 ka). It contains solifluction features and ice-wedge pseudomorph about 1.5 to 2 m high. The Vladimir stratum (23 to 25 ka) contains involutions that disturb the Briansk interstadial soil profile. The Yaroslav stratum (18 to 20 and 12 to 15 ka) lies close to the top of Late Valdai loesses and contains ice-wedge pseudomorphs up to 3.5 m high that form the polygons about 15 to 20 m in diameter. Traditional researches of the material compound of sediments linked with the paleocryogenic strata were supplemented with both the cryogenesis conditions and morphoscopic analyses of the psammite particles. As an index of cryogenesis conditions a cryogenic contrast coefficient (CCC) that is more than 1 indicates that cryogenesis was intensive. The ratio between quantities of particles with various rolling, the amount and the character of the particle edges analyze and other methods were also applied. The Valdai periglacial zone sediments analyze confirm submissions of Pleistocene permafrost existence far from the modern borders. According to CCC measurements, the most severe climatic conditions in late Pleistocene were during the periods of the Smolensk, the Yaroslav, the Vladimir palaeocryogenic strata formed. The climatic severity and cryogenic modification scales increased by the end of Late Pleistocene, reaching the maximum during the formation of Yaroslav stratum. The mean annual temperature of soil strata was approximately 2 to 2.5°C. Research was carried out by RSSI (03-05-64462, 04-05-64599) and INTAS (01-2211) projects.

Large grazing mammals of the “Mammoth” fauna as indicators of the Late Pleistocene paleoenvironment

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key words: paleoenvironment, “Mammoth” fauna, Pleistocene, Laptev Sea region

Recent multidisciplinary studies of the permafrost deposits in Northern Yakutia have greatly improved our knowledge about the Late Pleistocene environmental history of the region. One of the interesting facts about the past life on the Laptev Sea shelf region is the abundance of fossil mammal bones, found over the coastal lowlands and on the shelf land. More than 4000 fossil mammal bones have been collected in the Lena Delta Region, on the New Siberian Islands, Oyogos Lowland, Muostakh Island, and in the Anabar-Olenek Region.

Our investigations were focused on the study of the “Mammoth fauna”. All bone findings were collected and registered. Such an approach combined with radiocarbon dating of bone collagen makes it possible to reveal some important aspects of large animal distribution on the studied area during the Late Quaternary. In total the taxonomic composition of the collections from the Laptev Sea Region is close to the Late Pleistocene “Mammoth” fauna from other Arctic Siberia Regions but the relations of large grazing mammal species were collected on various localities are different (Table 2.1).

Table 2.1: Composition of the big grazing mammals of the “Mammoth” fauna from the Laptev Sea Region

Species	Lyakhovsky Island	Oyogos Yar	Bykovsky Peninsula	Oleneksky Channel	Mamontov Klyk
<i>Mammuthus primigenius</i>	26%	40%	37%	42%	9%
<i>Equus caballus</i>	25%	16%	18%	15%	30%
<i>Rangifer tarandus</i>	18%	12%	15%	16%	39%
<i>Bison priscus</i>	20%	22%	13%	5%	5%
<i>Ovibos moschatus</i>	7%	3%	1%		1%

Possibly, the diversity of mammal associations can be explained by local taphonomic and other random factors. But it can also describe the differences in paleoenvironmental conditions of the studied regions. Predominance of horse bones in some collection e.g. marks the regions with environmental conditions that are more favourable for the horse: hard soil, thick snow cover and etc. (for example, Mamontov Klyk). Other sites (e.g. Oyogos Yar, Bykovsky Peninsula, Oleneksky Channel) were more favourable for the woolly mammoth. The number of bison and muskox bones shows also differences in environment. Unusually high numbers of reindeer remains from Mamontov Klyk can be explained by the presence of modern bones.

The paleoenvironment had changed during Late Pleistocene too. The period of the most unfavourable environmental conditions for the woolly mammoth was probably between 22 ka BP and 15 ka BP, when only a few dates from woolly mammoth bones were obtained. It is interpreted as an extremely cold and dry period during the Late Pleistocene. The last “mammoth” period from 15 ka BP to 9 ka BP is characterized by a rapid increase of the number of dates with maximum is around 11 to 10 ka BP. It is also a period with the largest number of woolly mammoth dates during the Late Pleistocene. That was a period with the most favourable environmental conditions for the mammoths. Radiocarbon data on horse bones reflect no essential fluctuation during the last 50 ka BP.

A buried ice-wedge system as archive for the Late Quaternary environmental history near Barrow, Alaska

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key words: late Quaternary, paleoenvironmental history, buried ice wedge, oxygen and hydrogen isotopes, Alaska

At the northernmost point of Alaska, the Barrow area is one of the best-studied arctic regions, including permafrost research with a number of high-ranked research institutions on site (e.g NOAA, USGS, BASC). In this area, a small permafrost tunnel was excavated in the early 1960s by a CRREL team led by one of the authors (Brown). A 9 m long cavity about 6 m below the surface comprises a massive complex of vertically-foliated ice, covered and (on one side) laterally confined by sediment.

After more than forty years, the tunnel was reopened in 2003 and sampled in 2004 by the AWI Potsdam team for stable isotopes, sedimentological, palynological and microbiological analyses of ground ice and sediments. Stable isotope techniques have been used only sparsely in this region, especially for the characterisation of different types of ground ice. Hydrogen and oxygen isotopes are applied for palaeoclimate studies in ice wedge ice for the reconstruction of winter temperatures, whereas palynology is used to assess the summer conditions. Since in the 1960s neither AMS dating techniques nor stable isotope studies were readily available. The first step in the current investigations was to refine the age estimate of the site and, in a second step, to improve the understanding of the genesis of the buried ice within the tunnel. Detailed results of geochronological, sedimentological and micropalaeontological studies reflect different stages of Late Pleistocene and Holocene palaeoenvironmental evolution. Isotope geochemistry indicates the intersection of two, isotopically different, ice wedges ($\delta^{18}\text{O}$ of -24‰ and -26‰, respectively), representing different phases of the regional climatic history which extend to the Late Glacial Maximum. This is revealed by an AMS date of $21,670 \pm 500^{14}\text{C}$ years at the lateral contact of the wedge and the surrounding sediments. A direct AMS dating of organic matter (lemming droppings) within the ice wedge ice of $12,370 \pm 50^{14}\text{C}$ years indicates a Late Pleistocene ice wedge growth. The ice wedge is buried under 4 m of organic-rich sandy silt of Early Holocene age ($10,380 \pm 50$ and $9,930 \pm 40^{14}\text{C}$ years) covered by Late Holocene peaty silt ($945 \pm 40^{14}\text{C}$ years). For a palaeoclimate interpretation of ice wedges, one has to be aware that no secondary effects, i.e. exchange processes at the boundary ice wedge-sediment occurred. A case study for the upper boundary of the buried ice wedge to the sediment will demonstrate the importance of understanding these processes, which may alter the original stable isotope composition.

The Vault Creek permafrost tunnel - Late Quaternary climate and environmental history of the Fairbanks region, Alaska

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key words: Late Quaternary, paleoenvironmental history, permafrost tunnel, Alaska

The Fairbanks area in interior Alaska is characterised by discontinuous permafrost and a continental climate with mean annual air temperatures of about -3°C and annual precipitation of 263 mm measured at Fairbanks

Airport (1971 to 2000). The permafrost consists of sediment and ground ice, and preserves the signals for the reconstruction of late Quaternary environment and climate.

The Vault Creek gold mining tunnel is located 40 km north of Fairbanks, Alaska, and was established since 1990 by a local private gold miner. It is the deepest (>40 m) and longest permafrost tunnel (>200 m) ever being subject for research, comparable to the famous Fox research tunnel near Fairbanks constructed in 1963 by the US Army Corps of Engineers (CRREL). The study site has about 120 m thick permafrost. Average permafrost temperatures at 2 m below ground surface are relatively warm with -0.78°C . In this region, permafrost is considered to have developed after the Sangamon (or Eemian) interglacial period.

The sedimentary sequence consists of 40 m of Late Quaternary deposits above schistose bedrock. These are: (1) alluvial sediments mainly consisting of fluvial gravels with sand and several peat lenses in the lower part and (2) ice-rich silty sediments, most likely loess with high amounts of organic material including fossil bones as well as ice wedges in the upper part. In between, (3) a transition horizon of fluvial gravels interbedding with loess and ice wedges was held out. First AMS dates point out that loess accumulation took place in the area around 42 ka BP, whereas the fluvial sediments show infinite ^{14}C ages. In general, ice wedges contain information about winter temperatures, which were derived by stable isotopes ($\delta^{18}\text{O}$ and $\delta^2\text{H}$). Both, ice wedges and sediments were deformed presumably by post-depositional slope processes. In this paper, a picture of the regional environmental history is drawn using a multi-proxy approach including sedimentology, palynology, radiocarbon dating, microbiology, hydrochemistry and stable isotope geochemistry.

Palaeofaunistic evidence for recent climate change in Northern Ural (Russia)

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key words: Northern Ural, chironomids, lakes, palaeoclimate

Chironomid midges are sensitive indicators of modern- and palaeo- environmental and climatic changes. The distribution and abundance of midge taxa are strongly influenced by nutrient concentrations, water depth, pH, heavy metal concentrations as well as by air and water temperature. Arctic ecosystems are highly vulnerable to global warming, and palaeoclimatic data mainly from North America, suggest that unprecedented climatic warming has already occurred in the Arctic during 20th century. However, relatively few arctic sites have been studied in Europe and even fewer in Northern Russia.

Sediment samples from more than 20 lakes the Usa Basin (north-eastern Russia) and two short lake-sediment cores were investigated. Each core has been radiometrically dated.

The North Urals data have been compared with instrumental records over the last 100 years to assess the reliability of the modern calibration set. There is some evidence that some chironomid groups are responding to climate change by northern shift in distribution. Our results indicate that most chironomid taxa in the northern Urals are well represented in a Norwegian calibration set.

Mean July air temperature was reconstructed using a Norwegian chironomid-temperature inference model, generated from a modern dataset of 153 lakes (Brooks and Birks, 2001; unpublished) and supplemented with an additional 26 lakes from Bol'shezemel'skay Tundra, comprising 148 chironomid taxa and using weighted averaging partial least squares regression. The chironomid-inferred summer temperature increases by c. 1°C during the last ca. 100 years. There is evidence that recent diatom and chironomid changes in

both Mitrofanovskoe and Vanuk-ty Lakes have been driven, in part, by temperature. In Mitrofanovskoe Lake the evidence is clearer, the major compositional changes in chironomid and diatom communities are synchronous, and they are correlated with the increase in total diatom accumulation rate and LOI. It is therefore unlikely that global and regional pollution have a marked effect on the chironomid and diatom assemblages of the lake.

Chironomidae as indicators of climate change in Central Yakutia

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key words: chironomidae, climate change, Central Yakutia, temperature reconstruction

Palaeoenvironmental studies, using organisms as proxies for climate change over the past 15,000 years, can provide valuable insights on past climate variability and climate scenarios. These studies are particularly important in northern latitudes because results from GCM model indicate that climate change is amplified in high northern latitudes (IPCC, 2001). The premier method for quantitative temperature reconstruction in temperate and arctic environments is by means of chironomid-climate inference models. Chironomids compose a family of true flies (Insecta: Diptera) and are one of the best paleoclimatic quantitative indicators (Battarbee, 2000) due to several attributes:

1. their aquatic larvae constitute the most abundant bottom-dwelling macroinvertebrates of freshwaters (Armitage et al., 1995);
2. rapid generation time makes the chironomid response to environmental change effectively instantaneous;
3. larval head capsules preserve well in lake sediment deposits as microfossils;
4. the head capsule is identifiable and past faunas can be reconstructed;
5. the distribution and abundance of chironomids are mostly limited by temperature (Walker et al., 1991).

Chironomid-temperature inference models have been developed successfully in Western Europe and North America (REFS) and produce low error (0.7 to 1.1°C) temperature estimates. Application of these models to Holocene and late-glacial core have produced highly plausible temperature estimates and fine-tuned trends detailing high and low amplitude temperature oscillations at high temporal resolution. There are very few examples of quantitative palaeoclimate studies in Siberia. The main drawback of these reconstruction approach is the lack of a regional calibration dataset. In our study, an information on past climate dynamics of this region and the first quantitative mean July air temperature estimates for this region are inferred. Apart from information on climatic variability, the project provided information about the composition, distribution, abundance and ecology of chironomid taxa in these regions, which is important for completing a data base on national chironomid fauna and data, available on chironomid species migrations and factors these processes are driven by.

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Assessing Holocene permafrost dynamics through plant macrofossil analysis of peat deposits in northern European palsas

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key words: permafrost, palsa, plant macrofossil, cluster analysis, Holocene

Typical palsa stratigraphies are presented for northern continental Europe, from northern Fennoscandia to northeastern European Russia, based on a review of previously published data and recently obtained new results. Different pathways for permafrost aggradation and degradation are recognized. Absolute (radiocarbon) and indirect (pollen stratigraphic) chronological controls are used to date the initial phase of permafrost aggradation.

Permafrost-induced changes in mire development can be identified with the aid of detailed macrofossil analysis of the peat deposit, based on typical plant assemblages and successions. Due to the lack of clear indicator species for permafrost, some amount of uncertainty has to be accepted in interpretations. Other difficulties include hiatuses in peat stratigraphy as a result of erosion or ceased accumulation.

In classic mound-shaped palsas lifted from a flark the change from flark to palsa peat is abrupt. New types of vegetation often dominated by *Dicranum elongatum*, *Polytrichum strictum* and lichens invade the sites within a few years. In peat plateaus (flat palsas), permafrost can aggrade in *Sphagnum* peat. Taxa like *S. fuscum* and *S. capillifolium* continue growing, making it more difficult to trace the initiation of permafrost. However, the *Sphagnum* peat deposited by a peat plateau usually includes moister and drier phases resulting in typical stratigraphy of darker and lighter layers. In peat plateaus, permafrost can also develop under wet local conditions with *S. lindbergii* or *S. balticum*. Following gentle collapse, when a palsa sinks back to the flark, the palsa peat may be preserved and is followed by collapse scar peat with e.g. *S. riparium*. Degradation by block erosion is usually not traceable in peat deposits.

First results of a quantitative approach to predict the likelihood of permafrost occurrence from macrofossil assemblages are presented. Cluster analyses performed on modern palsa mire vegetation data distinguish permafrost sites relatively well. Several taxa, especially lichens and liverworts, are rarely preserved as macrofossils or are difficult to recognise. In other cases, the taxonomic resolution of the fossil assemblages is not as high as for the extant plant communities. Therefore, modern vegetation data were modified to resemble macrofossil assemblages. Despite these transformations, clustering of the modified modern vegetation data suggests that the potential for recognising the occurrence of permafrost is still high. In the final stage, macrofossil records are clustered together with modern vegetation data. Modern sites within the same cluster indicate the likelihood for the presence of permafrost at the time the peat sample was deposited.

Late Pleistocene ice-wedge casts from Tierra del Fuego, Argentina

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key words: ice-wedge cast, Late Pleistocene permafrost, periglacial environment, Tierra del Fuego Island

The discovery of ice-wedge casts in the central Atlantic coast of Tierra del Fuego Island, Argentina, is reported. These cryogenic structures have been observed at Cape Penas region (lat. 53° 50.15' S, long.

67° 35.20' W), about 10 km southeast of Rio Grande town, close to sea level. They are developed on up-raised marine beach deposits composed of interstratified levels of very well rounded gravels and sand corresponding to the La Sara Formation, a unit formed during Last Interglacial time, and covered by Holocene aeolian silty and sandy sediments. Observed casts are wedge-shaped, tapering downwards into a sharp end. They are oriented vertical and show an infilling predominantly composed of sand and silt of aeolian origin. The gravel and sand beds in contact with the wedge casts are bent up. The largest cast observed measures 60 cm deep and 20 cm wide at its top. The fact that these structures do not occur in isolation but form nets of evenly spaced casts, seems to point to the former existence of polygonal patterned ground. No glacial landforms or sediments of Last Glacial Maximum age have been found in Cape Penas, since this region remained in an inter-lobe position. Ice-lobe glaciers draining the Darwin Cordillera mountain ice sheet covered the landscape roughly 120 km northwestwards along the Inútil Bay depression and at Fagnano Lake valley ca. 80 km southwards. At this time the Atlantic coast of Tierra del Fuego Island was located between 120 and 140 m below present sea level, that is, 230 km farther to the East, leeward of predominant winds. Climate was continental, much colder than today, and a tundra environment with permafrost developed. Under such periglacial conditions ice-wedges grew. As the present mean annual air temperature around 5°C, the estimated thermal depression in central Tierra del Fuego Island would have been more than 11°C (perhaps up to 13°C) during Last Glacial Maximum time.

Late Quaternary signals of palaeo-winter conditions in Central Yakutia as inferred from the stable isotope composition of ice wedges

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key words: stable isotopes, palaeoclimate, Late Quaternary, ice wedges

In the scope of a joint German-Russian research project, dealing with the Late Quaternary development of climate and environment in the Verkhoyansk Mountains and the lowlands of Central Yakutia in northeastern Siberia, the stable isotope composition of ice wedges was studied. Ice wedges are common features of the permafrost landscape and hosted in ice-rich soils and sediments. They are understood to form mainly during spring time, when meteoric waters released by snow melt fill frost cracks that opened during the winter. This recurrent mechanism leads to storage of annual winter precipitation in ice wedges that can be used as a paleoclimatic indicator of winter temperatures.

From our collected data, coldest winter temperatures occurred between approximately 40 and 30 ka BP, as indicated by very light isotope composition of oxygen around -31‰ VSMOW and hydrogen around -235‰ VSMOW in Late Pleistocene ice wedges of the interfluvium of Lena and Amgar Rivers. In the post-glacial period, the isotopic composition of ice wedges in the mountain's foreland reflect relatively warm winter temperatures in the early to middle Holocene around 8.5 ka BP with mean values of -26‰ VSMOW for oxygen and -199‰ VSMOW for hydrogen. Young ground ice formed between 2.3 and 0.7 ka BP documents climate deterioration during the Late Holocene with light isotope composition of around -28‰ for oxygen and -215‰ VSMOW for hydrogen.

Using the relationship between isotope signals in recent ground ice and modern climate data of central Yakutia, a quantitative estimate of paleotemperatures can be inferred. Thus, the mean winter temperatures during the Late Pleistocene were 2 to 5°C colder than today, while the Early to Middle Holocene was probably up to 3°C warmer than today. During the Late Holocene, the mean winter temperatures fluctuated between 3°C colder than today and 1.5°C warmer than today. However, the inference of absolute paleotemperatures suffers from uncertainties in regard to kinetic fractionation processes that are difficult to assess.

Some evidence for the possible existence of figures associated with permafrost in Central Portugal

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key words: Central Portugal, sporadic permafrost, Serra do Caramulo, Pleistocene, pedogenesis

This paper will argue for the possible existence of various vestiges associated with a sporadic permafrost in central Portugal, offering a new perspective on the range of phenomena associated with cold in the extreme southwest of Europe during the upper Pleistocene. We have always been conscious of the fact (and prudent as well) that claiming manifestations associated with layers of deeply frozen soil, or even permafrost, in the case of Portugal, given the geographic characteristics of the territory (altitudes and proximity to the ocean), might not be easily accepted.

The Varzielas 3 geological cross-section is located at 810 m, in a valley with northern exposure, in the Serra do Caramulo, and is less than 30 km from the present coastline. Figures can be observed in this cross section (as well as the processes they reveal), which, in higher latitudes and at higher elevations, are usually related to the presence of an active layer of deeply frozen soil. Associated with networks of cracks and frozen fluid deposits containing blocks (“head deposits”), which can be observed in the paleoslopes of declivities near or greater than 5°, other types of figures are found at the bottom of declivities (less than 5°) - solitary dikes-relict sand wedges, “drops” and polygonal soils. We can also observe two pedogenesis phases in the Varzielas 3 cross-section, whose six ¹⁴C datings offer a very particular tableau in the context of our understanding of the paleoclimatic evolution of the superior Pleistocene in central Portugal, furnishing data for the interpretation of the vestiges of permafrost at a moment of intense cold during the Tardiglacial period (the recent Dryas).

Geophysical evidence of a deep Weichselian permafrost in NE Poland

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key words: borehole temperatures, climate reconstruction, deep permafrost decay, northeastern Poland

A precise temperature logging of several boreholes in northeastern Poland was carried out in 2003 and 2004 within the Czech - Polish project “Present and past climatic changes derived from borehole temperature logs and hydrogeological analysis”. The measurements confirmed an anomaly unmatched in Europe, when a temperature decrease with depth is observed between the surface (the mean annual ground temperature of about 8°C) and the depth of 400 m (5°C measured in 460 m deep borehole Sidorowka) in the area of the Krzemianka-Udryn anorthosite intrusion (horizontal dimensions 16 km by 8 km) hidden below more than 800 m of sediments. There are indications based on other temperature logs from 250 to 300 m deep boreholes that a value of the present-day subsurface temperature minimum at the depth of 400 m is as low as 3°C in the central part of the area, some 7 to 9 km to the NE from borehole Sidorowka. Combining the new data from borehole Sidorowka with industrial temperature logs from more than 2 km deep boreholes logged in the 80s and with results of the basic geothermal research in the area, we were able to analyse in detail the observed phenomenon, especially to compile a geothermal model of the site, to estimate a mean surface temperature of the region during the last ice age, to reconstruct a temperature - depth profile for the end of the glacial and to simulate the time evolution of the profile onward to the present by solving numerically the heat conduction equation. The resulting model, consistent with the observed facts, indicates that a mean glacial surface temperature attained -10°C, a thickness of permafrost was 520 m, an onset of the post-glacial warming with

a mean temperature of +7°C occurred about 14 ka ago, last remnants of the interstitial ice thawed only 4 ka ago in the depth of 300 to 400 m and the surface temperature has increased by another +1°C in the last 150 years bringing an overall amplitude of a warming since the last ice age to +18°C. A main reason for a disappearance of subsurface glacial conditions above the anorthosite intrusion more slowly than in the surrounding area (where no decrease of temperature with depth is observed) is probably an extremely low radiogenic heat generation of the anorthosite, which conditioned a smaller vertical temperature gradient and therefore formation of a permafrost layer thicker than that outside the intrusion.

The ice complex story - Composition, characteristics and formation of Late Pleistocene ice-rich permafrost deposits in northeast Siberia

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key words: Siberian Arctic, sedimentology, geocryology, paleoenvironment

Frozen, ice-rich paleosol sequences with large ice wedges are widely distributed along the coast of shelf seas and the large rivers in central and eastern Siberia. These sequences are ¹⁴C dated between >50 and 12 ka BP. The spatial distribution of Ice Complex deposits is connected with vast, numerous thermokarst lakes formed during the Holocene warming, leading to substantial thawing of ice-rich permafrost deposits.

The origin and formation of these 10 to 50 m thick sediments is uncertain and discussed for more than hundred years. At the end of the 19th Century, Eduard von Toll gave the first interpretation, describing “stone ice” as glacier remains, where glacier fissures were filled with moraine material. Later, in the 20th Century, the deposits have been controversially interpreted as being of glaciolacustrine, fluviolacustrine, alluvial, eolian or multigenetic origin.

Since 1998, Ice Complex sequences around the Laptev Sea have been studied within the multidisciplinary framework of joint Russian-German expeditions. The sequences are characterized by comparable cryolitho-genetical, sedimentological, hydrochemical as well as paleo-ecological signatures, and include always the same Late Pleistocene stratigraphical units (Zyryanian Stadial, Karginian Interstadial, Sartanian Stadial). The deposits occur as a widely distributed cover on plains with low inclination in front coastal range or surrounding rocky hills.

The formation of the Ice Complex cover is assumed to be connected with an increased occurrence of perennial snowfields and niveo-eolian accumulations during the Late Pleistocene. Abundant niveo-aeolian solid matter was probably collected therein. Because of an extreme continentality with low precipitation, only snowfields survived, unlike the formation of glacier ice sheet in western Eurasia during this cold period. Numerous snowfields at the slopes of arctic mountains as well as in the wide spread plains in front were sources of both water for braided streams crossing the accumulation plain and for clastic material forming Ice Complex deposits. The typical bi- and multimodal grain-size distribution of these sediments indicate that various kinds of transportation and accumulation took place more or less relating to snowfield processes. The paleogeographical situation has to be considered in connection with the dry Arctic shelf areas existing contemporaneously. Only a little drainage took place on these large flat areas and therefore water from snowfields flowed broadly without clear fluvial orientation over the shelf, where large ice-wedge polygon systems were formed. Their growth was supported by meltwater coming from snow patches as well as suspended clastic matter transported by numerous streams. Plant and fauna remains indicate the existence of a spotty mosaic of dry and wet patches. The terms “tundra-steppe” and “mammoth fauna” characterize this paleoenvironment. In this landscape the mammoth fauna existed until 12 ka BP, that is, until the end of Ice Complex formation.

The Ice Complex remnants of the Siberian Arctic coastal lowlands and archipelagos are considered to be residues of a unique Late Pleistocene landscape and preserved numerous paleoenvironmental records of this time.

Periglacial phenomena as indicators of the past climate change in the East Siberian mountains

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key words: mountain, vertical zonality, periglacial phenomena, indicators

Practically all sectors of Arctic are bordered by mountain systems. The peculiarities of permafrost distribution and hydrological regime in mountains have not been given enough attention. Some investigators consider the vertical geographic zonality in mountains as the natural model of latitudinal zonality. That allows studying the various permafrost conditions on small-minded area. The dynamics of geocryological processes are more rapid and intensive in mountains than on plains. Also we expect the soil thermal pattern is more sensitive to climate variations in the mountain regions than on the plain territories. The geocryological phenomena reflect the periglacial processes activity. We studied the areas of active and relict periglacial phenomena (frost-boils, kurums, nival terraces, rock glaciers, polygonal forms) in Northern Zabaykalye region (East Siberia) and in interior Alaska. The research identified the environmental conditions limits of actual active or "live" periglacial phenomena. We assume that the position of analogous relict forms reflects the similar conditions areas that existed in the Pleistocene epoch. Different periglacial phenomena have diverse time of transformation from active to relict form. This allows the reconstruction of climatic conditions for recent or distant event of Quaternary period. For example, kurums develop typically during periods lasting 50 to 100 ka and "can die" (i.e. became covered by vegetation) during 100 to 500 years. Frost-boils form 1000 times more quickly than kurums and can become inactive in just 10 to 20 years.

Cryogenic structure and genesis of Late Cenozoic watershed formations at the Primorsky mountain range adjacent to the Bykovsky peninsula, Laptev sea, Russia

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key words: ice complex, cryogenic structure, micromorphology, block tectonics, sedimentary rhythm

The Ice Complex, found on the watershed areas of Primorsky mountain range is compared to that rather well understood at the Bykovsky Peninsula separated from the range by Horogor depression. Study of the cryogenic structure, composition, micromorphology of facies varieties of the watershed permafrost allowed determination of the main mechanisms of its formation. Clastic and clayey frozen deposits more than 30 m thick are widespread in mountain ridge saddles formed by small creek valleys running from both sides of the range and inheriting tectonic fractures of the northeast and northwest strike. Bedrock of the Verkhoyansk complex at Primorsky ridge and adjacent area is separated by these fractures into subsided and uplifted blocks, with different relative altitudes. Due to tectonics, the Bykovsky Peninsula was separated from the rest of the range by deeply seated block and is itself on a subsided block. The characteristic sequence of the watershed saddle Ice Complex was studied at the saddle in the upper course of Horogor creek at the altitude 140 m above sea level. From the bottom up the section consists of: **(1)** bedrock dark gray siltstone, claystone, sandstone of the Verkhoyansk complex; **(2)** clastic crust of weathering, eluvium of sandstone,

slates, siltstone, with massive cryogenic structure, (4 m); (3) interbedding of slope, lacustrine-bog, tber, and till of clastic, sandy, silty-clayey deposits, with low ice content comprising rare horizontal and gently sloping zigzagging ice layers in the lower portion of the sequence, and steeply sloping zigzagging ice layers and crustlike cryogenic structure in the higher portion (13.4 m); (4) rhythmical interbedding of lacustrine-bog and slope deposits forming Ice Complex (13.6 m); (5) soil-peat and clayey horizon with small ice wedges and cryogenic structure following the bending of the underlying ice-complex roof, probably transitional layer (1.6 m); (6) organic mat (0.1 m). The active layer depth is about 40 cm. The Ice Complex, unit 4, contains rather thin polygonal ice wedges. It is subdivided into two main horizons. The lower one comprises mainly lacustrine-bog deposits with interbedding of drift with some clastic inclusions. The upper horizon is of slope mainly proluvium deposits, clastic with clayey matrix. The clastic component comes from local sources, arriving in the form of earth flows of variable intensity. The cryogenic structure in the unit 3 testifies to a freezing of the sequence in conditions of a uniform slightly inundated (drained) talik below the lacustrine bog deposits of two lower layers of unit 4. A notable feature of the Ice Complex is regressive rhythm starting with silty clay and roofed by clastic with clayey matrix interbeds. The cryogenic structure and stratification of deposits bear traces of tectonic breakage. The same formation is found on the Bykovsky Peninsula Karginsky-Sartan Ice Complex. It can be concluded based on the study of Ice Complex sequences that Late Sartan block tectonics separated previously continuous geological body into Bykovsky Peninsula (edoma), Horogor depression, reworked by thermokarst, and saddles and valleys of Primorsky mountain range.

New insights on diatoms as climatic and environmental reconstruction tools from NE Siberia (Russia)

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key words: diatoms, climatic reconstruction, environmental reconstruction, NE Siberia, Russia

Diatoms (Bacillariophyta) are photosynthetic, unicellar organisms. They are excellent bioindicators as they respond to short- and long-term changes of environmental factors. The cell wall (frustule) of diatoms is composed of delicately ornamented silica and is very often preserved in the fossil sediment, which allows to reconstruct past environmental changes. The most important factors, which influence the diatom flora in Arctic regions are: type of vegetation, dissolved organic matter, pH, light penetration, duration of ice-cover period.

First diatom studies in Siberia were concentrated around the present Transsiberian route. In Yakutia, the main diatom investigation were done by Komarenko (1956). Recently, more research is concentrated in Yakutian permafrost areas (e.g. Stachura-Suchoples, submitted). The main area studied encompasses permafrost originated lakes (North and Central Yakutia). Another research approach covers e.g. the Bungo-Land terraces of the New Siberian Archipelago.

To improve the use of diatoms as bioindicator tools and a key to understand a regionalism, it is required - in the light of new molecular data and SEM observations - to understand the taxonomy and biogeography of diatoms from cold regions. More environmental data (physical and chemical parameters of water) taken *in situ*, or analysed later in laboratories is also needed to build a database suitable for understanding of preferences and tolerances of diatom auto- and synecology.

Different approaches of diatom studies in Yakutian permafrost area, which encompass environmental and climatic reconstructions (High Arctic), building of reference collections supported by ecological data (North and Central Yakutia), as well as taxonomy and biogeography aspects on diatoms (NE Siberia) are presented and discussed here.

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Pleistocene glaciations in the Verkhoyansk Mountains, NE Siberia

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key words: glacier, Quaternary, Siberia

Pleistocene glaciations have a strong influence on landforms and thus on recent processes in mountain systems and the adjacent forelands. Former glaciated landscapes are still not in an equilibrium state. Especially gravitational processes are evident, which provide material for periglacial processes. Beside that the timing of glaciations influences distribution and depth of permafrost.

Fieldwork and remote sensing techniques were used to determine extent and timing of Pleistocene glaciations in the Verkhoyansk Mountains. The Verkhoyansk Mountains extend about 1200 km from Central Yakutia in the south up to the Arctic Ocean in the north. Summits reach maximum elevations of up to 2300 m asl. The climate conditions are extremely continental with mean temperatures in January of -50°C and mean temperatures in July of 20°C . Annual precipitation on the western side of the mountain system is about 400 mm and decreases towards the east to less than 100 mm. Recent glaciation is very limited.

Fieldwork was undertaken in two catchment areas in the southwest of the Verkhoyansk Mountains. Remote sensing data (Landsat ETM+ and Corona) was used to support fieldwork and to extend the geomorphological mapping to the more remote areas.

Three to four terminal moraines have been mapped in the foreland of the south-western Verkhoyansk Mountains. These moraines form large concentric ridges with heights between 200 and several tens of metres and have a diameter of more than 25 km. In some areas these ridges are dominated by a large number of lakes. Most of these lakes have been formed by the downwasting of buried glacier ice. Their recent shape is attributed to thermokarst processes. Beside these moraines in the foreland, one group of terminal moraines has been deposited within the mountains.

Until now, the innermost of the terminal moraines in the foreland have been attributed to the Sartan glaciation (Weichselian). However, new results from OSL (Optical Stimulated Luminescence) dating of the covering aeolian sediments show ages of up to 50 ka BP. Therefore the underlying glacial sediments must be older. The terminal moraine upstream in the Verkhoyansk is at least older than 30 ka. No other terminal moraines could be identified further upstream.

The authors conclude that there was no major glaciation in the Verkhoyansk Mountains during the Last Glacial Maximum (LGM). This may be caused by insufficient precipitation during the time of the lowest temperature. Glacier growth in this extremely continental area is presumably controlled by moisture supply.

Long lasting effects of the deep seated Weichselian permafrost in the NE of Poland

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key words: permafrost, paleoclimate, geothermics, paleohydrology, Weichselian

The late Pleistocene climatic variations have had considerable effect on the subsurface temperature regime. Several lines of evidence indicate that in Central Europe the period of the last 400 ka can be considered as the Ice Age with average surface temperature as low as -10°C, estimated in the NE Poland for the late Weichselian. This compares with the present annual temperature of about +7°C. Specifically, ground surface temperature (GST) changes in the last 100 ka were found to be the major factor controlling vertical variations of terrestrial heat flow density (HFD). Based on recent estimates of the heat flow densities in the Polish Lowlands, it can be said that the temperature profiles for the uppermost part (<2000 m) rocks are still in transient state between average temperatures of Holocene and Pleistocene (Weichselian glaciation). Coupled geothermal-hydrochemical studies carried out in the NE Poland in Suwalki anorthosite massive, have shown that alteration of the chemical composition of groundwater within the deep Cretaceous aquifers has been caused by cryogenic processes during the Weichselian glaciation. We have observed that the depth of temperature inversion corresponds to the recent hydrogeochemical cryogenic anomaly. The thickness of the permafrost zone depends mostly on the heat flow density. Our analysis based on geothermal and hydrogeochemical data revealed that the maximum thickness of deep freezing has occurred in Suwalki massive at the depth of about 545 m. It is expected that the new planned drillhole focused, according to geothermal modelling in the center of the anomaly, will perhaps reach the frozen rocks (permafrost). Knowledge about the occurrence of spatial and time extent of deep Weichselian permafrost zone can contribute to both, paleoclimatic reconstruction on the northern hemisphere as well as to terrestrial heat flow analysis over the world.

The relict block fields of the Ancares Sierra, northwestern Spain - A good Palaeoindicator of the lower limit of the continuous permafrost belt?

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key words: block fields, mountain permafrost, Late Pleistocene, palaeoclimatic reconstructions, NW Spain

Relict block fields are common features in the mountains of northwestern Spain. In this contribution the origin and the spatial distribution of the block fields of the Ancares Sierra is discussed. Consideration is also given to its significance to the reconstruction of Late Pleistocene local temperatures. The block fields of the Ancares Sierra are located at altitudes between 1700 and 1998 m a.s.l., and they are almost exclusively composed of quartzite macroclasts. Block fields are always topographically above relict rock glaciers. This fact permits to relate block fields to the occurrence of a continuous permafrost belt developed during the coldest periods of the Late Pleistocene. For that time, a mean annual air temperature drop between 12 and 14°C with respect to present-day values has been calculated (Valcarcel-Díaz, 1998, Martínez-Cortizas et al., 1999). The block fields of the Ancares Sierra always occur above the lower limit of the continuous permafrost belt estimated for the periods of greatest thermal depression of the Last Glacial Maximum.

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Evidence of a Middle Pleistocene “temporary” hydrolaccolithe in the alluvial fan of the Ornain River, Haute Marne, France

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key words: hydrolaccolithe, paleopermafrost, Middle Pleistocene, grézes alluviales, water escape

It is rather difficult to preserve traces of sills of ice or of frost blister as these features generally develop in unconsolidated sands gravels. After the ice melt, a circular depression is generally observed today, few metres in diameter, as also observed in sands in Northern Quebec. In the Austre Loven morainic arc (Svalbard), an hydrolaccolite of small size (10 m in diameter) remained for many years (50 years?), until the warming of 1995. Similar features may have existed in the terrace gravel of the Ornain, perched above the present valley of the river with a gentle sloppy surface to the W-NW. The form consists in a collapsed feature, 8 m wide in section, specifically stained by iron hydroxides and fed by piping (similar to water escape features). Piping features develop on joints affecting the gravel. The gravel consists in alluvial grézes, rather frost susceptible. The observed feature is also associated with ice rafted peat mats or debris and some cryoturbation. We suggest that the hydrolaccolite developed for several years when the water table was close to the surface, prior to the capture of the Ornain (dated circa 250 to 200 ka by ESR), when frost shattering was powerful and superficial drainage important (snow melt, during late OIS 8 or early OIS 6). Permafrost was probably present to trigger water injection into the frozen gravels, probably in early spring when lateral water seepage was available from the early thawed slopes. The present-day geometry of the perched fan does not allow the rising of such a water pressure. This reconstruction fits very well with the regional climate conditions of late OIS 8, but not OIS 6, which was much more boreal.

Evidences of periglacial activity during the Upper Miocene in Brittany

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key words: shore ice rafting, Upper Miocene, plate-form shaping periglacial

Traditionally in Western Europe, periglacial activity is believed to be restricted solely to the Quaternary. Recent reappraisal of the stratigraphy in Brittany and Cornwall with control by ESR dating allows us to define some periglacial episodes associated with eustatic lowstands in various position from the end of the Miocene (6.7 Ma) up to the onset of the Quaternary or Gelasian. These observations fit with the onset of ice cap building in the Northern Hemisphere and the southward migration of the inter-tropical convergence zone.

The effects of periglacial dynamics are mostly preserved in form of shore face rafting and frost shattering, often in association with slope deposits. These deposits are in most cases consolidated by a goethitic- Al^{3+} iron pan related with the Messinian low stand and podzolisation. Cliff retreat of sometimes more than Frost shattering and snowmelt favoured the development of braided river system in association with longwave length tectonic bulging. Frost activity podzolisation and shore ice rafting allowed a very rapid re-shaping of polycyclic plate-forms (Permo-Trias, Middle Cretaceous) in form of “plate-forme à écueils”. Similar observations can be done in Iceland, Gaspesia or Norway, developing in most of the case the large “strandflats” that generally pre-date the maximal glacial scouring along the Northern Atlantic coastline.

Distinguishing between tectonic and periglacial deformations of Quaternary continental deposits in Europe

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key words: periglacial, paleopermafrost, co-seismic deformation, tectonic Europe

Recognising tectonic deformations in Quaternary sediments is important for accurately interpreting palaeoclimatic developments. Distinguishing deformations caused by seismic processes from that induced by periglacial processes needs accurate observations. The present paper is a contribution to the understanding of the genesis and diagenesis of soft-sediment structures in continental areas that at times have been subjected to periglacial conditions. Field observations from active periglacial and seismic areas are integrated with relevant data from previous studies.

Several morphological criteria are proposed to define purely periglacial, purely co-seismic and combined periglacial/seismic forms. A reappraisal of the origin of involutions and associated deformations within an intra-plate region of Europe with continuous low-level seismic activity provides evidence of regional tectonic events independent of the recurrent glacial loading during Quaternary times. Reanalysis of involutions provides a more accurate insight into the permafrost extent during the cold phases of Quaternary times, and also enables recognition of the zones where perturbations of seismic or tectonic origin prevail.

Appearance of Heinrich events in radiocarbon dated pollen and spores diagrams of ice-wedge ice and its surrounding Edoma sediments of Kolyma river

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key words: pollen, spores, ice-wedge ice, Late Pleistocene, AMS, ¹⁴C-dates

Palynologic data have been obtained from large ice-wedges and surrounding syngenetic edoma sediments of Duvanny Yar cross-sections in the Kolyma River valley, Yakutia.

The Duvanny Yar edoma extends for more than 10 km along the coast with exposure height of more than 50 m above Kolyma River level. Within the edoma sediments is a multistage ice-wedge system. About 30 AMS ¹⁴C dates of organic micro inclusions in the ice-wedge and more than 80 conventional ¹⁴C dates of bones and plant material from surrounding sediments have been obtained. ¹⁴C dating has demonstrated vertical and lateral heterogeneity of Duvanny Yar edoma. The sediments consist of lenses of alluvial, lacustrine-alluvial, lacustrine, bog and marsh origin which occur in different parts of a cross-section at the same height.

Pollen plots of surrounding sediments were made on the basis of 93 samples. According to ¹⁴C dating it could be dated from 14 to 31 ka BP. Pollen plots of ice wedges were made from 28 samples. Direct AMS ¹⁴C dating of the ice-wedge ice indicates ice-wedge growth from 14 to 25 ka BP. Local components of pollen spectra such as *Bryales*, *Sellaginella sibirica*, unmaturred pollen of herbs predominate within pollen plot of the surrounding sediments. This indicates that local biocoenoses existed during stable conditions. Minimum salinity values coincide maximum amounts of unmaturred herb pollen, whereas salinity maxima correspond to maxima of *Sellaginella sibirica*. We consider that the pollen spectra from ice-wedge ice represents the

pollen rain of spring and early summer, and archives sharp changes of the regional components of pollen and spore spectra. These changes correspond with rhythms of syngenetic permafrost sediments and correlate with fluctuations identified in marine deposits and ice cores, with cycles of 6 to 16 ka named as Heinrich events. Pollen spectra from ice-wedge ice demonstrate two rhythms. The lower one consists of consequence of maxima *Bryales + Poaceae-Artemisia-Varia*. This rhythm is also identified in pollen plot of surrounding sediments and can be correlated with H2 (ice-wedge ice is dated 21 to 23 ka BP). The upper rhythm consists of the consequence *Poaceae- Artemisia-Betula sect. Nanae* and reflects the H1 event (17 to 14 ka BP). The data of variability of global, regional and local pollen and spectra components of syngenetic edoma sediments connected with periodicity rhythms are presented.

The ^{14}C -dated oxygen-isotope and deuterium plots of ice-wedge ice near Vorkuta town, Northern Europe

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key words: polygonal peatbog, ice wedges, Holocene, ^{14}C -dates, δD

In the Yun'yaginsky polygonal peatbog, 13 to 14 km to the east of the town of Vorkuta, the thickness of peat appreciably increases to the centre of polygon structures and exceeds 2 to 2.5 m. Ice wedges and peat wedges occur in the peat at the depth 2 to 2.5 m. The width at the top of ice wedge is about 0.4 m. The age of ice wedge formation has been established from 18 ^{14}C dates of the peat and wood. The isotope characteristics of ice wedges and other types of ice, snow and water have been obtained as follows:

1. In Holocene ice wedges values of δD vary from -119.1 up to -111.6‰, values of $\delta^{18}\text{O}$ from -16.28 up to -15.60‰ and deuterium excess values from 13.8 up to 9.8‰.
2. In ice lense ice values of δD vary from -128.4 up to -97.8‰, values of $\delta^{18}\text{O}$ from -17.48 up to -12.79‰, deuterium excess values from 11.2 up to 4.5‰.
3. In snow of old apron the values of δD is -134.4‰, $\delta^{18}\text{O}$ =-18.91‰ and deuterium excess value is 16.9‰.
4. In water of small pond within polygon values of δD is -87.4‰, $\delta^{18}\text{O}$ =-11.31‰ and deuterium excess value is 3.1‰.

Fresh snow fall in December 24, 2003 was sampled at Seida and Yeletskaya railway stations. The values of δD vary from -203.6 up to -189.48‰, the values of $\delta^{18}\text{O}$ from -27.22 up to -25.93‰, and deuterium excess value. Possible duration of ice wedge formation is determined from 9 to 7 ka. The age of the wood and peat from vertical peat wedge is 9.2 ka. Intensive frost cracking took place about 9.2 ka BP. Ice and peat wedges grew during the Holocene Optimum. Oxygen isotope and deuterium plots provide evidence for stable winter temperatures close to modern ones.

Pleistocene mountain permafrost in the west of the Iberian Peninsula south of 42° N (Serra da Estrela, Portugal)

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key words: Pleistocene permafrost, periglacial geomorphology, Iberian Peninsula, mountain permafrost

Different types of geomorphological features, but especially rock glaciers, have been used as indicators of permafrost occurrence during the Pleistocene in the mountains of Iberian Peninsula, especially in the Pyrenees, Sierra Nevada and Cantabrian Mountains. However, no sure evidence had been found for the occurrence of widespread permafrost during the Pleistocene in western Iberia south of 42° N, a region that is especially significant for paleoclimate reconstruction and modelling as indicated by several studies from marine sediment cores.

The Serra da Estrela is located in the southwest part of the Iberian Central System at 40° 20' N, 7° 35' W. It rises to 1993 m asl and is the highest mountain range in Portugal. The lithology is mainly granitic, but several petrographic varieties with important geomorphic implications occur. The relief above 1400 m is dominated by stair-like plateau surfaces deeply dissected by radiating valleys. In the Weichselian a 70 km² plateau ice-field with valley glaciers was present and produced a well-developed glacial landscape (e.g. U-shaped valleys, cirques, knob-and-basin topography, extensive areas with roches moutonnées and moraines). The average equilibrium line altitude of glaciers was at ca. 1640 m asl at the Last Maximum of the Glaciation of Serra da Estrela (LMGSE).

Relict periglacial phenomena in the Serra da Estrela include blockfields, blockslopes, blockstreams, stone-banked lobes, rock glaciers and possible cryoplanation terraces. In outcrops exposing fluvio-glacial and different slope deposits, platy structures are found. The analysis of the spatial distribution of the relict periglacial phenomena and of the factors that control them (e.g. altitude, lithology and position in relation to the glaciated area), supported by detailed geomorphological mapping, shows that seasonal frozen ground occurred, at least, above 700 m a.s.l. and that permafrost was present above 1350 m a.s.l. The presence of a few small protalus rock glaciers inside the limits of the valley glaciers of the LMGSE, and the existence of blockfields, blockstreams and stone-banked lobes in the uppermost plateau, also inside the limits of the glaciers of the LMGSE, indicates that periglacial conditions existed long-after the beginning of glacier retreat. The periglacial features suggest a minimum decrease of 10°C of the mean annual air temperatures.

Freshwater ostracodes in Quaternary Permafrost deposits from the Siberian Arctic

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key words: freshwater ostracodes, Late Quaternary, paleoenvironments, permafrost, Siberian Arctic

Ostracode analysis was carried out on samples from ice-rich permafrost deposits obtained on the Bykovsky Peninsula (Laptev Sea). A composite profile was investigated that covers most of a 38 m thick permafrost sequence and corresponds to the last ca. 60 kyr of the Late Quaternary. The ostracode assemblages are similar to those known from European Quaternary lake deposits during cold stages. The ostracode habitats were small, shallow, cold, oligotrophic pools located in low-centred ice-wedge polygons or in small thermokarst depressions. In total, fifteen taxa, representing seven genera, were identified from 65 samples. The studied section is subdivided into six ostracode zones that correspond to Late Quaternary climatic and

environmental stadial-interstadial variations established by other paleoenvironmental proxies: (1) cold and dry Zyrianian stadial (58 to 53 kyr BP); (2) warm and dry Karginian interstadial (48 to 34 kyr BP); (3) transition from the Karginian interstadial to the cold and dry Sartanian stadial (34 to 21 kyr BP); (4) transition from the Sartanian stadial to the warm and dry Late Pleistocene period, the Allerød (21 to 14 kyr BP); (5) transition from the Allerød to the warm and wet Middle Holocene (14 to 7 kyr BP); and (6) cool and wet Late Holocene (ca. 3 kyr BP). The abundance and diversity of the ostracodes will be used as an additional bioindicator for paleoenvironmental reconstructions of the Siberian Arctic.

The burrows of rodents as archive of information about Late Pleistocene environments of North-East Eurasia

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key words: fossil burrows of rodents, Late Pleistocene, paleovegetation, macrofossils analyses

It is well known that burrows and hibernacula containing nests of ground squirrel of subgenus *Urocitellus* and of other rodents (lemmings and mice) were found in Late Pleistocene ice-loess deposits of North-East Eurasia. Fossil burrows of ground squirrel contain various organic material in very good condition introduced from surface. It is important source of information about terrestrial environments. The radiocarbon age of burrows is about 32 to 28 ka. Deposits containing them formed about 50 to 28 ka ago in the Carga thermochrone period.

The main research goals were to determine paleovegetation of territory adjacent to burrows and to use nest materials to reconstruct the Carga thermochrone environment. Macrofossil analyses indicate a locally diverse, herb-dominated flora during the Carga thermochrone. The great volume (fed chambers can reach hundred thousands units) of fruits and seeds from fossil burrows belongs to family of Brassicaceae, Ranunculaceae, Caryophyllaceae, Poaceae and Carex. More than 40 plant species were determined including forbs *Arctous alpina*, *Arctophila fulva*, *Bistorta vivipara*, *Carex appendiculata*, *C. bonanzensis*, *C. concolor*, *C. juncella*, *C. misandra*, *C. vesicata*, *Festuca altaica*, *F. lenensis*, *Gentianopsis barbata*, *Hedisarum arcticum*, *Hordeum brevisubulatum*, *Minuartia arctica*, *Myosotis asiatica*, *Pedicularis kolymensis*, *Poa arctica*, *Polemonium acutiflorum*, *Potentilla nivea*, *Rhodiola rosea*, *Ranunculus repens*, *Rumex arcticus*, *Puccinella hauptiana*, *Sanguisorba officinalis*, *Silene stenophylla* and other; shrubs *Salix krylovii*, *S. polaris*, *Salix* sp., and woods remains *Larix cajanderi*. The seeds of *Silene stenophylla* Ledeb, *Bistorta vivipara* (L.) S.F. Gray, *Potentilla nivea* L., *Poa arctica* R.Br., *Poa botryoides* (Trin. ex Griseb.), *Rumex arcticus* Trautv. and different species of sedges were found more frequently in burrows.

Remains of vegetation, which would have flourished in cold and dry steppe conditions, including pioneer plants communities and sites of different moisture providing, dominate in studied macrofossils. The assemblage suggests open, pioneer-type vegetation that grew on well-drained substrates and destroyed ecotopes. These pioneer and steppe plant communities grow within modern the destroyed ecotopes. Although fossil burrows, as paleoecological records are a reflection of rodent diets, they represent important paleobotanical archives of vegetation. The research was supported by the Russian Foundation for Basic Research, grants no. 04-05-64748.

Chapter 3

Session 2 - Permafrost Affected Soils, Microbiology and Trace Gas Releases

Session Conveners: Liza Rivkina, Eva-Maria Pfeiffer
in association with: IPA Cryosol WG

Impact of freeze/thaw processes on the carbon balance in Siberian permafrost regions

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key words: climate change, thaw depth, dynamic global vegetation model, carbon cycle, runoff

There is high evidence that active-layer thickness has increased due to climate change in high-latitudes. Impacts on the carbon balance due to related alterations in the soil water balance are well documented for specific test sites. To contribute to the analysis of carbon pools and fluxes in a changing climate from a theoretical process-based point of view, and on a continental scale, we incorporated representations of freeze/thaw processes in the Dynamic Global Vegetation Model Lund-Potsdam-Jena (LPJ). With it the soil water balance is improved in permafrost regions. This leads to more reliable estimates of fire return intervals and biomass. Furthermore, the physiological control of productivity and respiration by frozen grounds is represented in the model now. The permafrost-enhanced model simulates a positive response of biomass to changes in summer air temperature and rainfall during the 1980s and 1990s. Biomass has decreased west of 95° E and increased east of it in Siberian permafrost regions. Since heterotrophic respiration also increased during this time period, Siberia acted as a slight carbon source. As a consequence of climate change, the LPJ-DGVM simulated the land surface to change to a higher source or smaller sink in Central Siberia and the opposite way round in West and Far-East Siberia over 1981 to 1999.

Characteristics and significance of the transition zone in permafrost-affected soils

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key words: arctic soils, transition zone, cryogenic processes, northern Alaska, Cryosols

In the three-component conceptual model of arctic soils, the transition zone is recognized as occurring between the active layer and permafrost. although typically frozen, it episodically thaws. We used the North Slope Soil Inventory (NSSI) data set that includes descriptions and analytical data of 293 pedons from northern Alaska to distinguish and characterize the transition zone. We were able to delineate the upper and lower boundary of the transition zone in 75% and 65% of the pedons, respectively. The transition zone features cryoturbation and contains abundant redistributed organic C, segregated ice in the form of lenses and nets (ataxic), and soil moisture. In moist acidic tundra, the transition zone has a higher pH and base saturation than the active layer, because of the lessened influence of biota. The surface of the transition zone averaged 35 ± 8 cm in depth and thickness of the transient layer is 23 ± 8 cm.

Ecosystem monitoring in the Canadian Arctic (Pangnirtung Pass, Baffin Island)

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key words: cryosols, monitoring, ecology, Canadian Arctic

The objective of this study is to monitor changes in ecosystems of the Canadian Arctic resulting from human activities and natural forces. Seven transects were established along Pangnirtung Pass between Overlord and North Pangnirtung Fiord in Auyuittuq National Park on Baffin Island. In the first phase of the study (1995 to 1996), detailed vegetation, soil, permafrost and surface condition data were collected along these transects. In the second phase, the transects were monitored from 1997 to 2001 by the park's staff and data were collected concerning the types and severity of disturbance. In the third phase of the study, the transects were revisited in 2002 and detailed data were collected again. Data indicate that most of the ecosystems associated with these transects were fairly dynamic and displayed changes resulting primarily from natural processes, with some also resulting from human impact. In addition to the impact of wind, water and direct human activities on the trails, changes in air temperatures and, therefore, soil temperatures may also be affecting this area. These higher temperatures have had a noticeable effect on thaw depth and soil moisture. In the northern part of Pangnirtung Pass the increase of thaw depth was much greater than in the southern part. Changes in vegetation were also observed between 1995 and 2002, especially in the northern part of the pass, where the vascular cover increased significantly. The vegetation changes may be a reflection of the higher air temperatures and greater thaw depths during the monitoring period.

Permafrost and soil development at the Lower Yenisej (North Siberia)

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key words: permafrost, Brown Earth, Lower Yenisej, North Siberia, soil geography

The Siberian taiga's permafrost associated soils belong to one of the Earth's less known pedogenic regions. The main focus of attention in this particular study explored the distribution and composition of the glacial deposits and focussed on the soils of the high-continental permafrost regions of the Lower Jenissej. Statements conveying a genetic and soil systematic approach were therefore possible.

Representative case studies were carried out in the central Taiga's and northern Taiga's landscape belts and in the nearby lying forested tundra regions. In the investigation area, the soil profiles and drillings were described in accordance with the German soil classification system (AG Boden, 1994) and integrated into soil catenas. Relict periglacial cover series form the most important parent material for soil formation. On plateaus, the relict periglacial cover series are often described as single developed series, on slopes however their development is usually of a dual nature. The hanging aeolian surface layer occurs more regularly, whereas the solifluctional character of the lying surface layers is more so bound to the valleys. The Brown Earths can be regarded as the zonal soil of the North Siberian Taiga. This particular soil type dominates at all terrestrial locations in all three landscape zones. In the central taiga, there in the investigation area where permafrost is missing i.e. in a permafrost-free zone, Brown Earth and Parabrown Earth elementary features are evident indicating deep, intensive and mature terrestrial soil formations. A very similar soil pattern evolves as is the case in Central Europe. This trend can likewise be observed in the northern taiga soils there where deep intensive soil formation and the absence of permafrost prevails producing terrestrial soil types in which the Brown Earths make up the dominate soil type. Only in the nearby lying forested tundra regions in the north is the impact of permafrost, its great spacial distribution and pedological character of relevance. The Brown Earth can be regarded as the main zonal soil formation at alluvial talik locations of the nearby lying forested tundra regions. Stagnosols occur at an active layer of 2 m. Otherwise, gleying and peat processes are more evident as depths less than this. Their intensity of weathering is similar as with the Brown Earths of the northern and central taiga. The North Siberian Brown Earths situated on Wuermian glacial sediments macroscopically and analytically correspond to the Brown Earths of the young moraine landscapes in Central Europe.

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Different impacts of climatic change in permafrost and permafrost-free areas in the Italian Central Alps

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key words: climate warming, vegetation, mountain permafrost

At the Stelvio Pass (Italian Central Alps) the regional impacts of climatic change on natural high mountain environments have been assessed analysing the vegetation evolution in the last 50 years and comparing them with permafrost patterns and climatic data. The study area has been free from human disturbance and recent glacial events, being therefore suitable for the assessment of climatic change impacts. Permafrost patterns

have been obtained by geomorphological surveys, BTS measurements, geophysical investigations and permafrost modelling. Discontinuous permafrost occurs above 2600 m with an active layer ranging from 2 to more than 5 m and different distribution on northern and southern slopes. Climatic change impacts have been quantified analysing the changes of vegetation since 1950 by comparing the phytosociological map of the actual vegetation with the phytosociological map by Giacomini and Pignatti (1955) referred to the vegetation of 1949 to 50. Below 2700 m vegetation experienced a significant increase in all the study area in terms of coverage, replacement of discontinuous with continuous communities, shift upwards of the altitudinal belts, ingression of communities from the lower altitudinal belts, development of the more evolved communities, replacement of the most xerophytic communities by mesic and chionophilous associations. On the contrary, above 2700 m vegetation shows different patterns depending on aspect. On the southern slopes vegetation became more evolved and increased its coverage. On the northern slopes vegetation disappeared or was replaced by pioneer and discontinuous communities. The changes observed below 2700 m are well compatible with most of the expected impacts of climatic change, while the regression above 2700 m is unexpected and could be explained by the surface instability triggered by the degradation of discontinuous permafrost. This hypothesis is supported by the ground surface temperature (Gugliemin, 2004) reconstructed by the permafrost thermal profile of the PACE project borehole at 3000 m a.s.l. near Livrio station. GST increased more than 2°C since the beginning of the XX century until 1978, had a drop of almost 1.5°C from 1978 to 1992 when a sharp increase started again. The climatic data show very large fluctuations of the mean annual air temperatures (MAAT), but the trend from the moving average of 30 years of MAAT confirms a general increasing since 1950. Among the impacts of climatic change these data support the permafrost degradation and demonstrate the different responses of the permafrost versus permafrost free areas with the more significant impacts occurring at the boundaries of discontinuous permafrost triggering surface instability processes.

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Active Layer characteristics and bacterial occurrence across a latitudinal gradient in Victoria Land (Continental Antarctica) as indicator of functional processes in permafrost environments and ecosystems

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key words: permafrost, vegetation, soils, Antarctica

Soil analyses have been carried out in permafrost environment in Victoria Land, Continental Antarctica, in 9 sites within the network of the sensitive system permafrost-vegetation for the assessment of climate change effects along a latitudinal and geographical transect (77° to 72° S). Within each site the samples have been collected in different ecological and environmental conditions concerning active layer thickness, vegetation type and coverage, substrata, occurrence of glacial and periglacial features. In each site the vertical profile of the ground have been described and the samples collected within the active layer representing all the layers with visible differences regarding texture, structure and color. Organic C and N show specific patterns allowing to discriminate: **(a)** vegetated vs unvegetated sites; **(b)** among the unvegetated sites, ground with and without disturbance processes, mainly represented by frost heave and salt concretions. The barren grounds with frost heave and/or salt efflorescences show highest values of organic C and N. In the vegetated sites,

organic C and N show different patterns related to the vegetation type and to their ecological requirements in terms of nutrient regime. The higher values are associated in particular with moss communities and with ground colonized by nitrophytic epilithic lichens. On inundated grounds the content of both organic C and N increases respect to close sites with similar vegetation. On the contrary, bacteria have a wide range of variability (between complete sterile soils to a more than 100 K of cells g^{-1} soil) with less clear patterns of spatial distribution. In the surficial layers (<5 cm) in the unvegetated sites the higher bacteria values couple with the higher values of Al and Fe, but not with the organic C and N. In these sites the higher bacteria values are always associated to the more xeric conditions while the only really sterile site is the true inland one (Cape Sastrugi). Although the vegetated sites show more abundant bacteria, the highest values have been found within unvegetated gelifluction terracettes soils. The vertical distribution of the measured parameters show regular patterns, with lower values at the surface, maximum at intermediate depth, and a decrease in the deeper parts of the profile, except for C and N in some sites with a progressive decrease with depth. These depths are consistent with the values of active layer thickness characterizing the different sites. The vertical profile of the bacteria are differentiated between vegetated soils and barren grounds, the former with the higher values in the upper layers, the latter with an opposite pattern. The relatively high values of bacteria in barren grounds and in strongly disturbed soils (as gelifluction terracettes) need further research especially because in literature these Antarctic environments have been considered “sterile” and therefore not particularly sensitive to the climate change.

Behavior of frozen gas hydrate contained sediments at nonequilibrium conditions

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key words: methane hydrate, frozen sediments, self-preservation, pore hydrate, metastability

On this day there are many data on gas hydrates existence in permafrost are known. Gas hydrates are fixed both on direct shows (gas hydrate contained cores) and on indirect shows in many areas of the world (the Arctic coast of Canada, Alaska, the north of Siberia, etc.). Gas hydrate contained cores from permafrost in several areas of Mackenzie Delta were reached up on surface (Dallimore et al., 1995, 1999). There are data on finds of relict gas hydrate in the top horizons of permafrost section (119 m), which existence in gas hydrate metastability zone due to self-preservation effect. Besides numerous gas hydrate display (on indirect shows) on shallow depths (up to 200 meters) have been fixed also in territory of the North of Western Siberia and other areas permafrost of Russia (Yakushev and Chuvilin, 2000). The opportunity of existence of gas hydrate accumulation on shallow depth represents special interest in the context of their existence under non-equilibrium conditions, as well as a serious geological hazard under development of these areas, and also emission of greenhouse gases at global warming. Due to the fact that relict gas hydrate accumulations are poorly investigated, experimental researches of metastability of hydrate contained frozen sediments under nonequilibrium conditions are significant.

For research of metastability (self-preservation) artificial methane hydrate saturated samples of sand and sandy-clay mixes were prepared. Then these samples were frozen. Change in time of gas- and gas hydrate content in frozen samples under nonequilibrium conditions (pressure 0.1 MPa and temperature -8°C) is studied during experiments. The received data have been used for calculation of self-preservation coefficient, which based on ratio of volume gas hydrate content in sediments under nonequilibrium and equilibrium conditions. The carried out experimental researches allow to propose a method of a quantitative estimation of gas hydrates self-preservation in frozen sediments under nonequilibrium conditions, which based on studying of hydrate dissociation in time. The first results of quantitative studying of metastability of frozen artificial gas hydrate saturated sediment samples have shown that the methane hydrate self-preservation in porous media is defined by the whole complex of parameters and characteristics of gas hydrate contained

sediments, such as location temperature (the main factors), macro and micromorphological features of gas hydrate accumulations, degree of pore filling by hydrate and ice, composition and properties of sediment matrix, etc. The received experimental materials allow to prove existence conditions of relict gas hydrate in shallow horizons of permafrost. This research was funded by the programme Russian Foundation Basic Research No 04-05-64757 and INTAS project No 03-51-42594259.

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Nitrification in permafrost soils of the polygonal tundra in Siberia

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key words: N-cycle, nitrification, permafrost soils

Since arctic wetland soils are the most important natural source of the climate relevant trace gas methane, many investigations focused on the microbial C-cycle of permafrost soils. But despite a close connection between C-cycle and N-cycle, the N-cycle is mostly unexplored.

In this study one important part of the microbial N-cycle, the nitrification was investigated. During nitrification ammonia is oxidized by chemolithoautotrophic nitrifiers, the ammonia and nitrite oxidizers, in two steps via nitrite to nitrate. In permafrost soils of the polygonal Siberian tundra these bacteria have to resist extreme gradients of temperature, moisture und high concentrations of inhibitory methane. In geochemical characterized soil samples of the active layers cell numbers of nitrifiers and potential activities of ammonia oxidizing bacteria were determined. Results obtained by MPN-counts showed that clearly higher cell numbers of ammonia oxidizers (4×10^3 cells g dw⁻¹) and activities (200 ng N-nitrite g dw⁻¹ h⁻¹) were found in the upper part of the dryer polygon rims compared to the waterlogged polygon centres. Cell numbers and activities of ammonia oxidizers in the upper parts of the polygon rims correlated with extreme high enrichment of nitrate (27 µg N-nitrate g dw⁻¹) which was connected with low concentrations of methane. Summarizing, the results showed obvious differences of nitrification and nitrate enrichment in the polygonal Siberian tundra mostly depending on the water content of the soil layers and a possible adaptation of these organisms to the extreme environment of the arctic permafrost soils.

Methanogenic archea from permafrost

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key words: methanogenic archea, phylogenetic analysis, enrichment culture

Until recently permafrost have been considered only as a depository of viable, but metabolically nonactive microorganisms. Preliminary investigation with ¹⁴C-labeled acetate and bicarbonate had demonstrated

methane generation in Kolyma lowland permafrost at temperature from +20 to -100°C. Isolation of microorganisms capable to realize this process is the aim of this study.

Two enrichment methanogenic cultures have been obtained. Strain of methanosarcina JL01 was isolated on acetate as a substrate. Investigation of physiological and biochemical properties and phylogenetic analysis revealed belonging of isolate to *Methanosarcina mazei* species.

Thin rods dominated in other enrichment culture named M2. Among tested methanogenic substrates growth was observed only on H₂/CO₂. The attempts to isolate pure culture were unsuccessful. Therefore we have analyzed this enrichment culture by molecular method. The total DNA was isolated, the gene of 16S RNA was amplified, cloned and clone library was analyzed by RFLP. All clones had similar RFLP patterns and had been sorted into two groups. Comparison of short sequences of two representatives from each group showed about 99% similarity. Phylogenetic analysis revealed that 16S RNA gene sequence one of the clones to be closely related to *Methanobacterium bryantii* (98% sequence similarity) and *Methanobacterium ivanovii* (97% sequence similarity).

Strains JL01 and M2 had a wide temperature growth range and temperature optimum higher than 200°C. Probably an important role in their ability to grow at low temperature play adaptive changes those are of phenotypic origin.

Characteristics of Actinomycetes of rare genera in Mongolian soils

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key words: rare Actinomycetes, Mongolia, cell sugar pattern analysis, strains

Ecosystems of Mongolia have natural structure and structure form contrast combinations and besides here anthropogenous factors of infringement of a surrounding environment it is imposed on natural extreme ecological conditions. Soils of Mongolia along with similarity with soils other territories of the Euroasian continent similar to zone attributes, possess the original properties caused by an originality of an environment of the country. Till last decade was considered, that the most widespread in soil of the actinomycetes are genera *Streptomyces*. Use of selective methods of isolation allows to reveal in soil and others genera traditionally considered rare genera.

Population and taxonomy of actinomycetes in Mongolian soils were studied. A total of 111 strains rare actinomycetes strains were isolated from soil samples collected from Mongolian soils. The 111 strains rare actinomycetes containing meso and diaminopimelic acid in the cell wall. By conducting the whole cell sugar pattern analysis it is confirmed that they belong to genera *Streptomyces*, *Micromonospora*, *Actinomadura*, *Streptosporangium*, *Saccharopolyspora*, *Saccharomonospora* and *Dactylosporangium*. Number of actinomycetes in dominant soil ecosystems of Mongolia changes from hundreds thousand up to tens thousand CFU g⁻¹ depending on type of soils and the character of ecosystems.

It has been revealed that, in mountain soils, the population of actinomycetes is small (thousands of CFU g⁻¹ of soil in forest soils and tens of thousands of CFU g⁻¹ in steppe mountain soils), and they belong to three genera *Streptomyces*, *Micromonospora* and *Streptosporangium*. In steppe chestnut and steppe-desert pale brown soils of Southern Gobi, the population of actinomycetes increases slightly (tens of thousands of CFU g⁻¹), and the taxonomic diversity rises. Along with *Streptomyces*, *Micromonospora* and *Streptosporangium* actinomycetes from rare genera *Saccharomonospora*, *Saccharopolyspora*, *Actinomadura* and *Dactylosporangium* were found here. The actinomycetes of the following six genera were isolated from the samples

of Alluvial meadow soils: *Streptomyces*, *Micromonospora*, *Saccharopolyspora*, *Saccharomonospora*, *Actinonmadura* and *Streptosporangium*. The collection actinomycetes in isolated soils of Mongolia can be used for research of producers of new antibiotics or bioactive compounds and others pharmaceutical valuable substances.

Soil organic matter storage and microbial activities in cryoturbated tundra soils

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key words: cryoturbation, soil organic matter decomposition, C and N mineralization, involutions, $\delta^{13}\text{C}$

At the Gydansky peninsula, Western Siberia (69° 43.0' N, 74° 38.8' E), 12 soil profiles were examined within an area of approximately 50 × 50 m. In all soil profiles involutions of organic soil material were encountered, located from 20 cm depth down to the permafrost (at approximately 60 cm depth) and beyond. These cryoturbated layers formed irregular horizons of a dark colour within the lighter coloured B-horizon. Based on our data we estimated 4.7 kg C m⁻² was stored in the cryoturbatic involutions at the study site.

Estimation of the radiocarbon age (¹⁴C, pMC) revealed that the involutions were younger than the surrounding B horizon (age of involuted horizons: ≈ 1350 years; regular B horizons: 4300 to 7300 years), but older than the shallow A horizons (age ≈ 550 years). The soil organic matter content of the buried horizon was similar to that of the A horizon but far higher than the surrounding B horizon, indicating that the involuted horizon and the A horizon may be roughly at the same state of decay. However, microbial activities (e.g., C and N mineralization) and microbial biomass were much lower in the cryoturbated layers than in the A horizons, and similar to that of the B horizons. This suggests that the decomposition processes in such involutions are retarded compared to a normal soil development: assuming a similar base material (i.e., litter and slightly to moderately decomposed material of the O horizon) the buried cryoturbated layer took approximately 3-times longer than the current A horizon to reach the same stage of development. The alternative explanation, that the buried horizon originates from an A horizon and further development stopped after the cryoturbation occurred, seems unlikely in the light that arctic microbes are well adapted to low temperatures and wet conditions, that are characteristic of deeper soil horizons.

A detailed analysis of carbon isotope composition of the buried horizons showed a high enrichment in ¹³C compared to the much older B horizons, which is surprising considering that it has been repeatedly demonstrated that ¹³C in SOM enriches progressively with age, and that slower decomposition rates lead to a smaller enrichment than faster carbon turnover. Several reasons may be responsible for these unexpected results: a delayed increase in physical protection of SOM in buried horizons (due to slower decomposition rates), changes in microbial community composition (due to changing abiotic conditions after burying) or a different carbon isotope signature of vegetation or litter at the time of burying.

In summary our data demonstrate that burying of organic layers into deeper soil horizons causes a significant delay in decomposition, emphasizing that cryoturbation constitutes a major mechanism for long-time carbon storage in high latitude soils.

Simulation of Siberian permafrost carbon stock and its response to the global warming

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key words: permafrost, carbon cycle, global warming, modelling

The Siberian permafrost carbon stock has been studied using a newly developed soil model. The model describes the following processes: (1) heat conduction taking into account soil moisture freezing and thawing; (2) consumption of the soil carbon by means of oxic biomass decomposition and methanogenesis, both accompanied by heat generation; (3) hydrology of the upper meter of the soil; (4) diffusion of oxygen and methane; (5) methanotrophy; (6) vertical transfer of gases due to the pressure difference.

The results show a possibility of a positive feedback between the global warming and the soil response. Atmospheric warming can lead to melting of some of the permafrost. Microbial activity then starts in the thawed regions of the soil decomposing the biomass therein producing CO₂ or methane at the same time releasing additional heat. The latter helps to further melt the permafrost and liberate more carbon-rich soil for decomposition. The decomposed soil carbon is emitted to the atmosphere in the form of CO₂ or CH₄, the latter constituting up to one fifth of the soil carbon consumed. Among the factors essential for existence of this feedback are availability of oxygen (for the oxic biomass decomposition), methanogenesis and methanotrophy, as well as local climate conditions.

Spatial differentiations of methane and carbon dioxide distribution in permafrost upper layers

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key words: methane, carbon dioxide, permafrost, Yana-Indigirka lowlands

Methane and carbon dioxide are distributed in the upper layers of permafrost very irregularly. Recent studies held on Yana-Indigirka lowlands in summer 2004 detected methane in lake-alluvial and swamp peaty deposits while it is absent in icy complex sediments.

Frozen ground samples were degassed using "headspace" technique in two components media of saturated sodium chloride solution and nitrogen. We Gas concentration measured gas concentration with a gas chromatograph equipped with flame ionizing detector for methane or thermic conductivity detector for carbon dioxide.

Middle Pleistocenic sands of massive cryostructure characterize with layer-like methane distribution and concentration maximums of 3.0 ml kg⁻¹ on 3 m depth, 2.9 at 5 m, and 2.1 at 8 m. Carbon dioxide concentrations not extend 0.4 ml kg⁻¹ in the upper part of the core, its distribution is quite proportional. Silty sediments of keremesit sequence demonstrated comparatively high methane (3...5 ml kg⁻¹) and carbon dioxide (1.3...1.5 ml kg⁻¹) content. Methane absence in Icy complex deposits in this area confirms the rarely observation conclusions. Carbon dioxide concentration is more than 2 ml kg⁻¹ due to high enrichment with organic matter. Carbon dioxide and methane is likely to be an indicator of organic matter consistence and microbiological activity.

Methanogenic bacteria isolated from Arctic permafrost sediments of different age

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key words: methanogenic archaea, Siberian permafrost, methanogenic activity

Methanogenic microorganism belongs to the kingdom of Euryarcheota in the domain of Archaea. Methanogens are heterogeneous group strictly anaerobic nonsporogenic bacteria, with characteristic combination methanogenic and power processes. In previously published articles described methanogenic bacteria in microbial community in permafrost and the data confirming an opportunity of metabolic processes in frozen sediments and ice.

The aim of our researches was studying methanogenic community in the different age permafrost sediments. We have tried to find out, how the long presence in cryolithosphere influences on the metabolic activity and viability of microorganisms. Researches were carried out on the Kolyma lowland (155 to 160° E and 67 to 70° N). Samples were selected with all from two horizons of different age (2920 years and 1 to 1.5 million years) and genesis (peaty loam and sandy loam). Investigation is carried out with use of radioactive marked substrates ($\text{H}^{14}\text{CO}_3^-$ and $^{14}\text{CO}_3\text{COO}^-$). From the result of experiment we can conclude, that methanogens keep viability in a frozen ground and show metabolic activity at negative temperatures. Long-term presence in cryolithosphere result in psychrophilization of microbial community. From a sample of 2920 years old after long incubation have been isolated methanogenic bacteria. Strain JL01 is made multiple copies by non-uniform division. On morphophysiological parameters strain JL01 it is related to *Methanosarcina sp.*, and by results of the phylogenetic analysis to cluster *Methanomicrobiales*. The binary culture M2 consisting of cells of 2 types. First type - slightly bent rods in the size 0.35 to 0.40 μm in diameter and 3.0 to 6.0 μm at the length, consecrated in ultraviolet. Studying of physiology and taxonomy of this culture is complicated in connection with low growth rate (0.0037 h^{-1} on H_2/CO_2). We observed methane formation from a sample 1 to 1.5 million years old with addition special growth medium after 1 year incubation. We detected temperature optimum for methanogenesis from 20 to 28°C. In multicomponent culture there are rods of the different size, motile and not motile, consecrated in an ultraviolet. At the subsequent microscopy it was not possible to reveal precisely prevalence of the certain morphotype of methanogens.

Characterization of nitrite-oxidizing bacteria enriched from permafrost soils in response to different growth temperatures

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key words: nitrite-oxidizing bacteria, enrichments, temperature optima, identification, Nitrobacter

Nitrification is one of the key processes in nitrogen cycle. It provides the linkage between ammonia and nitrate - the highest oxidation state of the element nitrogen. It's mediated by lithoautotrophic nitrifying bacteria (NB) and consists of the oxidation of ammonia to nitrite by ammonia-oxidizing bacteria (AOB) followed by the oxidation of nitrite to nitrate by nitrite-oxidizing bacteria (NOB).

The global climate change (the overall temperature increase) has been shown to enhance permafrost thawing. Therefore viable microorganisms from permafrost become involved in active biological processes.

Nitrification is regarded to be one of the important processes in the functioning soil ecosystems. Therefore the investigation of the peculiarities of the permafrost NB community is of high interest. The aim of this work was to identify the responsible NOB enriched from tundra and permafrost soil and measure growth rates in response to the different incubation temperatures.

Samples from tundra soil and permafrost deposits of river Lena delta (Samoylov and Kurungnakh islands, Russia) from depths of 5 to 5520 cm below surface were investigated. The age of permafrost ranged between 3000 to about 17000 years. Viable NB have been detected in all tundra soil samples and approximately in 50% of permafrost samples. Surprisingly there were less AOB found than NOB though these groups of bacteria are linked trophically. The low amount of AOB positive samples may be the result of unsuitable conditions e.g. there is poor knowledge of physiological peculiarities of AOB from low temperature habitats. In addition nitrification showed a great adaptation potential in response to incubation temperature in the range of 4 to 27°C. This might be caused by heterogenous nitrifying population.

To determine whether the community of NOB has been adapted to psychrophilic or psychrotrophic growth we examined growth rates over a range of different incubation temperatures. Enrichments from tundra soil and deep permafrost deposits were mostly found to be mesophilic with optimum growth temperature over 20°C, while samples from the upper permafrost revealed the presence of psychrotolerant nitrifiers with optimum growth temperature at 17°C.

The enrichment cultures of NOB were characterized by molecular techniques e.g. the use of specific PCR primers based on 16S rRNA gene sequences and denaturing gradient gel electrophoresis (DGGE). These data showed clearly that under the applied conditions the dominant NOB were members of the genus *Nitrobacter*.

Adaptation and composition of methanotrophic communities

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key words: methanotrophs, permafrost, biodiversity, carbon cycle

Wet tundra environments of the Siberian Arctic are considerable natural sources of methane, a climate relevant trace gas. Current climate models predict a significant change in temperature and precipitation in the northern hemisphere. The potential impact on the Arctic carbon reservoirs is highly influenced by changes in microbial processes like methanogenesis and methane oxidation. Methanogenesis describes the terminal step in the anaerobic degradation of organic matter and is done by methanogenic Archaea. The emission rates of the biologically produced methane from arctic Permafrost soils are highly divergent. Seasonal methane emission from a low-centred-polygon, which are characteristic for the microrelief of the Lena Delta, ranged between 53.2 and 8.7 mg d⁻¹ m⁻² from the polygon depression and 4.7 to 2.5 mg d⁻¹ m⁻² from the polygon rim. The amount of methane released is mainly controlled by obligately aerobic or microaerophilic α - and γ -Proteobacteria, the methane oxidizing bacteria (MOB). First research on activity of the methanotrophic community in floodplain soils of Samoylov Island (Lena Delta, Siberia) at different temperatures indicate a change in the temperature optimum with depth. While MOB in the upper soil layers of the Typic Aquorthel appeared to have their highest activity at temperatures >21°C the maximum methane oxidation rates in deeper and colder horizons were determined at 4°C. The activity of MOB also seems to depend on the methane concentration where at the substrate affinity of the methane oxidizing community appeared to decrease with depth. Fluorescence in situ hybridization of MOB also indicates a shift in the community structure with depth from the appearance of Type I MOB (γ -Proteobacteria) only to coexisting Type I and Type II (α -Proteobacteria) MOB. Further research on the adaptation to temperature changes in combination with biomarker analysis, cell counts and community changes using CARD-FISH will be done. For detailed diversity analysis a clone library of the methane oxidizing community in low-centred-polygons from the Lena Delta will be constructed.

The response of permafrost microbial community to gamma radiation stress

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key words: microbial communities, gamma radiation, low temperatures, permafrost

Recent papers propose that frozen cells could be more resistant to gamma radiation stress. According to modern theories of cell cryoconservation, microbes in permafrost endure drying from 50% of intracellular water, and, after that, pass through the stage of intercellular ice formation, which cease further dehydration of cytoplasm. It is known that dried cells are much more resistant to gamma radiation. The stabilising role of low temperatures is also very important because of decrease of all reaction's rates according to the Arrhenius law. Thus, permafrost matrix provides a set of unique and necessary conditions for cryoconservation of viable bacteria cells, and increase resistance of cellular structures to stress factors. It was shown earlier, for non frozen samples, that the amount of viable cells decrease exponentially for the radiation doses of 1, 10, 20, 50, 100, 200 Rad. The dose effect for non-frozen samples, pre-melted and stored at 20°C before the irradiation, was 6 times higher than for ones which were melted right before the irradiation. The aim of this work is to show the dependence of permafrost bacteria cell's resistance upon the gamma radiation dose in the native core samples treated frozen. The samples were treated with gamma radiation below zero under sterile conditions in specially designed container device. The result this work is bacteria inactivation and reactivation curves for permafrost samples of different age and origin. The samples were treated with different doses of gamma radiation in the frozen state, that is important for understanding the real opportunities for cells surviving in the permafrost.

Modern forming process of steppe phytocoenoses and soils in permafrost regions of extreme North-East of Asia

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key words: tundra, disturbed habitats, steppe plants, steppe soils

The phytocenosis with participation of steppe plants were repeatedly described in permafrost areas of north-eastern Asia. Soils of these phytocenosis are less studied. It is believed that steppe plants in these regions are relicts of the highly productive tundra-steppe phytocenosis occupying the large areas in Pleistocene. We revealed the existence of modern colonization of disturbed (naturally or anthropogenic) habitats by steppe plants in a zone of tundra and forest-tundra of northeastern Yakutia.

Steppe plants spread to the North along disturbed habitats. This process is contemporary. Disturbed habitats (waterside slopes, baidzherakhs, quarries, ground roads, village streets, roadside, embankment, etc.) are good for studying recent natural processes - successions and fluctuations of vegetation, soil forming processes, etc. The study of the disturbed habitats in the Kolyma Lowland (tundra and forest-tundra) showed that the processes of their self reclamation is of a common schematic character under conditions of dry and cold climate with not infrequent hot days in the summer period.

First, these disturbed habitats are vegetated with plants of the neighboring habitats and erosiophyllous plants - *Tripleurospermum hookeri* Sch. Bip., *Descurainia sophioides* (Fisch. ex Hook.) O.E. Schulz, *Lactuca sibirica* (L.) Maxim., etc. These species are generally regarded as weeds or ruderals, but serve as pioneers in this case. Then steppe plants appear on dry bulges of the disturbed habitats: *Artemisia dracuncululus* L.,

Festuca lenensis Drob., *Poa botryoides* (Trin. ex Griseb.) Kom., *P. attenuate* Trin., *Eremogone tschuk-tschorum* (Regel) Ikonn., *Dracocephalum palmatum* Steph. ex Willd., *Thymus diversifolius* Klok., etc. The projective cover is small. Soil similar to steppe ones are also formed: humus is accumulated but not peat, soil reaction is about neutral, and the amount of exchangeable calcium and magnesium increases. The humus content accounts for 1 to 1.5% in upper horizons of minor soils and about 3 to 8% in fine earth from grass tussock. All investigated soils have neutral or close to neutral reaction. The research was supported by the Russian Foundation for Basic Research, grants no. 04-05-64748.

Soil thermal regimes and effects of changing land use in the European Russian Arctic

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key words: permafrost, soil thermal regime, land use, Russia

One-to-nine-year-long temperature records were obtained for seven fine-textured, two coarse-textured and two organic soils in 1996 to 2004 in the East-European Russian Arctic (the Seida River basin, the Vorkuta area and the Polar Urals). Data-loggers registered temperatures in the active/seasonally-frozen layer and the upper layer of permafrost with temporal resolution of one to four hours and vertical increments from 10 to 50 cm. The area is tundra where permafrost is present under 50% of lowlands and is almost continuous in the Ural Mountains. Permafrost temperatures are between 0 and -2°C in the lowlands and reach -5°C in the Urals. Permafrost thickness varies widely with its maximum values around 400 m.

Five of the studied soils have permafrost within two meters of the soil surface and are Gelisols according to the US Soil Taxonomy; the others are mostly Inseptisols with Cryic (if loamy) and Isofrigid-Cryic (if coarse-textured) thermal regimes. Differences in winter and annual thermal indices between Gelisols and non-Gelisolic soils are an order of magnitude larger than those in summer indices. The summer indices are especially uniform over the area in the upper root-bearing soil horizons, in agreement with the relative uniformity of the ground vegetation covers. For example, summer N-factors are equally high (0.8 to 0.9) in all soils, whereas winter N-factors vary from 0.1 in Gelisols with shallow snow in winter to 0.4 to 0.6 in non-Gelisolic soils with the snow thickness exceeding 50 cm. Snow thickness and Freezing Degree Days (FDD) in the air explain 80% of variability in the FDD on the soil surface with equal contribution of the two variables, whereas snow density (observed range 0.19 to 0.37 g cm³) has no explanatory power at $\alpha = 0.05$. Mean annual soil temperatures (MAST) are below zero at all measured depths in Gelisols and above zero in non-Gelisolic soils. However, a mineral Gelisol with permafrost within the second meter of the soil surface showed a 0.5°C 'thermal offset' in its active layer with a subzero positive MAST on the soil surface.

A grassland sown with perennials 45 years ago has permafrost within the second meter of soil surface. A 30-year-long chronosequence of soils of deserted grasslands was studied to reveal changes in soil temperature regime following desertion. The change of land use 'easily' (within a decade) changes soil temperature regime and permafrost table position, first of all due to rapid colonization of a site by shrubs which facilitate snow accumulation. Changes in soil horizonation demonstrate a several decade lag as compared to changes in vegetation, soil thermal regime and permafrost table position. This study was partially supported by NSF (OPP-9732051), INTAS (Open 97-10984) and NWO (047.011.2001.003).

A proposed minimum field dataset for collection of soil data in the Antarctic

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key words: Antarctic soils, minimum dataset, correlation, Antarctic soil map

Recently, the Cryosols Working Group of the IUSS, the SCAR Expert Group on Permafrost and Periglacial Environments and the IPA working group on Permafrost and Periglacial Environments identified the need for a soil map of the Antarctic similar to that of the Arctic. A meeting was held in Madison Wisconsin that established ANTPAS (Antarctic Permafrost and soil working group) to develop the proposed maps and associated databases. To produce such a map within a limited timeframe, existing soil data will be used predominantly. However, if new field soil data is to be collected, for this or other purposes, a minimum data set would be useful. A minimum data set would also give confidence to non-soil specialists that field data collected was adequate. We propose a minimum field soil data set that will assist in production of a soil map of the Antarctic, with soils classified using the USDA Soil Taxonomic classification and the FAO world soils database. The proposed minimum data set is:

- Collector
- Affiliation
- Date
- GPS location, elevation
- Parent material
- Landform
- Depth to top of each soil layer by number
 - Soil colour for each soil layer
 - Soil texture for each soil layer with estimate of organic matter, gravel, cobble and stone percentage.
- Weathering stage (Campbell and Claridge, 1975)
- Salt stage (Bockheim, 1990)
- Maximum depth visible salts
- Maximum depth of coherence
- Maximum depth of oxidation
- Maximum depth rock ghosts
- Depth to ice-cemented permafrost
- Depth to ice-cored moraine
- Cryoturbation/patterned ground description
- Surface vegetation
- USDA Soil Taxonomy classification to family level

The non-specialist collector will require a copy USDA Soil Taxonomy in the field because many of the classification criteria are not in the minimum dataset list given above. Although significantly more field soil data could be collected the list above will allow the data to contribute to a small-scale soil map of the Antarctic and allow correlation of similar soils. Collectors should also note any other features of interest for each soil and site.

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About soil classification of the European North-East

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key words: geography, genesis, permafrost, classification, diagnostics

Automorphic soils in silty loam on drained relief elements of the European North-Eastern tundra are traditionally represented by the complexes of tundra gley soils and tundra surface gley differentiated soils. The first are recognized by a morphologically pronounced gleyzation in all mineral horizons, while the second are marked through a strong surface gleyzation. The soils are shown in the State Soil Map 1:1000000. Our research has confirmed the presence of gley and surface gley profiles and revealed the soil profiles, the mineral horizons of which have no signs of morphologically pronounced gleyzation. The soil profiles presented below are identified in the “Soil Classification of Russia” (SCR) (2004).

1. O-G-CG profile. There is a bright bluish-grey thixotropic gley mass under a peaty litter, often with cryoturbation features. In accordance to the SCR, the profile corresponds to the Type of Gleyzems in the Order of Gley Soils. The soils occur on gently slopes and flat hilltops under small shrub/moss vegetation in spotted and hilly tundra, normally in the nearest presence of permafrost. In accordance to the WRB, the profiles correspond to Gelic Gleysols or Gleyi-Turbic Cryosols (in the case of permafrost presence within 1 m).
2. O-CRM-C profile. The profile has a peaty litter and a light-brown (varying from pale-yellow-brown to bluish-grey-brown) cryometamorphic horizon with a grumous structure, turning fine crumbly and nutty when dried out. No morphologically pronounced gleyzation, possible weak signs of it are observed exclusively in the upper and lower parts of the profile. In accordance to the SCR, the soils correspond to the type of Organo-Cryometamorphic soils in the Order of Cryometamorphic soils. They develop under most dry conditions on hilltops and slopes under lichen-moss-shrub tundra vegetation. The soils correspond to WRB Gelistagni-Gelic Cambisols or Turbic Cryosols (permafrost presence within 1 m).
3. O-G-CRM-CG profile. The profile is characterized by a combination of a peaty litter, surface gley and middle metamorphic structured horizons. Gleyzation is limited to upper 20 to 25 cm and is marked by a bright bluish color, often with upper and/or lower reddish margins. The structure of the gley horizon turns platy when dried out. The profile features allow for ascribing the profile to the Type of Cryometamorphic Gleyzems in the order of Gley Soils (SCR). The soils occur under lichen-moss-small shrub tundra vegetation and more drained conditions than Gleyzems. In accordance to the WRB, they correspond to Gelistagni-Gelic Cambisols (Gleyic) or Epigleyi-Turbic Cryosols (permafrost presence within 1 m).

There might be a weak texture differentiation in all three profiles owing to lithological deposits differences at a depth of 60 to 80 cm, as we propose. All three types of profiles are characterized by the presence of cryoturbation, humus illuviation etc. Permafrost is not always observed within 1 m in the period of maximum thaw.

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Bacteria from supercooled water brine within permafrost and their adaptation to environment

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key words: bacteria from cryopeg, adaptation to subzero temperature

Supercooled water brines within permafrost (cryopegs) are the aquatic systems with permanently subzero temperature (-100°C), high salinity (170 to 300 g L⁻¹) and isolated from external influence over the geological time. We carried out microbiological analysis of cryopeg water and it was shown, that this unique ecological niche is the habitat for microorganisms. Experiments on ¹⁴C-glucose incorporation have demonstrated, that psychrophilic halotolerant microbial community of cryopegs is metabolically active at subzero temperature. The aim of this study was to isolate microorganisms from cryopeg water, to investigate their biochemical features and the modes of adaptation to subzero temperature and high salinity.

As the result of this investigation two new species of bacteria were isolated and described: psychrophilic spore forming anaerobe *Clostridium algidum* sp.nov. and psychrotrophic aerobe *Psychrobacter murincola* sp.nov. Aerobic gram negative bacterium strain 3ps poses such pheno- and genotypical features, which allow considering it as the representative of new genus within Enterobacteriaceae family.

Study of adaptation mechanisms of microorganisms to cryopeg conditions is of peculiar interest. We showed that bacteria isolated are able to grow at subzero temperature and in wide salinity range, extend substrate spectrum with the temperature decreasing. Analysis of lipid content of cell wall revealed, that their membrane is adapted to function at low temperature and high salinity. We have begun search of compounds that accumulate in response to high osmolarity and subzero temperature in the bacteria isolated.

The arctic cryopegs meet the requirements made for exobiology models. Therefore, microorganisms isolated may be considered as potential inhabitants of extraterrestrial ecosystems and their features as survivor strategies on the cryogenic planets.

Nonsorted circles and soil formation in Arctic Canada

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key words: cryosol, cryoturbation, nonsorted circle, cryogenesis, arctic Canada

Soils and vegetation communities associated with nonsorted circles formation were investigated on Banks Island, Northwest Territories, Canada. The study sites were selected to represent a toposequence; consisting of the ridge top, shoulder slope, back slope, and the adjacent alluvial fan. The vegetation community is described as Subzone B characterized by Graminoid, prostrate dwarf-shrub, forb tundra. The circles are generally bare and the vegetation cover in inter-circles is thin and discontinuous. There is a lack of an organic horizon but a discontinuous A horizon forms beneath the vegetation cover. Carbonates undercoating on surface gravel reflects the semiarid environment. The parent material is mainly glacial-fluvial deposit with a coarse sandy loam to sandy texture. Pebbles and gravel are common in soil profiles and cobbles are common in the substratum on back slopes. There is a mantle of Holocene sand deposited on the surface. The substratum consists of weathered shale with a silty clay texture. Both the sandy A and B horizons are strongly cryoturbated with frost cracks filled with recent eolian sand (C). Generally, the A horizon forms

under the tundra areas between the circles and frost-churned downward. In addition, the underlying clayey material was "squeezed" upward. This evidence suggest that during freezing, the clayey substratum that has reached the liquid limit due to thawing of upper permafrost in some years, was squeezed into the frost cracks in the sandy matrix caused by back freeze from the permafrost. This paper describes the polygenic nature of both the nonsorted circles and the soils associated with them.

Methane and methane generation in Cenozoic permafrost sediments of High Arctic

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key words: methane, carbon dioxide, methanogens, metabolic activity

Rich in organic components, tundra and forest-tundra are characterized by humid conditions in which production of methane and carbon dioxide and is possible everywhere during the summer. As the sediments freeze, CH₄ and CO₂ were withdrawn from the biogeochemical cycle and were conserved in the permafrost in the passive form. Consequently, considerable amounts of CH₄ and CO₂ are found in the permafrost below the soil profile. To evaluate possible release of greenhouse gases into the atmosphere, it is necessary to estimate concentration of methane in major stratigraphic and genetic types of the permafrost. In the beginning of the 90th, we found the presence of methane in the sedimentary cover of the cryolithosphere and established patterns of its distribution throughout Kolyma Lowland. Contents of ancient CH₄ in the permafrost of Kolyma Lowland mounts to 40 ml kg⁻¹. In the lower courses of Indigirka River we have studied the sediments of Holocene and Pleistocene age. Contents of methane in the icy alas sandy loams on the right bank of the Khroma Bay (East Siberian Sea coast) decreases downward from 20 down to 12 ml kg⁻¹. Underlying sediments of late Pleistocene Icy Complex of this area and areas of rivers Allaikha and Keremesit are characterized by the absence of methane, which in concordance with the data obtained earlier for other regions of the eastern sector of Arctic. Middle Pleistocene sediments in this area presented by detritus rich sands and loams contain 2 to 6 ml CH₄ kg⁻¹. Holocene coastal and alas sediments on the Laptev Sea coast (Ivashkina Lagoon, cape Bykovsky) contain methane in the amounts of 10 to 20 ml kg⁻¹. Carbon dioxide is found in syncryogenic and epicryogenic sediments. The concentration of CO₂ in the late Pleistocene Icy Complex is quite stable 2.9 ml kg⁻¹. In alas sediments, contents of CO₂ vary in the wide range from 0.8 to 12.8 ml kg⁻¹. In gas-condensate field of Varandei peninsula, Kara Sea coast, methane content was measured in the permafrost with mean annual temperature of -2°C which is considerably different from the sediments of similar genesis studied earlier. The latter ones are characterized by considerably lower mean annual temperature -10 to -12°C. Methane contents in the sediments of Holocene age in this area vary from the minor quantities in aerated lacustrine sediments up to 22 ml kg⁻¹ in lacustrine-bog and coastal sediments. Layering in CH₄ distribution in late Cenozoic section is caused by the alternation of epygneic and syncryogenic sediments in Eastern Arctic (Kolyma and Yano-Indigirskaya Lowlands, Laptev Sea coast). Maximal concentrations of methane are found in the lacustrine and bog phases of Holocene (15 to 20 ml kg⁻¹), minor quantities - in the late Pleistocene Ice Complexes (0 to 0.3 ml kg⁻¹). It was shown that Fe²⁺ contents in the late Pleistocene Icy Complex amounts to 70 to 100 mg per 100 g soil, in the sediments of lacustrine-bog and alluvial genesis 171 to 470 mg per 100 g soil. Thus, direct relation between methane contents and contents of bivalent iron is observed. For permafrost sediments of age from thousand to several million years it was shown that methane forming bacteria not only retain viability within the permafrost but also are capable of carrying on metabolic reactions at subzero temperatures. The duration of microorganisms stay in permafrost sediments helps their adaptation and essentially lead to the psychrophilization of microbial community from late Pliocene sediments compared to those from relatively young Holocene sediments.

Dissolved methane in the East-Siberian and Laptev Sea

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key words: Laptev Sea, methane, offshore permafrost, East Siberian shelf

Over the Holocene (last 10⁴ years) the largest temperature change occurred in the Arctic Siberian shelf sea; consequently, the Arctic region of shallow offshore permafrost may be critical to the problem of gas hydrate release; these hydrates constitute the largest potential source of CH₄ emission to the atmosphere. Doubling of the atmospheric CH₄ from present conditions requires release of less than 0.1% of the sub sea permafrost hydrate reservoir. The extensive Russian Arctic shelves play an especially important role because of their large area and usually shallow sea depth. There is not much data to support the statement that hydrate instability is increasing at present, but it is clear that hydrates definitely will become unstable if warming continues. We can suggest that the submarine permafrost under the tectonic fault might have decayed, in part or completely, allowing the release of CH₄ from the gas hydrates. In some coastal areas the temperature of near bottom seawater and surface sediment has already become positive, which causes additional heating effect, resulted from present global warming. Here we present new¹ CH₄ data obtained over the shallowest and broadest Arctic East Siberian shelf which may indicate that processes of permafrost warming and release of CH₄ from destabilized CH₄ hydrates may already be in progress. A positive mean annual sea floor temperature may be an additional indirect piece of evidence suggesting the existence of an open talik under the spot where especially high values of dissolved CH₄ were observed.

¹The data were obtained in framework of the First and Second Russia-US cruises organized and supported by Headquarters of FEBRAS ("Environmental Changes in the East-Siberian region under climate effects and catastrophic processes"), IARC, Russian Foundation for Basic research and National Science Foundation.

Activity and characterization of nitrifying bacteria derived from permafrost soils

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key words: nitrification, activities, sequence analysis, fatty acids, Nitrospira

Lithoautotrophic nitrifying bacteria have a global impact on the functioning of the nitrogen cycle in marine and terrestrial ecosystems. Two physiological groups of organisms, ammonia and nitrite oxidizers, are responsible for the oxidation of ammonia to nitrite and further to nitrate. Release of nitrogen oxides as by-products makes them relevant to global climate changes. Nitrifiers are well adapted to extreme conditions like low temperature, but only limited information is available about the distribution of such organisms in frozen deposits.

Investigation sites are located in North-East-Siberia. Experiments were performed with polygonal tundra soils and a core in the Lena Delta and fossil soils of the cape Mamontovy Klyk with most ancient permafrost from the Late Pleistocene. Additionally, nitrifying bacteria in sediments of the Laptev Sea and the Lena river were examined. With regard to repeated freezing/thawing cycles in tundra environments, investigations were performed under optimal laboratory conditions with samples stored at +4°C respectively -20°C.

Active ammonia and nitrite oxidizing bacteria could be detected in most of the samples up to depths of 5 m. Using the MPN-technique (most probable number), low cell numbers were found in frozen, but high cell numbers in unfrozen material (4°C) and recent permafrost contained more nitrifiers than ancient deposits. Activities decreased during freezing and affected ammonia oxidizers more than nitrite oxidizers. Potential nitrifying activity was further inhibited with increasing substrate concentrations. Accumulation of nitrate was regulated by denitrifying organisms in samples with high microbial activity.

Environmental samples as well as selective enrichment cultures were used for molecular characterization including DNA extraction and PCR amplification. Genes of the 16S rRNA were separated by DGGE/TGGE electrophoresis and phylogenetic affiliation of dominant ammonia and nitrite oxidizing bacteria was clarified by partial 16S rRNA sequence analysis. Hereby we could monitor the enrichment process and reveal that nitrite oxidizing bacteria obtained from permafrost and tundra soils were members of the genus *Nitrospira*.

Fatty acid profiles of nitrite oxidizing bacteria grown at 4, 10 and 17°C were determined in order to monitor adaptation to decreasing temperatures and to identify responsible organisms (Lipski et al., 2001). In polygonal tundra, a community shift from the dry rim to the wet center as well as a specific biomarker for representatives of *Nitrospira* could be detected. This genus seems to be one of the dominant nitrite oxidizers in permafrost habitats in Siberia.

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Phylogenetic diversity of Tundra cryosol microbial community in Arctic ecosystems

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key words: cryosol, microbial community, phylogenetic diversity, 16S rDNA

Arctic tundra soil contains a rich source of psychrotrophic, heterotrophic bacterial biodiversity. Since a middle of the last century many researches have reported viable microbes belonging to *Arthrobacter*, *Micrococcus*, *Brevibacterium*, *Streptomyces*, *Cellulomonas*, *Flavobacterium*, *Pseudomonas*, *Aeromonas*, *Myxococcus*, *Bacillus*, *Rhodococcus*, *Corynebacterium*, *Pseudomonas*, *Flavobacterium* and *Mycobacterium* in Arctic soil. These genera are a restricted number of cosmopolitan taxa. Besides those, phylogenetic analysis of cloned 16S rDNA gene sequences from Arctic cryosol allowed us to detect yet uncultured strains related to *Chloroflexus*, *Nitrospina*, *Prostheco bacter*, *Flexibacter*, *Hyphomicrobium*, *Azospirillum*, *Blastochloris*, *Methylosinus*, *Bradyrhizobium*, *Sphingomonas*, *Caulobacter*, *Rhodocyclus*, *Comamonas*, *Rhodoferax*, *Lepthotrix*, *Oxalobacter*, *Xantomonas*, *Methilomonas*, *Desulfuromonas*, *Rhubrobacter*, *Brevibacillus*, and several groups of environmental clones.

To investigate highly diverse and uncharacterized microbial populations of Arctic cryosol, molecular genetic tools were employed. Genomic DNA was isolated from the active layer of tundra soil collected from the Kolyma lowland, Northeast Eurasia. The SSU rRNA genes were amplified with universal eubacterial primers from the bulk genomic community DNA and cloned into plasmid vectors. About 250 SSU rDNA clones were obtained. Phylogenetic analysis based on partial sequences (from 400 to 800 bp) and using the neighbor-joining method revealed the prevailing of two major groups to be *Proteobacteria* (46%) and *Gram*

Positive Bacteria (24.8%). Most of the clones of the former belonged to the Beta (26.9%) subdivision of the Proteobacteria, with lesser proportions in the Alpha (6.2%), Gamma (6.2%), Delta (4.9%) and Epsilon (1.2%) subdivisions. Fewer than 15% of the clones belonged to the *Low GC Gram-positive bacteria*, and 13% of the clones were related to *Nitrospina*.

The majority of the clones shared less than 85% of the 16S rRNA gene sequence identity with previously described bacteria or clones. About 35% of phylotypes detected in this study were closely related to the environmental clones from *Acidimicrobium ferrooxidans subgroup*, *Anaerobaculum thermoterrenum Group*, *Azoarcus indigens subgroup*, *Rhodoferax fermentans subgroup*, *Geobacter metallireducens subgroup*, *Rubrobacter radiotolerans Group*, *Brevibacillus brevis Group* and *Environmental clone OPB80 Group*, *Environmental clone OPB35 Subgroup*, *Environmental clone IIII-8 Group*, *Environmental clone WCHB1-31 Group*, *Environmental clone MB1228 Group*, *Environmental clone S027 Group*, *Environmental clone DA101 subgroup*, *Environmental clone RB40 Group*, *Mount Coot-tha Environmental Clones II Group*, *Environmental Clones MC4 Group*, reflecting the fact that most of the tundra soil microorganism have never been isolated and as a result the physiology of their members appears to be unknown. The results suggest that these tundra-derived clones are very diverse in phylogeny, indicating a very complex microbial community of Arctic soil.

First examination of microbial communities immobilized on the ancient seeds surface

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key words: permafrost, ancient seeds, plant seeds microbiology, microbial communities in permafrost

Ancient permafrost deposits of North East Siberia contain buried seeds of different plants. Some of these seeds preserve its life potentialities until presens. Microbial communities immobilized on the seeds surface as well as microorganisms penetrated under the surface could play an important role for seeds conservation processes and its reactivation after long-term cold stress. Microbial metabolites, for example Alkyl-oxy-benzole derivatives, could function as signal molecules for transition of seeds to deep dormancy or vice versa for their resuscitation. The goals of research are the following:

1. Direct SEM (scanning electron microscopy) observation of microorganisms on the surface of ancient seeds;
2. "Ecolog"-Multiplat-Analyses technique (on different culture-medias), to investigate functional-diversity of different microbial communities;
3. Investigation of cells viability, isolation and identification of strains;
4. Study of isolated strains by high-resolution SEM and AFM (Atomic Force Microscopy) techniques.

Prokaryotic and eukaryotic microorganisms were detected on ancient plant seeds by different methods. The abundance of cells on seeds was greater then microbial content in sediments. Microbial communities immobilized on seeds surface and microbial communities in inclosing sediments were very different (in its functional-diversity), in spite of its were colselly contacted during the long period of time. The functional deversity of microbial communities associated with seeds surface was much greater than functional-diversity of microbial communities in inclosing sediments.

The data, that already obtained, indicate long-term preservation of living microorganisms interacting with plants in permafrost and possibly can be preserved in extraterrestrial environments. Improving of this research could give useful information about seeds conservation processes in nature. This information can be used, for example for future human missions planning introduction of plant seeds into extraterrestrial soil.

Microbiological study of Kluchevskaya volcanoes group area permafrost sediments

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key words: Kamchatka permafrost, volcanoes, thermophilic bacteria, isolated strains

The Kamchatka region is the one of the virgin areas, well known because of its volcanic activity. It is the unique place where permafrost is associated with volcanoes. The permafrost of this region is comparative young and another feature is the thermal shock due to eruption previous to its formation. Aim of this work is to investigate the microbial community of Kamchatka permafrost samples, which were taken sterile from the boreholes drilled at Kluchevskaya Volcanoes group area in 2002 to 2004. The amount of cells was investigated by standard plating method and direct luminescent microscopy. Also the comparison of different temperature groups of bacteria, investigation of their morphology and Gram reaction were done. Isolation of permafrost bacterial strain was made onto different nutrient media and at different temperatures. The temperature grades used in this study were 4, 20, 35 and 55°C. The following nutrient media were used for isolation permafrost bacteria strains: Argentin-Glycerol, R2A and TSB. The main feature of this study was to find aerobic thermophilic or thermotolerant bacterial strains in the permafrost. The idea of this challenge was that thermotolerant bacteria could occur in permafrost sediments associated with volcanoes only as a result of eruption, thus brought with material from the areas nearby crater.

Finally, it could be considered that viable aerobic heterotrophic bacteria cells are preserved in young volcanic permafrost. The majority of isolated strains were mesophiles but also there are strains, which grow at temperature of 50°C - the fact that was not discovered earlier for permafrost aerobic microorganisms.

Effects of microbial communities and organic matter quality on methane fluxes in different areas of a Siberian polygon tundra

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key words: methane cycle, microbial communities, organic carbon

Wet tundra environments of the Arctic are natural sources of the climate relevant trace gas methane. The underlying microbial and geochemical processes are not yet well understood. The field investigations were carried out on the island Samoylov (72° N, 126° E) located in the Lena Delta, Siberia. The study site represented an area of typical polygonal patterned grounds with ice-wedges. For the understanding and assessment of recent and future carbon dynamics of permafrost soils the processes of CH₄ production and oxidation, the microbial community structure and the quality of DOM were studied in two soils of a polygonal tundra.

The mean flux rate of the depression was $53.2 \pm 8.7 \text{ mg CH}_4 \text{ m}^{-2} \text{ d}^{-1}$, whereas the mean flux rate of the dryer rim part of the polygon was $4.7 \pm 2.5 \text{ CH}_4 \text{ m}^{-2} \text{ d}^{-1}$. Activities of methanogens and methanotrophs differed significantly in their rates and distribution patterns among the two investigated profiles. Community structure analysis showed similarities between both soils for esterlinked PLFAs and differences in the fraction of unsaponifiable PLFAs and PLELs. Furthermore, a shift of the overall composition of the microbiota with depth at both sites was indicated by an increasing portion of iso- and anteiso-branched fatty acids related to the amount of straight chain fatty acids. The quantity of dissolved organic matter (DOM),

which represents an important C pool for microbial communities, correlated significant with the total concentrations of phospholipid fatty acids and ether lipids (PLFA and PLEL) a measure for microbial biomass. Although permafrost soils represent a large carbon pool, it was shown, that the reduced quality of organic matter leads to a substrate limitation of the microbial metabolism. This is an important finding for modelling and calculating trace gas fluxes from permafrost environments, because the known models are consider only the total carbon amount.

It can be concluded by the presented results firstly that microbial communities in permafrost environments are composed by members of all three domains of life at numbers comparable to temperate soil ecosystems and secondly that the permafrost microorganisms are well adapted to the extreme temperature gradient of their environment.

Environmental controls on methane oxidation in permafrost soils

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key words: methane oxidation, PLFA-biomarkers, permafrost soils

Arctic wetland soils are among the most important natural sources of the climate relevant trace gas methane. Emissions from these cold environments are reduced by methanotrophic bacteria, oxidizing varying amounts of methane before it is released to the atmosphere. In our study, microbial methane oxidation was characterized in four heterogeneous tundra wetland soils and in various samples from perennially frozen sediments and paleosoils. Potential activities were determined by incubating soil samples with varying oxygen/methane concentrations. Methanotrophic population size and structure were assessed by measuring concentration of specific PLFA (phospholipid fatty acid) biomarkers. In completely waterlogged peat soils covered with a carex dominated vegetation, potential methane oxidation was highest in densely rooted parts of the soil profiles, with a maximum value of $87.1 \text{ nmol h}^{-1} \text{ g}^{-1} \text{ dw}$ (4 to 9 cm depth, 0°C). Thus, oxygen transport through wetland plant roots into the waterlogged soil seemed to be an important control of methane oxidizing activity in these environments. Measurements of substrate kinetics suggested that only directly below the water table, where in situ methane concentrations were low, methane oxidation was limited by methane supply. Activity rates with 0.5% O_2 were slightly higher ($84.9 \text{ nmol h}^{-1} \text{ g}^{-1} \text{ dw}$) than with 20% O_2 ($73.2 \text{ nmol h}^{-1} \text{ g}^{-1} \text{ dw}$), indicating that methanotrophs were adapted to microaerophilic conditions around plant roots. In a mineral soil with a deeper water table, methane oxidation peaked in the unsaturated oxic section of the soil profile. Water saturated deeper parts contained only minor plant roots, therefore oxygen supply for methane oxidation in this zone was not provided. Incubations at different temperatures showed that there was a distinct rise in activity in the span of prevailing in situ temperatures of the thawed tundra soils (0°C : $57.8 \text{ nmol h}^{-1} \text{ g}^{-1} \text{ dw}$; 10°C : $211.0 \text{ nmol h}^{-1} \text{ g}^{-1} \text{ dw}$), indicating that, besides O_2 and CH_4 , temperature was an important controlling factor of methane oxidation. However, maximum methane oxidizing activity in topsoil and colder subsoil was found at 28°C , far higher than the in situ temperatures. PLFA analyses revealed varying concentrations of biomarkers specific for Type I-methanotrophs in the four soils investigated, while no PLFA-biomarkers of Type II-organisms could be detected. Largest concentrations of Type I-biomarkers were found in a peat horizon above a silty substrate ($45.3 \text{ nmol g}^{-1} \text{ dw}$), indicating higher methanotrophic population sizes than in the other analysed soils. Investigations of methane oxidation activity in perennially frozen paleosoils and sediments showed that methane oxidizers partly survived for several thousands of years under these extreme conditions and could be activated after thawing of permafrost.

Chapter 4

Session 3 - Periglacial Landforms and Cryogenic Processes

Session Conveners: Matti Seppälä, Ole Humlun

in association with: IPA WG on Periglacial Processes and Environment

Microscopical characterization of thermokarst ice from an area of Andean permafrost, Central Andes of Mendoza, Argentina

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key words: thermokarst ice, microcrystallography, Central Andes, Argentina, Andean permafrost

The analyses focus on ice samples extracted from thermokarst in an area without uncovered ice but with ice covered by sediments, and thus constituting a completely new and recent periglacial environment. That way, the permafrost level extends to heights over 4200 to 4300 m, hidden under a thick layer of sediments. The study area is located in the Cordon del Plata in the Andean Cordillera of Mendoza, Argentina.

The samples are taken from two profiles and different walls of the thermokarst that were analysed between 1999 and 2002. It was proven that through the techniques of plastic replica and thin layers studied under crossed polarizers, it is possible to establish microscopical differences between sedimentary ice and glacial ice under stress.

In the present work microcrystallographic studies of samples extracted from two almost perpendicular thermokarst walls are compared. In the first case, an E-SE wall sampled in 1999, the samples were exposed to a major pressure in direction of the glacial flow than that of the second case, a N-NW wall examined in 2002, where the glacial flow caused mainly shear stress. These facts influence the structure and the internal characteristics of the ice.

The results of this work allow to distinguish between glacial ice, with bubbles that are deformed in the direction of the main flow of the glacier, and the sedimentary ice with completely spherical bubbles. In the samples of the sedimentary ice, taken in 2002, a very low density of bubbles is observed and the average size of the crystals is considerably bigger than in 1999. This is interpreted as an increase of the mean temperature of the thermokarst. The reactivation of old thermokarst would also indicate a degradation of the Andean permafrost.

Synoptic-scale soil temperature observations from Marion Island, Subantarctic, and its implications on soil frost activity

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key words: Marion Island, Subantarctic, diurnal soil frost, slope aspect, *Azorella selago*

Marion Island (47° S, 38° E) possesses a highly maritime climate with low mean diurnal and seasonal temperature amplitudes, high cloud cover and frequent precipitation. Soil frost activity is dominated by diurnal frost cycles from sea level to above 1000 m asl. In this paper the importance of slope aspect and vegetation on ground temperature conditions is assessed at the synoptic time scale.

Soil surface temperatures were measured at four aspects and top of a volcanic cone and grey lava clast. Despite the difference in spatial scale, in both situations westerly circulation conditions with high cloud cover result in minimal temperature differences by aspect. In contrast, southerly air circulation results in clear skies and enhanced nocturnal cooling, leading to preferential soil frost on cooler slope aspects. Soil and air temperature, wind speed and soil moisture measurements at various forms of *Azorella selago* cushion plants do not show significant differences under westerly air circulation conditions. Over the period 1951 to 1999 annual sunshine hours show a high variability, but have increased from ca. 1250 to 1450 hr, or 3.3 hr per year (Smith, 2002). Based on the presented measurements, increased clear sky conditions on Marion are expected to increase the role of slope aspect as a control on soil frost cycle frequency. This may lead to a higher spatial variability in soil movement rates and indirectly, increased patchiness in vegetation patterns. Longer term ground temperature monitoring at an island scale is underway to further test this hypothesis.

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Litho-Cryostratigraphic mapping of syngenetic permafrost in the CRREL permafrost tunnel, Fairbanks, Alaska

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key words: permafrost, ground ice, cryostructures, thermokarst, pseudomorphs

Ice-rich syngenetic permafrost that formed during the Late-Pleistocene in loess and retransported silt is exposed in the CRREL permafrost tunnel, near Fairbanks, Alaska. Three-dimensional litho-cryostratigraphic mapping indicates that layered, lenticular-layered, and micro-lenticular cryogenic structures are typical of the original syngenetic permafrost while reticulate-chaotic and massive cryogenic structures indicate epigenetic freezing related to localized thermokarst erosion along ice wedges. Secondary alteration has resulted in the development of (i) ice-wedge pseudomorphs, represented by either gravel, silt, ice or silt/ice mixtures and (ii) ice pseudomorphs. The latter are interpreted as thermokarst-cave ice. Observations show that emplacement of thermokarst-cave ice does not mark the termination of ice-wedge growth because veins of secondary ice-wedges are common within the thermokarst-cave ice. It appears that syngenetic permafrost growth occurred concurrently with localized erosion that acted preferentially along ice wedges leading to the development of gullies, tunnels and pseudomorphs. Instead of recognizing the regional thaw unconformity described in previous studies, we identify a number of localized thaw unconformities that have resulted from episodic fluvial-thermo erosion along ice wedges. This should be regarded as a normal characteristic of syngenetic permafrost growth.

Understanding palsas and lithalsas through computed tomography scanning: Inferences on internal structure and genesis

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key words: geocryology, frost heave, ice lensing, lithalsa, tomodensitometry

The growth of ice segregation lenses in frost sensitive sediments in the discontinuous permafrost zone is the dominant mechanism for the formation of permafrost mounds, such as palsas and lithalsas. The chain of physical processes during segregation involves cryosuction of ground water, phase changes, growth of ice lenses, and structural deformations. The growth of successive ice lenses in the ground as permafrost gets thicker and thicker pushes the soil upward, a mechanism known as heave, that raises the surface upwards thus generating the mounds. Thawing of these mounds creates the innumerable thermokarst lakes that can be seen in the Hudson Bay area. The presence of the permafrost in mounds and its expansion, are closely linked to climate regulation, local Quaternary geology, and environmental factors such as topography, vegetation, snow cover, and surface humidity. Variable size and morphology of the permafrost mounds can be attributed to the local physics of ice segregation process, water supply needed for the ice growth, and nature of the soil into which aggradation takes place. Necessarily, the internal study of the permafrost mounds, frost heave, and ice segregation, is a necessary approach in order to improve existing knowledge, which so far has remained mainly based on surficial descriptions.

The purpose of our study is to obtain some new information concerning the ice segregation and frost heave processes taking place in permafrost mounds of different shapes. We use an innovative and non-destructive approach that makes use of a tomodensitometric scanner. This instrumentation produces high-resolution computer images of ice lenses, soil layers, faults, sedimentary structures and gas bubbles. It allows interpreting of ice lensing and soil cryo-structure resulting from permafrost aggradation. It also provides an accurate estimation of ice and gas volumetric contents present in the permafrost. Chemical analyses on the various phases of the permafrost (i.e. ice, gas, and soil) provide supplementary information. The cryostratigraphic observations from different kinds of permafrost mounds and plateaus, distributed across our study area following latitudinal and longitudinal gradients, allow some interpretations of the ice layers sequences in term of formation processes of the permafrost. Following these interpretations, we attempt to provide an explanatory and simplified diagram of the internal structure of the most common type of lithalsa.

Permafrost in bedrocks of the transantarctic mountains region

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key words: permafrost, bedrock, cryogenic, weathering, Antarctica

Permafrost occurs in all of the exposed and widely scattered ground surface areas of the Transantarctic Mountains that in total comprise only about 23000 km² or 0.15% of the area of Antarctica. Till deposits cover most of this ice-free area and permafrost in these materials is present at depths ranging from 5 cm to around 70 cm from the soil surface. The permafrost varies from ice bonded to ice free or dry frozen permafrost and its characteristics are a function of local climatic conditions (Campbell et al., 1998), the interactions between solar radiation or surface heating, air cooling and precipitation or available moisture from thawing. It is estimated that up to 10% of the ice-free ground of the McMurdo-Dry Valley region may be bedrock exposures (Claridge et al., 2002) although the proportion of bedrock through the remainder of the Transantarctic Mountains may be much higher. To date, little attention has been given to the nature or

significance of permafrost in these materials. However, observations of numerous bedrock exposures suggest that the fracture patterns and arrangements of surface rock clasts have resulted from similar processes to those forming the permafrost and patterned ground in the associated tills.

The effects of cryogenic processes in bedrock are most commonly observed in rocks of the Beacon Sandstone, a widespread terrestrial and massive deposit with low angle bedding. Freshly exposed surfaces may have an intensive pattern of narrow but shallow vertical cracks, forming blocks up to 1 m². On older surfaces, blocks are separated, sometimes in regular patterns and the cracks are filled with fragmental materials. Occasionally, distinct evidence of rifting can be seen while uplift and tilting of individual blocks may occur. Over time, abrasion and exfoliation may reduce the cover of fractured bedrock to a thin stone pavement, and when the underlying massive sandstone becomes exposed, the cyclical weathering process begins again (Campbell and Claridge, 1987). The processes involved in the evolution of the surface features are considered to be; thermal expansion and contraction which forms the initial crack pattern on the rock surfaces: crack infilling with sand and coarse materials; penetration of moisture and ice accumulation along cracks and in fracture planes; and differential lateral and vertical movement of blocks of rock resulting from the irregular accumulation of ground ice and wedging processes. Bedrock cryogenic processes in the Transantarctic Mountains have also been observed in other rock types including granite, dolerite and igneous rocks, although the manifestations are less spectacular than those observed in the Beacon Sandstone rocks. Important attributes of the rock that influence surface forms are the rock colour, rock tensile strength, inherent bedding and fracture patterns.

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An example of subnival erosion of bedrock from the mountains of northwestern Spain

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key words: subnival erosion, snow patch, snowslide, snowcreep, NW Spain

The ability of seasonal or semipermanent, mobile snow cover to scour bedrock surfaces and to detach and transport rock fragments has been long recognized. In this communication bedrock erosional features of nival origin are discussed from a seasonal, late-lying mobile snow patch located in the Cuiña Cirque, northwestern Spanish mountains. The site substrate is composed of low-grade metamorphic, fine-grained Ordovician shales and quartzites. Both lithologies are densely jointed and shales particularly show a highly developed cleavage. The snow patch usually begins to form by mid-autumn and completely disappears by mid-summer. Its thickness is very uneven due to the irregularities of the substrate and the redistribution of snow made by the wind. The slow movement of the snow patch over the bedrock causes the detachment of rock fragments of very different size. Plucking is favoured by the fracturing pattern of the bedrock and also by increasing slopes. Rock failure occurs by breakage along pre-existing weakness planes. The plucking of large rock fragments seems to be progressive and on rare occasions is accomplished in a single year. Detached rock fragments are subnivally transported and dragged over the bedrock surface. The stresses at

the bottom of the snow patch are responsible for the crushing of clasts. Rock tools carried at the base of the moving snow patch scour the underlying substrate and reduce its surface roughness. Subnival abrasion becomes apparent in the polished and smoothed appearance of numerous bedrock surfaces and protuberances. Abraded surfaces show plenty of minute scratches, striae, abrasion tracks and small grooves. Bedrock steps and protuberances show blunt edges. Actively abraded surfaces are mostly lichen-free. Striae and abrasion tracks are very abundant on polished surfaces. Both of them are broadly aligned with the direction of displacement of the snow patch. Rapid, avalanche-like movements of the snow pack are rejected as the cause of abrasion and detachment of bedrock. Full-depth avalanches are exceptional, and are confined to steep surfaces. The described erosional features have been caused by the non-rapid movement of the snow patch due to snowcreep and snowslide. Subnival erosion is strongly dependent on the thickness of the snow cover. Therefore, an important increase in the erosional activity of the snow patch takes place in heavy snowy years. On the other hand, light snowy years are characterized by little or negligible erosion.

Ice-wedge activity in Svalbard

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key words: ice-wedges, Svalbard, crack monitoring, snow depth monitoring

Ice-wedges are the most widespread permafrost landform in the extensive periglacial lowland areas with continuous permafrost. Ice-wedge casts are a key indicator for the existence of continuous permafrost in palaeoenvironmental reconstructions of former periglacial areas. We do, however, not have a detailed understanding of the ice-wedge dynamics, and therefore all year round field studies of ice-wedge dynamics were carried out in Svalbard for the last two years. Modern climate at sea level in Svalbard locates these islands close to the southern limit of the continuous permafrost zone, with a mean annual air temperature of -4 to -6 °C. However, thermal contraction cracking is demonstrated to be widespread in the Adventdalen study area in Svalbard. As with other permafrost landforms ice-wedges are largely controlled by the winter meteorological conditions, making them especially important for reconstructions of palaeoclimatic winter conditions.

Collecting different types of data from the Adventdalen ice-wedge site have improved the understanding of the ice-wedge dynamics. Snow depths were monitored continuously using an automatic digital camera (Christiansen, 2001), and a maximum of 35 cm of snow occurred mid winter in the ice-wedge troughs, allowing thermal contraction cracking. Ground thermal conditions in the active layer above the ice-wedge show that long, significantly cold periods seem to control ice-wedge cracking (Christiansen, in press). Benchmark distance measurements across the ice-wedges and inside the polygons have been carried out for almost 2 years, as in the long-term studies by Mackay (2000). The results of these high frequency measurements show annual variations of up to 2 cm in distance across the ice-wedges and within the polygons. Winter extension of up to 2 cm across the ice-wedges occur before any cracking takes place, indicating creep of the frozen ground. To determine exactly the timing of thermal contraction cracking, high sensitivity miniature shock loggers were registering acceleration of the ground in the top of the cracks in the active layer above the ice-wedges. Significant ice-wedge cracking occurred only after extensive ground cooling. All these results demonstrate that in permafrost areas with a maritime climate like Svalbard, ice-wedge cracking can be widespread, but it is necessary to have stable meteorological blocking situations, with high pressure in winter, to cool the ground significantly enough for ice-wedge cracking to occur.

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Thermal regime in a low elevation cold talus slope : first results from a recently drilled borehole (Swiss Prealps) and air flow modelling

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key words: talus slope, low elevation permafrost, air circulation, borehole, air flow modelling

Internal ventilation may lead to the sporadic occurrence of permafrost in talus slopes located far below the regional lower limit of the discontinuous mountain permafrost belt. A 15 m borehole was drilled and instrumented for temperature measurement (9 thermistors) in November 2004 in such a talus slope in order to better understand both the ventilation mechanism and the heat transfer at depth in the debris accumulation. Simultaneously, efforts for the modelling of the ventilating process and its consequences on the ground thermal regime have been carried out.

The studied talus is laying between 1550 and 1630 m a.s.l. at Dreveneuse in the western Swiss Prealps (46° 16' N, 6° 53' E), faces to the East and consists of limestone clasts. Mean annual air temperature is about +4°C. The presence of dwarf red spruces on the lower part of the scree suggests the occurrence of cold ground conditions and even permafrost. Gravity discharge of cold dense air is easily perceptible in the area during summer time. During winter time, large snow melt windows open in the upper part of the slope and evidence a reversed ventilation : intense ascent and release of relatively warm air. The borehole was drilled in the middle part of the scree slope, where the air is supposed to transit. Vertical electrical resistivity sounding suggested permafrost also to occur at that place. First results from 23th November 2004 to 17th January 2005 showed that the ground temperature was below 0°C during most of the period down to about 10 m depth, what corresponds to the thickness of the accumulation of coarse debris. Moreover, no increase in temperature occurred with depth and no apparent relationship was distinguished between the temperature regime at 8.5, 6 and above 4 m depth. Indeed, variations of about 3°C within a few days were recorded at 6 and 8.5 m depth where the temperature was sometimes the coldest. Consequently, the ground heat flux was definitely not only conductive during the measurement period but predominantly driven by the ventilation mechanism acting throughout the talus slope. However, the precise understanding of the mechanism, which appears to be particularly complex, requires further data to be available. Complementary measurements (ground temperature, meteorology, velocity, direction and humidity of the air flow in the lower part of the slope...) are therefore carried out or foreseen. Simultaneously, a simple numerical model of the air circulation is being developed. By analogy to the description of airflow in open caves, an air circulation model in "talus slopes" can be developed upon the hypothesis based on the airflow of "land/sea breeze", and therefore be treated analytically. Model validation will be carried out after further fields measurements are made available.

Air circulation and permafrost occurrence in talus slopes and relict rock glaciers in the Swiss Prealps

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key words: air circulation, talus slope, relict rock glacier, sporadic permafrost, Swiss Prealps

Investigations about the internal circulation of air and the concomitant occurrence of permafrost within scree slopes and relict rock glaciers were initiated in 2004 in several sites between 1400 and 2200 m a.s.l. in the Swiss Prealps. First results show that the circulation of air is a mechanism common to all prospected sites.

Moreover, permafrost is likely to occur in most cases (according to electrical resistivity measurements) despite a mean annual air temperature (MAAT) between +1 to +4.5°C depending on elevation. Air circulation throughout an accumulation of loose sediments is primarily controlled by the thermal gradient between the surrounding air and the ground. The flow direction seasonally reverses: to an ascent of relatively warm light air in winter, which favours consequently the penetration of cold air at the base of the debris accumulation, succeeds a gravity discharge of relatively cold dense air during summer. The process leads to a strong annual negative anomaly of the ground temperature in the lower part of the ventilated formation. Our study focuses on a more detailed comprehension of the ventilation mechanism and its implication in the occurrence and preservation of sporadic alpine permafrost. Field investigations prevail: detailed geomorphic mapping, frequent site visits, ground surface temperature and electrical resistivity measurements. Frequent field visits allow to describe the varying nature and significance of phenomena, that can be observed at the ground surface and associated to both intensity and direction of the air stream in the debris accumulation (e.g. snowmelt window, hoarfrost, basal icing of the snow cover, funnelling, condensation fog, ground icing, aspiration holes). Air circulation appears to be more complex than previously assumed, particularly during the periods when the contrast in temperature is weak: e.g. daily reversibility of the flow direction, apparent superimposition of under-systems on the main ventilation system. First electrical resistivity measurements systematically show the presence of high resistivity layers (20 to 50 kΩm) in the apparently overcooled ventilated areas (rooting zone of a relict rock glacier, lower and median parts of talus slopes). The resistant layers are located in each case between about 2 and 20 m depth. The high resistivity values may be due either to the large porosity or to the frozen state of the sediment or, more probably, to the frozen state of an open-void material. Performing a BTS (bottom temperature of the snow cover) mapping after a long period of cold weather has revealed to be a valuable method for determining both the efficiency and the spatial extent of a ventilation system acting throughout a debris accumulation even in the presence a thick snow cover. An intensive use of the method is foreseen for the winter 2004 to 05, if the necessary conditions (cold period, safe avalanche risk) occur.

Subarctic alpine permafrost occurrence in a periglacial environment in northern Sweden derived by geomorphological mapping and geophysical surveys

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key words: subarctic periglacial environment, geomorphological mapping, electrical resistivity imaging, altitudinal limit of permafrost

In a subarctic periglacial environment in northern Sweden, the spatial distribution of permafrost and its characteristics related to typical periglacial landforms was investigated using different methods. The geomorphological mapping was performed using a legend for high mountain geomorphology. The digital cartography was realized within the geographical information system software ArcGis. In order to evaluate the permafrost distribution in the investigation area on a larger scale, measurements of the bottom temperature of the snow cover were carried out (so-called BTS-method). For the characterisation of the subsurface lithology 2D resistivity surveys were performed additionally. Bedrock consists of amphibolite, gneiss and mica schists. Numerous solifluction/gelifluction lobes indicate active permafrost in the slopes. Results of BTS-measurements in the proglacial area of two small mountain glaciers indicate a widespread occurrence of perennially frozen ground which is expressed by patterned ground with sorted polygons in the flat parts of the investigation area. Geomorphological mapping confirmed an altitudinal zonation of permafrost-related landforms and processes. 2D resistivity tomographies carried out on typical periglacial landforms provide detailed images of the subsurface internal structure of solifluction terraces, patterned ground with sorted polygons and an ice-cored moraine. With the combined methods the altitudinal limit of the permafrost distribution of this high-latitude subarctic periglacial environment could be delineated.

Periglacial morphodynamic, high mountain environment and Little Ice Age relict ice relationships in Picos de Europa, Cantabrian Mountains, North Spain

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key words: periglacial morphodynamic, BTS measurements, Little Ice Age relict ice, Picos de Europa, Cantabrian Mountains

The abrupt and vertical relief of the Picos de Europa, its altitude that accomadates the highest altitudes of the Cantabrian Mountains (Torre Cerredo 2.648 m.s.l., Torre del Llambrión 2642 m.s.l.) and its proximity to the Cantabrian Coast which amounts to 15 km, favours the existence of some particular climatic and environmental conditions that define the massif as a deglaciaded high mountain environment. The massif is characterized by a nivoperiglacial morphodynamic, with some strictly periglacial conditions, limited to the highest areas.

In Picos de Europa the periglacial environment is predominant 1900 m.s.l. up, which at the same time, is the inferior limit of the high mountain belt. Picos de Europa high mountain belt were defined in relation to landforms and processes. Geomorphological maps, scale 1:25000 and scale 1:10000, were used as an inventory of active, inactive and relict landforms to find the altitudinal location and orientation of different landforms and processes and to identify landform associations and active processes of the high mountain environment. Periglacial landforms of Picos de Europa high mountain belt have been related to the main periglacial processes, which are determined by climatical variations, introduced by altitude, topography, orientation and exposition. Nowadays, the cryonival belt (above 2300 m a.s.l.), is characterised by colder thermal conditions, that imply an intense gelifraction and the presence of gelifluction and cryoturbation processes and landforms limited to the more favourable areas. Some of those areas have been occupied by glaciers during the Little Ice Age, but today there are only small relict ice patchs covered with debris. Furthermore botton temperature of winter snow (B.T.S.) measurements have been made. B.T.S. measurements were completed with ground measurements to observe the ground thermal regime and the winter evolution and distribution of the nival layer. The BTS measurements point out the non-existence of environmental conditions to get probable permafrost development. Nivation processes are weak indicators of periglacial environments as they are not associated with either permafrost or frost action, but are common in Picos de Europa high mountain environment. The interactions exist between the ice bodies and actual periglacial morphodymanic are analyzed in 6 glacier cirques, where there are interesting morphogenetic processes and landforms associated, actives and sensitives to the current environmental changes. So it forms a privileged "indicator of changes", showing the morphogenetic answers of the high mountain environment of Picos de Europa, to the climatical current conditions and their future evolution.

The Western Altai: Features of altitudinal geocryological zonation

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key words: Western Altai, noncryogenic subzone, permafrost zone

The western part of the Kazakhstan's Altai includes a number of low (up to 2778 m) wood mountain ranges. This territory is located on the right bank of the Irtysh River between 51° 00' to 49° 20' N and 82° 30' to 85° 30' E. Mountains of the Western Altai are characterized by an unique geocryological zonation. Here,

within the limits of 600 to 1500 m a.s.l., there is no seasonal freezing of soils. The main reason is that the thick snow cover (more than 2 m) in the fir forests cover thick layer of dying off high grass laying. This fact determines a feature of altitudinal geocryological zonation. The soils of the lowest zone from piedmont plains to 600 m a.s.l. are exposed to deep seasonal freezing. Within the limits of 600 to 1500 m a.s.l. there is non-cryogenic sub-zone where freezing of soils is absent. There is permafrost zone above 1500 m a.s.l.

Eolian processes of the Arctic Tundras of Yamal

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key words: Yamal, Arctic Tundra, eolian processes

The annual redistribution and accumulation of snow in one landscape is determined by climatic conditions and take place in a fixed natural way. The relief and vegetation participate in dimensional variability of a snow mantle. On observations of 2004 the stratigraphic structure of snow in Central Yamal on the area of the settlement Harasavei has one feature : the combination of layers of friable snow, a frozen snow-crust and eolian sediments. The greatest accumulation occurs in the lowerings of the relief and in the wind shade. The maximal accumulation of the eolian sediments happens in the hydrographic network formed by the gullies and rivers. There is a gradual reduction of the layer of the eolian sediments from the shore of the Kara sea in the direction of the terrain. On the coastal area in the inferior streamings of gullies the layer of the eolian sediments has the thickness of 0.4 to 1.99 mm and can achieve 11.45 mm. This layer makes up 0.10 to 0.15 mm within one kilometer's distance from the shore and the layer has the reduction up to 0.01 mm within two kilometer's distance. The accumulation of the eolian sediments in the snow mantle has the average thickness of 1.20 mm on the coastal strand of two kilometers width. The formation of a frozen snow-crust has the considerable influence on the transmission and accumulation of the eolian particles in the ground layer. The formation of a wind shade by separate plants and plant communities can result into the formation of snow blockages which at thawing weather form a frozen snow-crust. The last, having height up to 0.4 to 0.5 m, is capable at change of a wind to form its own natural wind shade. As a result the formation of the snow mantle and accumulation of the eolian sediments can differ essentially in limits of the same landscape in different years. The accumulation of the snow forming a frozen snow-crust can take place in various directions of a wind. On the one hand the comparison of the data adjournments of the eolian sediments specifies the strong denudation as a result of blowing-off and the fissile processes of adjournment - on the other hand. Clay grounds on naked surfaces and also sandy grounds are exposed to blowing-off.

Full-scale cold room simulation of gelifluction processes associated with one-sided and two-sided active layer freezing

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key words: solifluction, laboratory modelling, two-sided freezing, one-sided freezing, frost heave

Solifluction is virtually ubiquitous in the periglacial zone, and field studies have shown two distinct climatically determined styles of shear strain. In areas with seasonal ground freezing, shearing is often observed to increase towards the surface, while in permafrost areas where active layer freezing takes place from the surface downwards and the permafrost table upwards (two-sided freezing), soil shearing is frequently concentrated at the base of the active layer, giving plug-like displacements. Most field and all laboratory investigations have focused on the first of these, that is, solifluction associated with top down freezing and

thawing. In this paper we describe two controlled full-scale cold room simulation experiments currently in progress in the CNRS laboratories in Caen, France. Identical slope models with 12° gradients formed of natural aeolian clayey silt have been constructed in a cold room in which air temperatures can be lowered to -10°C. Model slope lengths are 5 m, widths 1.2 m, soil thickness is 0.35 m, and in both cases models are constructed over a basal drainage layer and connected to an external water supply at the top of the slope. In Model 1 refrigeration pipes are embedded within sand immediately beneath the model drainage layer (separated by a waterproof membrane), to allow development of permafrost at the base of the slope model. In Model 2, no such basal freezing facility is included. Models were saturated, then the basal permafrost layer was established in Model 1. Lowering of the air temperature to -10°C allows both models to be frozen, in Model 1, two-sided freezing occurs, while in Model 2 freezing is from the surface downwards. Both slopes are instrumented with Linear Variable Differential Transformers (<http://www.lvdt.co.uk/howtheywork.html>) (LVDTs) supported on a track above each slope model and connected to base plates embedded in each model slope surface. Thus, frost heave and downslope displacements are monitored continuously using a PC-based logging system. Thermistors record soil temperatures, Druck miniature pre pressure transducers record changes in pore water pressures, and in each slope the volumetric water content in the central zone of the active layer is recorded using an Echo 2 probe measuring the dielectric constant of the soil. Thermal regimes, frost heave, thaw settlement, downslope soil displacement, and pore pressures are compared for the first three cycles of freezing and thawing, and inferences drawn concerning differences in the style of solifluction.

Field monitoring of gelifluction, Dovrefjell, Norway: A validation of physical modelling experiments

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key words: solifluction, Norway, field monitoring, frost heave, physical modelling

In this paper we present initial results of field monitoring of gelifluction processes on a turf-banked solifluction lobe in Dovrefjell, Norway. The field experiment is designed to validate full-scale and scaled centrifuge laboratory simulations of gelifluction processes resulting from seasonal surface-downwards ground freezing and thawing. Field instrumentation comprised a pair of Linear Variable Differential Transformers (<http://www.lvdt.co.uk/howtheywork.html>) (LVDTs) suspended from a tubular steel frame to record heave and downslope displacements of a footplate embedded in the soil surface, together with buried vertical arrays of miniature pore pressure transformers and thermistor probes. Thermistors were also installed on the ground surface and in a vertical above-ground array to a height of 2 m. Data is recorded at hourly intervals on a Campbell CR23X logger. In addition, Rudberg Columns consisting of 1cm long sections of plastic tubing were buried in a transect across the lobe, to record profiles of downslope soil displacement. Instrumentation was installed in July 2001, but a lightning strike in November 2001 resulted in logger malfunction. Continuous recording was recommenced in May 2002 and has continued since that date. Thermal data shows ground freezing to around 30 cm in the winters of 2002/3 and 2003/4 and associated frost heave of 37 mm and 45 mm respectively. Downslope surface displacement as recorded by the LVDT footplate was slightly greater than 11 mm in each year. Ground surface vectors for both years were identical to those recorded during earlier full-scale cold room simulation experiments (e.g. Harris and Davies, 2000). Pore pressure data show a significant rise during thaw consolidation, but also suggest seepage of groundwater beneath the seasonally frozen soil. The significance of these field data in the context of laboratory simulation studies is discussed.

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Environmental determinants of earth hummock occurrence in Finnish Lapland: a case study based on generalized linear modelling (GLM) and hierarchical partitioning (HP)

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key words: earth hummock, distribution modelling, generalized linear modelling, hierarchical partitioning, Finland

Numerical studies between periglacial processes and their environment are important because they provide understanding of the main drivers in geomorphological systems. With the aid of geographic information systems (GIS) and new multivariate techniques it is possible to construct models to study the relationships between periglacial phenomena and environmental determinants. However, collinearity between explanatory variables and spatial autocorrelation can hamper the detection of key environmental factors underlying process-environment relationships identified by traditional regression approaches. This study utilized two alternative statistical methods to address these difficulties in geomorphological modelling, namely generalized linear modelling (GLM) and hierarchical partitioning (HP).

We evaluated the differences of the results derived from GLM and HP analyses using an empirical geomorphological data set, which is spatially autocorrelated and many of the predictors are significantly intercorrelated. The study was carried out in Finnish Lapland in a region of 600 km². The distribution of earth hummocks (mineral pounus) was modelled in a spatial grid system with 2272 grid squares of 25 ha. The data was split to the model calibration (70%, n=1590) and model evaluation (30%, n=682) sets. First, a GLM model was built with the earth hummock information and environmental predictors derived from the digital data sources. Second, a HP method, which overcomes multicollinearity, was used to determine the independent effects of the environmental predictors and spatial variables on the response.

The earth hummocks are prevalent patterned grounds in the study area (present squares=68.4%). The GLM model indicated that the probability of the earth hummock occurrence increased when peat and shrub (mainly *Betula nana*) cover as well as soil moisture and moisture variability increased and mean altitude decreased. HP indicated that the most important environmental variables for earth hummock occurrence were shrub and peat cover, mean altitude, soil moisture and its variability as well as proportion of concave topography. In contrast to GLM model, HP provides deeper insights into the relative importance of individual explanatory variables, because HP calculates for each variable separately, an estimate of the independent and conjoint contribution with all other variables. Overall we consider that the results of the two approaches were similar and most importantly, all five predictor variables in the GLM model were among the six most important environmental determinants in the hierarchical partitioning.

Vegetation-frost heave interactions of nonsorted circles in the Alaskan Low Arctic

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key words: patterned ground, thermal insulation, active-layer depth

The vegetation and soil patterns in arctic tundra are influenced by the distribution of nonsorted circles, which are patterned-ground features caused by frost heave. Nonsorted circles display tight linkages between the vegetation canopy and frost-heave activity. A change in vegetation characteristics or a shift in plant functional types on nonsorted circles, possibly caused by global climate change in the near future, could

alter the frost-heave regime and lead to new landscape patterns. This project examined experimentally the influence of vegetation on thermal insulation and the effect of different plant functional types on active layer depth and frost heave. We selected 28 similar frost boils at a moist nonacidic tundra site next to the Dalton Highway, northern Alaska. An area of 0.5 m² in the center of each frost boil received one of four treatments in July 2002: 1. control, no manipulation, 2. removal of the vegetation mat, 3. vegetation removal and transplanting graminoid seedlings, and 4. vegetation removal and transplanting a 0.1 m thick moss carpet. We monitored frost heave, thaw depth, soil-surface stability, near-surface soil temperature and volumetric soil moisture. Average frost heave and thaw depth were greatest in the bare plots (16 cm and 81 cm, respectively) and lowest in the moss plots (8 cm and 69 cm, respectively). Soil-surface stability was greatest in the moss plots and lowest in the bare plots. Moss plots showed significantly reduced soil temperatures in the summer, and freezing and thawing were delayed. Soil moisture was greatest in the moss plots (mean 46%) and lowest in the bare plots (mean 39%). The sedge seedlings in the graminoid plots did not expand their root systems over the course of the experiment, which might have been caused by frost heaving and the formation of needle ice. Moss treatments had decreased frost-heave activity; the shallower active layers presumably had fewer ice lenses and thus less frost heave. In contrast, vegetation removal led to greater heat fluxes at the soil surface and increased frost heave and soil-surface disturbance. This study suggests that a possible shift in plant functional types and increase in biomass due to global warming could suppress the activity of nonsorted circles significantly. The potential loss of these cryogenic features could result in decreased soil temperatures and less landscape heterogeneity.

Aspects on the formation of solifluction lobes in recently deglaciated cirques - Schober Group, Central Alps, Austria

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key words: solifluction lobe, glacier retreat, paraglacial

The retreat of glacier systems commonly exposes a landscape that is susceptible to rapid morphological changes. In such a paraglacial environment destabilized rock walls and debris slopes above a glacier cause potential debris release and thus generally enlarges the input of debris on top of the retreating glacier and on ice-free areas at the foot slope. The present paper discusses the relation between recent retreat of glaciers and formation of solifluction landforms for the innermost part of two neighbouring cirques (Koegele cirque, Hinteres Langtal) of the Schober Group (Central Alps, Austria) with the aid of aerial photo interpretation and field studies. During the LIA-maximum glaciation the Koegele cirque was completely covered by a small cirque glacier (0.21 km²). In the early 1980s glacier ice still covered about 0.08 km² but mostly disappeared by end of the 1990s. Today, only small patches of glacier ice are found in radiation-sheltered areas. In close vicinity to these patches a number of vegetation-free solifluction lobes have recently formed. The Hinteres Langtal is the neighbouring valley to the north of the Koegele cirque and comprises a well-known complex rock glacier. The two root zones of the rock glacier show two distinct depressions. At least in the northern root zone a small cirque glacier (0.06 km²) existed during the LIA-maximum glaciation, but completely disappeared in the first half of the 20th century. Perennial snow patches, probably 'relict' glacier ice and solifluction lobes are found at both rooting zones. The observed solifluction lobes at both study sites seem to be very active according to their fresh geomorphic appearance. Samples of clasts revealed that these landforms lithologically consist predominantly of platy mica-schist with a long-axis to short-axis ratio of 1:0.23 to 1:0.31. Mean absolute values of long-axis are normally 25 to 45 cm and of short-axis 6 to 14 cm, respectively. In close vicinity to the solifluction lobes some debris slopes show now signs of deformation, which is due to a different lithology in the rock face above and thus clast characteristics. The differences in slope material indicate that finer-grained material favours the formation of solifluction lobes, whereas coarse-grained debris slopes show no sign of solifluction but nourish blocky landforms instead. It

can be assumed at both study sites that ice is occurring underneath the solifluction landforms. At least some solifluction lobes seem to be underlain by remnants of the cirque glacier. Such lobes can be considered as supraglacial solifluction lobes. In contrast, near-surface ice is absent at less radiation-sheltered lobes and therefore the lobes have the appearance of typical periglacial solifluction lobes. Due to their topographical position it is most likely that they are underlain by permafrost. It can be concluded that similar looking solifluction lobes may form on slopes underlain by permafrost as well as on remnants of glacier ice.

Climate and geomorphology of the periglacial belt in the Central Mountain Range, Taiwan

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key words: East Asia, high mountain geomorphology, relict periglacial landforms, Holocene

The Holocene geomorphology of the uppermost regions of the Central Mountain Range of Taiwan has not been studied yet. Investigations based on field work and air photo study in Nanhuta Shan (3742 m) and Yushan (3952 m) and the analysis of climate data indicate the presence of a periglacial belt with a lower limit at 3600 to 3700 m. The upper limit of the periglacial belt in Taiwan is not met. Ground temperature measurements in Nanhuta Shan show that freeze-thaw activity at 3560 m during the winter is reduced to the top few centimetres of the ground and the maximum frost depth is ~25 cm. The strongest indicator for present periglacial activity are the formation of smooth slopes as a consequence of frost weathering. The high relief energy accounts for the absence of other periglacial landforms. Relict solifluction terraces, debris cones and slope failures found in Nanhuta Shan are strong evidence for a period of increased slope activity during the Holocene. In two cases this period could be dated by OSL to approx. 3 ka. At least one solifluction terrace developed during a cooler phase between 3 ka and today.

New perspectives for periglacial geomorphology through the application of 2D resistivity imaging

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key words: 2D electrical resistivity imaging, periglacial geomorphology, subarctic periglacial environment, alpine periglacial environment, permafrost

The use of 2D resistivity imaging for the investigation of typical periglacial phenomena is shown on different case studies from the mid-latitude high-alpine and high-latitude subarctic periglacial environments. Application of geoelectrical surveys in periglacial environments often implies one major problem which is the coupling between the electrodes to the sometimes heterogeneous and rocky ground surface. From these extremely rugged terrain conditions in periglacial environments the limitations of application of geoelectric methods can arise since good electrical coupling between the electrodes and the ground is a prerequisite for geoelectrical surveys. Insufficient coupling of the electrodes to the ground and great heterogeneity of the surface terrain can lead to bad data quality resulting in noisy model interpretations of the subsurface. Nevertheless, this method is considered as the most multifunctional geophysical method and could be first choice for geomorphologists working in periglacial environments if only one single method can be applied.

This contribution aims to provide an insight into the broad opportunities, perspectives and limitations of 2D resistivity imaging for the investigation of typical periglacial landforms from the mid-latitude high-alpine

(glacial till underlain by permafrost, rock glacier, push moraine) and high-latitude subarctic periglacial environments (solifluction terrace, patterned ground with sorted polygons, ice-cored moraine). Applicability of different array geometries is discussed. A major advantage and future perspective of two-dimensional resistivity imaging for studies in periglacial environments is the possibility of performing a detailed mapping of the subsurface resistivity distribution on a small spatial scale using overlapping profiles to obtain reliable results as well as a geoelectrical monitoring of spatiotemporal evolution of permafrost. The resulting pseudosections yield - depending on the array geometry and chosen spacing - detailed images of the subsurface. This enables new fields of application for various research aspects within periglacial geomorphology which can provide new insights into the internal structure and evolution of different phenomena as indicated through the described case studies.

The structure and dynamics of earth hummocks in the subarctic forest near Inuvik, Northwest Territories, Canada

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key words: earth hummocks, Northwest Territories, ground ice, permafrost table, hummock dynamics

Surface micro-relief, permafrost table, ground-ice and soil organic-matter contents were described in an area with collapsed and poorly-developed mud hummocks and well-developed vegetated hummocks. Diameters of collapsed earth hummocks were significantly greater than those of vegetated features. Mean minimum and maximum hummock relief and hummock to hummock distance increased along the continuum of forms, with well-developed vegetated hummocks characterized by the widest spacing and greatest micro-relief. Collapsed hummocks were underlain by a planar or concave down permafrost table, whereas a bowl-shaped permafrost table mirrored the surface relief of the poorly-developed and well-developed hummocks. Segregated ice lenses oriented parallel to the permafrost table and small bodies of pool ice were observed beneath the latter. Statistical relations between the configuration of the permafrost table and hummock relief, long-term observations of active-layer and hummock change, and hummock response to surface manipulation indicate that development of a bowl-shaped permafrost table and near-surface ground ice can thrust soils radially inward and upward causing hummock growth, whereas thaw subsidence can result in outward spreading and collapse. Reaction-wood rings in black spruce growing on hummocky terrain indicate that tree tilting was associated with periods of surface organic accumulation, active-layer thinning, aggradational-ice development and hummock growth. Cessation of reaction wood coincided with a period of active-layer deepening, degradation of ground ice and outward spreading of the hummocks. In subarctic forests, hummock dynamics can be driven by ecological change associated with the fire cycle.

Dendrogeomorphological reconstruction of spatial and temporal thermokarst development in Western Siberia

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key words: thermokarst, tree-ring chronology, thermoabrasion

Thermokarst is a widespread phenomenon in Western Siberia. Due the neighbouring appearance of Thermokarst depressions with a range in diameter of a few metres up to several hundred metres in a small area the

question of their age and their causes arises. Tree-ring chronology analysis of Siberian stone pine (*Pinus sibirica*) affected by the thermokarst depressions and additional geomorphological research and analysis of temperature and precipitation records are used to reconstruct the spatial and temporal development of the depressions as well as possible causes for their appearance.

The study site is located in Western Siberia at the left riverside of the river Synja, a small tributary of the river Ob (65° 03' N, 64° 40' E) at an elevation of approximately 20 m a.s.l. The whole area is underlain by permafrost with an observed annual thaw depth of about 40 to 200 cm dependent on exposition. The silty soil is covered by a 30 cm thick moss layer under a canopy predominated by *Pinus sibirica*. Mean annual air temperature is about -4.8°C, precipitation is about 480 mm a⁻¹. The surface of the waterlogged, bog moss covered depressions is 0.5 to 2.0 m lower than the surroundings. The ground beneath the water body with a depth up to 2 m presumably remains unfrozen during winter whereas the depth of the permafrost table is unknown. The biggest investigated thermokarst depression with a diameter of about 80 m was initiated approximately 500 years ago. Since not yet enough samples from the inner part of the depression could be collected, it cannot definitely be settled if this thermokarst depression is caused by climatic changes or a destruction of vegetation. The derived average rate of radial widening of the depression is about 2.6 to 5.3 cm a⁻¹ between 1500 and 1750, rises up to 10 cm a⁻¹ between 1750 and 1900 and stays stable at a high level of about 16 cm a⁻¹ until today with a maximum rate of widening of 21 cm a⁻¹ between 1900 and 1920. The sample size according to the respective years, supported by the discovery of charcoal, indicates an almost complete destruction of the former vegetation by a fire event between 1822 and 1832. This fire event seems to be the main reason for the disruption of the thermal equilibrium of permafrost followed by a destabilization of the whole area round 1850 and an accelerated widening of thermokarst depression at latest since 1900. Thermoabrasion seems to have an important influence on the widening process since permafrost on the depressions' slopes is receding beneath the waterline. Agafonov et al. (2004) describe an increased rate of thermokarst expansion in the same area for the second half of the 20th century, "depending primarily on increasing precipitation rather than increasing air temperature" (Agafonov et al., 2004: 183). The nearby existence of thermokarst depressions at different stages of development indicates a linkage between local relief and thermokarst by ponding these higher amounts of precipitation. Together with wild fires thermokarst development at this area seems to be controlled by local rather than global phenomena.

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Paleocryogenic formations of alluvial terraces on the north of Western Siberia

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key words: paleocryogenic formations, wedge formations, alluvial terraces, Western Siberia

Paleocryogenic formations doubtless excite the interest in connection with predicted Global Change as indices of paleoclimate. Field research of former cryogenic processes traced in alluvial terraces of Pur-Nadyum region were made in 2004 by teachers and students of Tyumen State Oil and Gas University. Wedge formations and cryoturbations were studied within the lake-alluvial terrace of Late Pleistocene (laQIII¹) with H_{s.l.}=75 to 80 m. Now formation of polygonal ice systems on the alluvial terraces is absent as mid-annual temperature of the ground changes about 0°C and thickness of snow reaches one meter. Frozen cracking is observed mainly on the peat bogs.

Soil profile studied in the sand-pit dug consists of two parts. Lower part is presented by sorted layered sands with inclusions of coarse material; exposed thickness is 6.5 m. Upper part (up to 4 m) consists of loam, loamy sand and sand with paleocryogenic formations. Paleocryogenic formations are presented by four stages of ground wedges, layers of cryoturbations and involutions, postcryogenic textures of sediment. Wedge formations include pseudomorphs of the three generations formed after melting of former ice wedges. Large pseudomorphs have double structure: wide trench (up to 1.5 m) in the upper part and sufficiently narrow wedge (up to 0.5 m) in the lower part. The height of the wedges reaches 4 to 5 m. Texture of pseudomorphs testifies about epigenetic formations of the former ice wedges. Initial-ground and humus wedges are located in the sediment covering pseudomorphs.

There are several interruptions of accumulations traced as cutting of layers sometimes with formations of Fe-Mn crusts and ferrous diffusion sublayers. Involutions and new formations are caused not only by processes of freezing and melting in the active layer but by deep melting of the upper part of permafrost. In the same time direct analogy of degradations of ice wedges with climate warming can be absent because ice melting could be caused by local thermokarst after flooding of the territory. The further detailed research of paleocryogenic formations of West Siberia will allow us to obtain more specific information about cryogenic and postcryogenic processes in the different epochs of Late Quaternary. This research was made in the frame of Integration Programme of RAS No13, part "Fundamental Problems of the Functioning and Evolution of Cryosphere under Global Change".

The distribution of permafrost and periglacial features in the mountain areas of continental Asia

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key words: alpine permafrost, periglacial features, rock glaciers, solifluction, Siberia, Mongolia

Recent studies concerning the kind and distribution of periglacial phenomena of mid-latitude mountains of continental Asia are presented. These are in particular the mountain areas of Western Mongolia, the Russian Altai, and the Verkhoyansk Mountains. The distribution of various periglacial landforms depends on several different factors (e.g. climate, topography, geology and substrate, vegetation, soil water). The distribution of different periglacial landforms in these mountains is compared to the European and Japanese Alps. Periglacial phenomena are generally controlled by cold climatic conditions, where the mean annual air temperature (MAAT) as well as the duration and depth of snow cover are low. Active solifluction (or gelifluction) generally occurs above the timberline as the forests stabilise and protect the ground. The periglacial phenomena can be divided in the humid European Alps into two sub belts: the lower limit of bound solifluction (occurs roughly above the timberline) and the zone of unbound solifluction, dominated by blockfields, patterned ground, and bare bedrock. Active rock glaciers and other indicators of discontinuous permafrost are assumed to be generally in the upper periglacial sub-belt of the European Alps and of similar mountains. The upper limit of the periglacial belt results from steep high mountain topography or from the extent of perennial snow and ice in the higher altitudes (glacial belt). Alpine discontinuous and continuous permafrost is present in all these mountains, but in the humid this zone is very small due to the lower elevation of the snowline (equilibrium line of glaciers = ELA). In the more continental regions of Asia, like the Altai Mountains, this zone is much broader due to high elevation of the ELA. In addition, cryoplanation terraces, patterned ground, and rock glaciers occur in relative low elevations and are also widespread within the forest ecotone. Other periglacial processes, especially solifluction, are determined through existence of soil humidity during the freeze-thaw cycles. Therefore the distribution of these features is smaller than in the humid European Alps and, for example, restricted to northern slopes or higher elevations. Observations and soil temperature measurements in the Altai Mountains show that active rock glaciers and discontinuous

permafrost occur in lower elevation than solifluction features. These results shows, that solifluction landforms in continental Asia depend more on moisture supply than rock glaciers. However, towards the arid regions of Central Asia the lower limit of solifluction landforms, glaciers and the lower timberline are rising in general, whereas the distribution of rock glaciers is even lower than in the humid parts of Europe. The Verkhoyansk Mountains are further north in latitude and therefore even the mountain foreland and in the boreal forest of the Lean-Aldan Basin periglacial features are widespread on continuous permafrost.

Permafrost and periglacial processes in Hurd Peninsula, Livingston Island, Maritime Antarctica

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key words: periglacial processes, rock glacier, permafrost, South Shetland Island, Antarctica

The Hurd Peninsula is located at Livingston Island (South Shetland Island) on a cold maritime climate with the annual isotherm 2°C next to the sea level. The geomorphology of Hurd Peninsula is characterised by the glacial landforms and raised marine features with plains and steep slopes alternation. The periglacial landforms can also be found and periglacial processes are dominant with evidences of intense recent and active periglacial processes. In Hurd Peninsula there are two periglacial morphodynamic environments that has been studied: platform morphodynamic system and slopes morphodynamic system.

The work is based on a geomorphological map, slope transept and vertical electric sounding (VES). The geomorphological mapping of Hurd Peninsula to 1:10000 scale, have created an inventory and genetic classification of periglacial landforms. On the map we have made spatial and altitude analysis of landforms and a periglacial synthetic map and the altitudinal distribution and spatial relations of landforms and processes have been quantified. The landforms association have been used as indicators of periglacial activity and permafrost presence. We have made different transept on slopes with analysis of proximal, distal and medial slopes, wall-deposit ratio, superficial fabric and texture, lithology, piroclast and wet content of fines sediments, active layer depth, orientation and vegetation, and a detailed analysis of Hurd rock glacier. The field work have been completed with vertical electric sounding (VES) and mechanical sounding to analyse the presence of frozen body and the permafrost distribution. Fourteen types of periglacial landforms linked to the gelifluction, gravitational and active layer processes have been inventoried on Hurd Peninsula and permafrost patches have been detected from the upper part of Holocene raised beaches. The continuous permafrost exist up to 25 m a.s.l. on platforms and slopes, where all periglacial processes are related to the permafrost and active layer.

Recent reactivation of an inactive rock glacier (Arolla, Swiss Alps)?

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key words: rock glacier, creep, DC resistivity, Swiss Alps

Comprised between 2460 and 2650 m a.s.l., the west orientated Tsarmin rock glacier is located in the headwater basin of a torrent system. A debris flow, whose starting zone was situated in the lower part of this torrent system, removed a bridge in 1993. The rock glacier front is characterised by an unstable topographical position dominating a steep slope. It furnishes an important amount of debris that accumulates

in a gully. Up to now, there is no historical records of recent debris flow triggered from the rock glacier derived deposits. However, referring to the quantity of available loose sediment and to the slope angle, the occurrence of a debris flow event is likely to expect in a near future (years to decades).

The distribution and characteristic of permafrost were investigated on the whole rock glacier by two complementary DC resistivity techniques. Six vertical electrical soundings (VES) using dissymmetrical Hummel configuration were completed with a longitudinally resistivity mapping at a fixed pseudo-depth of about 6 to 10 m. VES revealed a 5 to 15 meter thick permafrost layer with low specific resistivities ranging from 10 to 120 k Ω m. The resistivity mapping showed that the permafrost layer had not large spatial resistivity variations (apparent resistivities between 10 and 50 k Ω m). A dense colonisation by lichens characterises the blocky surface layer of the rock glacier and attests a relative inactivity during at least several decades. A closer observation however reveals the presence of lichens on non exposed faces of some boulders, that indicates a recent tilting of the blocks. Micro landslides and the presence of fine materials at the surface of the extremely porous superficial blocky layer are other evidences of the current destabilisation of the landform. Six huge blocks drawn by the cartographer on a 1983 map (scale 1:10000) are visible on an orthophoto taken in 1999. The superposition of both documents allowed us to estimate the surface movement of the rock glacier during those 16 years. Between 1983 and 1999, the five blocks located in the middle and upper part of the rock glacier moved on a distance of about 15 meters (mean velocity around 1 m a⁻¹). The sixth block, situated in the lower part, moved around 25 meters (mean velocity around 1.5 m a⁻¹). In 1999, the top of the front was located about 20 meters downstream its 1983 position. As a part of the material certainly collapsed during this period because of the unstable position of the front, it can be assumed that the effective displacement of the rock glacier front was even more important. All these observations points to the probable recent reactivation of a former inactive rock glacier, or at least to a severe acceleration of this landform. It is foreseen to reconstruct the past development of the rock glacier "crisis" with a retrospective photogrammetry analyses of airborne imageries taken in the area during the last 50 years. The monitoring of the future behaviour of the Tsarmin rock glacier has begun in autumn 2004 with the first survey of 40 points by GPS technique.

Towards standardization of techniques and establishment of a global network for monitoring periglacial processes

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key words: periglacial processes, monitoring, global network, Svalbard

Monitoring networks have been developing in periglacial environments, yet so far focusing on the ground thermal regimes. When combined with monitoring of surface processes, such a network reinforces our understanding of climatic controls on periglacial landforms and sediments and further predicting of potential geomorphic hazards. A new project of the IPA working group "Periglacial Landforms, Processes and Climate" aims to standardize techniques and establish a monitoring network for surface processes and associated environmental parameters. To promote the network globally, the monitoring system should involve all of the major parameters, consist of automated, inexpensive and portable instruments and operate under harsh climates. In order to test and compare techniques the project has started with constructing model experimental sites in Adventdalen, Svalbard, where a variety of periglacial landforms develop in a small area and good accessibility encourages participation to the project or visit to the sites. In the summer of 2004, we instrumented an ice-wedge site near Longyearbyen and started monitoring of horizontal and vertical ground movements, crack generation, soil moisture and temperature and snow depth. A rockwall was also instrumented with sensors for recording crack widening (frost wedging), moisture and near-surface temperature. The next plan is to construct experimental sites for periglacial mass movements (frost heave/solifluction and

permafrost creep) in the summer of 2005. The field campaign may further involve processes like frost sorting, frost mound growth and river bank erosion. The monitoring network will be enlarged to circum-Arctic, alpine and Antarctic regions with the cooperation of other IPA and ESF networks.

The role of vegetation in the development of polygon mires

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key words: development of polygon mires, vegetation, macrofossil analysis, ground temperature field, active layer thickness

Vegetation modifies the active layer thickness in permafrost areas due to its influence on the heat exchange between atmosphere and ground. In literature, frost cracking, ice wedge growing, and the development of ice wedge polygons are mostly described as a function of air temperature, physical soil characteristics, and snow thickness. Little attention is paid to the role of vegetation. This study tries to characterize the influence of vegetation on the development of ice wedge polygons. High resolution mapping of two low centre polygons, one high centre polygon, and one initial stage shows a close relationship between vegetation types and singular species on the one hand and site parameters including relief, active layer thickness, pH, and C/N-ratio on the other hand. This relationship is not unilaterally caused by the ecological requirements of the plants, but also by their influence on heat exchange. Investigations of the subsurface temperature field show clear differences in thermal diffusivity of different vegetation types. On the basis of literature data and macrofossil analyses reconstructing the development of a low centre polygon, a model is developed to explain the evolution of polygon mires as a result of frost cracking and the interrelationships between water, vegetation, peat and ice.

Bedrock fracture by ice segregation: 1. the effect of water content

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key words: ice segregation, physical modelling experiment, rock brecciation

A physical modelling experiment on bedrock fracture by ice segregation has simulated the thermal regime associated with **(a)** one-sided freezing in non-permafrost regions and **(b)** two-sided freezing of an active-layer above permafrost. Crack development, rock surface heave, temperature and pore pressure have been monitored in 10 blocks of siliceous chalk 45 cm high during the course of more than 20 freeze-thaw cycles. The location of cracking varies according to the rock thermal regime. With two-sided freezing of the active layer, cracking commenced at a depth determined by the permafrost table, and significant ice segregation occurred during thaw cycles. By contrast, in seasonally frozen rock (1-sided freezing), the location of cracking was more variable and closer to the rock surface. Rock heave and settlement varied according to temperature and moisture content, with the drier rocks showing a sinusoidal seasonal heave pattern - out of phase with that of the wetter rocks - attributed to thermal expansion and contraction. Two modes of rock heave behaviour were observed in the active-layer experiments in the wetter samples of rock. Gradual net heave over the course of several seasonal freezing and thawing cycles is attributed to the gradual development of microcracks. A threshold was then crossed, after which rapid heave commenced during thawing cycles, recording the rapid growth of segregated ice in one or more macrocracks. Over time, ice segregation formed an ice-rich layer of brecciated rock just below the permafrost table, similar to formed in a pilot experiment in the Caen Cold Laboratories and to naturally brecciated ice-rich permafrost in porous rocks in Svalbard and Canada.

Modelling of frost boil systems along the arctic gradient in Alaska

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key words: frost boil, thermo-mechanical model, finite-element, Arctic, vegetation

This research investigates cryoturbation processes in the Arctic tundra, and mechanisms that cause differential frost heave in the active layer. The project explores the influence of seasonal freeze/thaw cycles on the dynamics of frost boils north of the Alaska's Brook Range. The main question to be addressed is, "How changes in surface conditions such as vegetation, snow cover and climate affect the seasonal dynamics of water and heat within frost-boil systems?" A coupled thermo-mechanical model of the frost boil phenomena based on principles of non-smooth thermomechanics will be presented. The soil is treated as a heterogeneous fully saturated mixture of ice, water and soil particles, which obeys laws of elasticity for slow deformations in a porous media. The pore water migration towards the freezing zone and its consequent freezing are the main driving forces of the soil deformation. The model includes the heat and mass conservation laws, continuity equation, the Clapeyron's equation, and an empirical formula, which relates unfrozen water content to temperature. The basic system of equations is reduced to a computationally convenient set of coupled equations for temperature, liquid water pressure, porosity, and the velocity of soil particles in a three-dimensional domain with an assumption of cylindrical symmetry. A finite element method and an implicit scheme in time are utilized to construct a non-linear system of equations, which are solved iteratively. To investigate stability of a predicted differential frost heave, we also study sensitivity of the numerical model to thermo-rheological properties of the soil and other physical constrains. Modelling of frost-boil systems along the Arctic gradient and reaction of them to changes in climate, in the active layer and in vegetation cover is performed by specifying boundary and initial conditions and soil properties. Using this model we explore interaction between vegetation cover and thermo-mechanical processes in the Arctic tundra.

Soil stripe influence on active layer dynamics on Alaska's North Slope

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key words: active layer, soil, patterned ground, Alaska, energy balance

Periglacial landforms are ubiquitous in the Alaskan Arctic. Within a small catchment in the northern foothills of the Brooks Range, several types of ground patterning at different scales may be found whose distribution is correlated with topography. Soil stripes and unsorted frost circles cover the crests and shoulders of the slopes, where drainage leads to drier soils and greater thaw depths. The pattern at the surface consists of vegetation differences and slight differences in topography perpendicular to the slope. These vegetation differences affect the spatial distribution of active layer bulk apparent thermal diffusivity. The effect of differences in thermal diffusivity is to change the active layer depth distribution and heat transfer to the permafrost. These changes in turn have the potential to affect the downslope routing of water.

We compare aerial photos and measured topography from the centimetre to kilometre scale to define the region characterized by soil striping, and the differences in vegetation that characterize the mesic and xeric regions. Sensor profiles were installed in the soils defining the soil stripes. Three-year temperature and moisture profiles in the shallow subsurface of soil stripes show small differences in thaw depth heat transfer.

The drier stripes are warmer in summer and colder in winter than the wetter sedge-dominated stripes. The greater accumulation of organics outweighs the effect of moisture on the thermal diffusivity of near-surface

layers, leading to shallower penetration of the surface heat flux. Active layer temperatures in the dry soil stripes are over 3°C and up to 10°C warmer throughout the profile at the warmest time of summer, leading to an undulating frost table at a meter to decameter scale.

Pingos in the north-western part of Wedel Jarlsberg Land (Spitsbergen)

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key words: pingo, permafrost, Spitsbergen, Svalbard Archipelago

Pingos are ice-mineral hummocks created due to cryogenic processes in the permafrost area. They assemble mainly in large valleys of central Spitsbergen. Investigations were carried out in Dunder Valley getting to the Greenlandic Sea and in Chamberlin Valley connected with the Recherche Fiord. Both genetic types and the Mackenzie Delta type with the closed water circulation system are found.

Dunder Valley is a wide depression on a fault in the zone of the monocline of the Precambrian Hecla Hoek formation. The glaciers in the vicinity of Dunder Valley affect the hydrological system determining supply and circulation of waters in the permafrost. Pingos are of the domed cone shape of a relative height about 9 to 40 m and a diameter about 200 m at the foot. In Chamberlin Valley pingos of both Greenland and Mackenzi Delta types are found. The former, similar to those of Dunder Valley, formed not in the valley axis, but at the foot of the mountain massif slopes. Pingos belonging to the form of closed system occur within the accumulation bottom of Chamberlin Valley at different heights and in a large distance from the tidal plain and the contemporarily formed delta. The pingos were found to have been formed in the Quaternary deposits at various heights and are similar to the levels of raised marine terraces. The morphological features of the pingo of closed system as well as compact vegetation indicate that they are forms of different ages and in different stage of degradation. Pingos in Dunder Valley and Chamberlin Valley are in different stages of development and contemporary activity. Their arrangement, depending on geological structure and morphology, points to the relation with migration towards the surface of waters from the supply area which are firn fields of contemporary subpolar glaciers and permafrost penetration into marine deposits filling the sedimentation basins (deltas in bays) due to glacioisostatic movements. The role of climate, on which dynamics of geomorphological processes, evolution of permafrost and glaciers depend, is unquestionable. The reaction of permafrost in the Atlantic sector of periglacial zone to the contemporary global and regional climate warming is differentiation of development dynamics and active layer thickness, greater activity of solifluction, thermoerosion and thermokarst. In morphology it is evidenced by degradation of various forms of ground ice like ice wedges and palsas, formed on both mineral grounds and peatbogs. Contemporary activity and degradation of pingos is one of the most important indicators of permafrost reaction to global and regional climate warming. The paper realization was supported by the grant No PBZ-KBN-108/P04/2004 - by the Committee Scientific Research.

Permafrost distribution in limestone talus slopes located near the lower limit of alpine discontinuous permafrost (Swiss Alps)

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key words: talus slope, permafrost distribution, air circulation

The permafrost distribution was studied in eight limestone talus slopes in the Grand Chavalard area (Western Swiss Alps, 46° 11' N; 7° 07' E). The prospected landforms are oriented to the north (NW to NE) between

2300 and 2600 m a.s.l., that is at the lower limit of alpine discontinuous permafrost. The grain size is in most cases lower than 20 cm. DC resistivity prospecting was carried out on the different slopes. 14 vertical electrical soundings using dissymmetrical Hummel configuration were completed with 8 longitudinally resistivity mapping at a fixed pseudo-depth of about 6 to 10 m.

The obtained results strongly differ from one talus to another one. Resistivity values ranging from 10 to 15 k Ω m were measured on probable unfrozen loose sediments, while bedrock shows values between 0.5 and 1 k Ω m. These relatively high resistivities are explained by the high porosity of a limestone scree slope - because of karstic dissolution, the matrix is indeed reduced - and make the interpretation of resistive layers sometimes difficult. Much higher values were measured on two talus slopes that dominate in both case an active/inactive rock glacier. In the first case, resistivity values reached 2000 k Ω m in the upper part of the slope and decreased downstream (1200 k Ω m). This probably points to the presence of a buried ice patch under a 2.5 m superficial blocky layer. In the second case, high resistivities were evidenced in the lower part of the slope (670 k Ω m), whereas lower values were measured in the upper part (400 k Ω m). An outcrop of ice 1.5 m below the ground surface seems to prove that these high resistivities are related to the ice content and not to porosity. A marked contrast in electrical resistivities between the upper and lower part of the talus was evidenced on the three last prospected landforms. The low values measured in the upper parts (15 to 20 k Ω m) probably point to the presence of unfrozen sediments, while resistivities ranging from 50 to 150 k Ω m indicate that permafrost is certainly present in the lower part of the slopes.

Other studies have already demonstrated that permafrost seems to be confined to the lower part of some talus slopes. It has been demonstrated that the ventilation system evidenced in many scree slopes located far under and around the lower limit of discontinuous permafrost plays an important role in the occurrence of permafrost. This process is probably active in some of the landforms prospected in this study and should even be very efficient according to the high porosity related to limestone sediments. This has however to be validated by new observations and new BTS measurements.

Rock moisture fluctuations on Svalbard: implications for cryogenic weathering

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key words: weathering, Svalbard, rock moisture content

Rock moisture content has been monitored all year-around in Longyearbyen over the period 2001-2003 in order to better understand the impact of rock moisture content on cryogenic weathering in a high latitude environment. Rock moisture content is monitored by daily weighing of rock tablets exposed to the natural environment. Complementary rock moisture content measurements were carried out in the field during the determinant snowmelt periods. Conclusions are drawn about the impact of lithology, block size and weather conditions on moisture content values. In most cases, the major part of the total water exchanges take place within the outermost part of the blocks.

Large and quick variations in moisture content are common. They are linked to weather changes during most of the year. But winters are characterized by a progressive drying of the rock samples, due to a sublimation process. Rocks rarely reach high saturation values, and when it is the case, this happens in the fall and in the spring.

Temperatures are monitored in blocks, and in a sandstone rockwall at depths of 40 cm, 10 cm, 1 cm and at the rock surface. Combining moisture content and temperature data allow to underline that conditions favorable to cryogenic weathering (i.e. freezing of the rock when its moisture content is high) are met only rarely. But when these conditions are met, frost action can be very aggressive, because of the high rock moisture content, the quick cooling or the extended duration of freezing periods. A regular evaluation of rock weathering (before cracking, weight loss or any other visible change) is assessed for rock specimens exposed to the natural environment using as a criteria the variations of their dynamic Young's modulus.

Geophysical and sedimentological investigations of relict and active open system pingos in Wales and Svalbard

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key words: pingo, internal structure, geophysics, Last Glacial, Svalbard

Geophysical and sedimentological investigations of relict Pleistocene ground-ice mounds at several sites in south-west Wales are described. Although previously interpreted as the remains of open system pingos or mineral palsas, uncertainties regarding the precise mechanisms for the origin of many of these landforms remain. Electrical resistivity surveys, drilling and trenching at selected sites have provided key information on the internal structure of these landforms, critical for understanding the processes responsible for their origins and development. Since for pingo formation to have occurred, a source of groundwater to supply the growing ice core would have been critical, particular attention has been paid to the current hydro-geological regime.

At Llanpumsaint, although the bedrock is characterised by low permeability, numerous springs and stream issues are found in and around these relict landforms. Our interpretation is that the hydrogeology of the area is controlled by groundwater percolating through fracture zones associated with faults, or units of more permeable sandstone within the dominant mudstone lithology. If the current groundwater regime approximates that of the Last Glacial Stage, then the subsurface flow of water would at that time have been impeded by permafrost. Under these conditions, subsurface injection ice is likely to have developed, resulting in pingo growth. Drilling and geophysical investigations at this site suggest that ground ice grew at the interface between glacio-lacustrine clays and overlying silts and gravels.

We also present the results of ground penetrating radar investigations of the internal structure of fault-guided open system pingos in Adventdalen, Svalbard to establish the geometry of the sub-pingo ground ice and its likely mode of formation. These data are critical to inform accurate interpretation of relict landforms. Pingos in Svalbard were chosen as possible modern analogues due to similarities between the current Svalbard environment and that of Wales during the Last Glacial Stage when ice margins overlapped the permafrost zone. The radar surveys suggest that the internal structure of pingo ice is characterised, at least in its uppermost zone, by alternating bands of ice and sediments. No clear evidence for the presence of large bodies of massive ice was found, although relatively pure ice bodies probably exist at depth, beyond the penetration of the radar signal. Geochemical analyses of water from a spring on the surface of Innerhytte Pingo indicates derivation from a deep groundwater source.

Sporadic permafrost distribution in Shikaribetsu mountains, northern Japan

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key words: sporadic permafrost, block slopes, DC resistivity imaging, vegetation mapping, ground ice

DC resistivity imaging and vegetation mapping revealed the special distribution of sporadic permafrost preserved in coarse block slopes. The results of DC resistivity soundings in three transects showed that the permafrost is concentrated in the lower part of block slope and valley bottom, where Sphagnum spp. dominates in the forest floor. Vegetation was categorized into four types based on the tree species, ground covers and the ground surface type. Among them, the *Picea glehnii* forest type with ground cover of Sphagnum spp. is considered as an indicative vegetation of permafrost, and it spreads in the lower part of the block slope and valley bottom. Such a vegetation pattern indicates that the permafrost is restricted to the lower part of the slope and valley bottom, where ground water flow (i.e. snow-melt water and percolating rain water) is expected to occur. In consideration of the previous results (Sawada et al., 2003; Sawada 2003), which revealed that the ground ice is mainly formed by refreezing of the snow melt water in the voids of coarse blocks, the distribution pattern of extra-zonal permafrost in the block slope can be restricted as a result of ground water freezing within the voids of coarse active layer.

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Dating problems of palsas

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key words: frost heave, ecological condition, peat formation, interpretation of datings

Dating problems of palsas Frozen peat of palsa cores can be sampled and studied in many different ways: macro remains of peat forming plans can be identified, pollen stratigraphy can be analysed and material can be dated throughout the core. If we like to know the date of the palsa formation these studies do not give us the answer. The dating of palsa formation should be based on the knowledge of the effects of the uplift on the ecological conditions and changes in the peat formation caused by the rise of the hummock. On the wet mire surface dominating plants forming the peat are: Sphagnum, Carex and Eriophorum species. When frost uplifts a part of mire surface that part dries and the ecological conditions change totally. Former dominating plants will die and other plants take over the dry surface on the frozen core of a new palsa. The small hummock is covered by shrubs (Ericales), mosses (Bryales), lichens and cloudberry (*Rubus chamaemorus*). They form xerophilic peat and the peat formation decreases. The dating of palsa formation should be based on the change of peat formation. By digging out the contact of these two peat layers and sampling peat below and above the contact we can date the rise of the palsa. If there is a great difference between these two dates then the reason may be abrasion of palsa surface by wind. Most of dated palsas in the Nordic countries are 1000 to 3000 years old but also very young features (ca. 100 years old) have been found. Some detailed examples of dated palsas will be presented and discussed.

Mountain permafrost mapping of Pyrenees

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key words: permafrost map, mountain permafrost, periglacial morphodynamic, Pyrenees

In the Pyrenees the permafrost occurrence is known from eighty years when it began the study of active rock glaciers. The map includes glaciological and periglacial information related to the permafrost presence to regional scale. The map is based on a combination of field data, published and unpublished sources and model-based data. The map is compiled from a limited amount of direct field data. These data have been supplemented with air climate data and other geomorphological data such as periglacial processes and landforms considered to be indicative of permafrost occurrence. The map is built with detailed information of small portions of Pyrenees high mountain, the Argualas-Infierno, Vignemale, Monte Perdido, Posets, Maladeta and Bessiberri massifs, but the data have a high representativeness. We have used the cited massifs as "key areas", with detailed survey and from which the information is extrapolated to the whole of the Pyrenees high mountain. Field data from different massifs are BTS measurements, ground temperature measurements, detailed geomorphological maps and vertical electric sounding.

The modelling techniques are based on the approach initiated by Haeblerli and Swiss researchers. Permafrost distribution in the Pyrenees is based on the model relying on a digital terrain model and information on slope, altitude, mean annual air temperature data and potential direct solar radiation. The output map contains information on glaciological and periglacial features (glaciers, ice-patch and rock glaciers) and four terrain categories, probable permafrost, possible discontinuous permafrost, possible isolated patched permafrost and no permafrost.

The permafrost map of Pyrenees is a tentative work that shows the current state of knowledge on permafrost in Pyrenees. The map tries to be useful and meaningful for the periglacial knowledge in itself, and for terrain analysis on sensitivity to change, human and natural, as part of environmental protection, specially at Pyrenean Natural Protected Areas.

Comprehensive model of frost boils and Earth hummocks formation

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key words: patterned grounds, aggradational ice, intermediate layer, perennial frost heave

Frost boils and earth hummocks widely occur in the permafrost region. Features of the first type generally occupy the northern part of the permafrost region; of the second type occupy its middle part. In some areas they occur simultaneously. Formations of frost boils and hummocks have been described in general terms of cryoturbations - a complex of seasonally interchanging processes of frost heave and thaw settlement. Most of properties of frost boils and earth hummocks such the bowl shape of boils, a continuous organic accumulation at the periphery of the active layer, and risen elevation of boils and hummocks above surrounding areas cannot be explained by seasonal reversible changes. Also frost boils and earth hummocks occur in the permafrost region; all existing hypotheses do not explain the role of permafrost in their formation.

Frost boils and inter-boil areas are integrated into one well-organized and long-term functioning system linked to dynamics of the upper permafrost zone. Formation of this system starts with occurrence of vegetation in inter-boil areas in shallow thermal cracks limited by the thickness of the active layer. Such cracks have been described on numerous occasions in Russian permafrost literature. Vegetation and products of its decomposition in the inter-boil area change the thermal properties of the active layer which depth steadily decreases. It triggers the intermediate layer formation with accumulation of aggradational ice and perennial frost heave beneath vegetated inter-boils and in some extent under boils. Perennial frost heave related to accumulation of aggradational ice forms bowl shape of frost boils and is responsible for the rising surface of frost boils. Inter-boil areas are a source of organic, which moves under boils along cracks of post-cryogenic structure due to formation and thawing of ice at the border with permafrost. Solid particles of organic accumulate at the bottom of the active layer. Dissolved organic moves upward to freezing front in winter or to drying boil surface in summer. With time in many cases, layer of organic covers completely the periphery of boils in others it is incomplete but always adjusts to its source - the vegetated inter-boils area.

Vegetation development on the boil surface and readjustment of the upper permafrost leads to the development of hummocks. A hummock is formed from a frost boil by cumulative perennial frost heave due to long-term accumulation of aggradational ice in the intermediate layer of permafrost which replaces the a part of the active layer in response to vegetation development on the boil surface. Loss of vegetation on the hummock surface leads thawing of the aggradational ice and to substantial thaw settlement. Differential accumulation of aggradational ice and formation of the intermediate layer of uneven thickness in upper permafrost play the important role in formation of different patterned grounds.

Permafrost development and periglacial phenomena on the flood plain of the Lena River (Central Yakutia)

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key words: Central Yakutia, flood plain, permafrost development, ice and soil wedges, permafrost temperature

Knowledge of recent periglacial phenomena in permafrost areas is significant for an effective use of fossil analogues in present day and former periglacial regions for paleoclimate reconstruction. This poster presents data on the permafrost formation and related periglacial phenomena on the flood plain of the Lena River 50 to 120 km north of Yakutsk.

Central Yakutia is characterised by continuous permafrost and a boreal taiga as zonal vegetation. In addition, this region is quite specific due to extremely continental climate, so that steppe and salt affected soils are widely distributed. The Lena River in the study area forms a braided-river system. Its hydrograph shows an extreme runoff peak during spring snow melt and break-up, as well as some lower peaks during summer rainstorms. A lower, middle and upper level of the flood plain with heights of up to 3.5 m, 4 to 8 m and 8 to 13 m above normal water level, respectively,

can be classified. Each geomorphologic element of the flood plain is characterised by a specific flooding regime, hydrological and thermal conditions, vegetation, sedimentary processes, soil formation and permafrost development.

Based on studies of over 30 exposures, test pits and bore holes we characterise the evolution of sediment accumulation, pedogenesis and permafrost formation on different landforms of the flood plain. A great deal of attention was directed on the distribution and character of ice wedges and soil wedges as well related polygonal frost crack systems. Temperature measurements carried out in five bore holes with depth of more than 25 m show the relations between local environmental conditions, cryogenic structure of deposits and permafrost temperature.

Trenching non-sorted stripes to examine their physical and structural characteristics, Pituffik, Greenland

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key words: non-sorted stripes, cryoturbation, solifluction, gelifluction

Non-sorted stripes are pervasive features in High Arctic environments; however, their formative mechanism is not well understood. They form on slopes and transition continuously to non-sorted nets on level terrain. At our study site near Pituffik (Thule Air Base), Greenland (76° N, 68° W), we excavated an 18 m long by 2 m wide trench to the base of the active layer (≈ 1 m) across a series of stripes for detailed study of their texture, mineralogy, chemistry, and structure. In addition, soil moisture, temperature, and movement are monitored continuously. The stripes consist of alternating barren ridges with vegetated troughs. The barren ridges are ≈ 2 to 3 m wide separated by ≈ 0.5 m vegetated troughs. The troughs function as water pathways, contain well-sorted sands with narrow vertical cobble lineations, and provide a relatively stable environment favorable for plant growth. The barren ridges are unsorted, contain abundant silts, and are thixotropic; this zone is frost susceptible. Flow features and folds below the barren ridges entrain organic matter to depth. Our first data set provides new insights into the characteristics and dynamics of non-sorted patterned ground.

Extra-zonal permafrost and ground air circulation at a slope along the Kanoko-dam, Oketo town, Hokkaido, Japan

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key words: extra-zonal permafrost, wind-hole, ground air circulation, wind speed, Hokkaido

Extra-zonal permafrost was observed at several sites in non-alpine regions at altitudes below 1000 m a.s.l. in Hokkaido, Japan. Monitoring of ground temperature was conducted at the lower part of a slope along the Kanoko-dam, Oketo, Hokkaido. Mean annual air temperature there is around 5°C. Ground ice was discovered at the slope when it was artificially changed at the time of a road construction in 1970. Though permafrost existence was confirmed in 1987, it melted at least by 1990. However, permafrost occurred again in 2001 when it was cool. It survived at least by the fall of 2004. There are several wind-holes on the lower part of the slope which consists of porous materials. While cold air comes out from the wind-holes during warm period, cold outside air enters from the holes inside of the slope during cold period. The wind speed at the wind-hole is controlled by the difference between air temperature and average temperature of the slope inside. The larger the difference is, the higher the wind speed is. Ground air circulation stops when the air temperature is equal to the average temperature of the slope inside. So-called chimney effect is verified by the wind observation in both warm and cold periods.

Turf hummocks along a climatic gradient in Arctic Canada: Characteristics and development

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key words: hummocks, patterned ground, genesis, arctic, Canada

Turf hummocks were studied in three bioclimatic zones ranging from the coldest on Prince Patrick Island (Zone A) through Banks Island (Zone B) to the warmest on Ellesmere Island (Zone C). These hummocks generally occur on 5 to 20% slopes and are 11 to 40 cm high and 18 to 60 cm in diameter. The depth of thaw is approximately 30 to 50 cm and the soils are dominantly silt loam in texture. The vegetation cover on these turf hummocks is dominantly mosses and lichens with *Luzula* sp. on Prince Patrick Island and *Dryas integrifolia* and *Cassiope tetragona* on Banks and Ellesmere islands. These turf hummocks differ from earth hummocks and peat hummocks in that their entire development depends on the capture of eolian materials by the vegetation growing on the hummocks. Their internal morphology reveals multiple buried, organic-rich layers, representing former hummock surfaces. The intervening soil horizons also contain a high amount of well-decomposed organic matter that is dispersed uniformly throughout the horizons. Radiocarbon dates for the buried organic layers suggest that a minimum of 1200 to 2000 years is required for the turf hummocks to develop to their present stage. Data obtained from the multiple organic-rich layers suggest that each former hummock surface was stable for 100 years or more. This paper provides both information about the internal and external morphology and thermal properties of the turf hummocks and a model for their development.

Towards a permafrost map of the Dry Central Andes: A comparison of mapping and modelling techniques for creeping mountain permafrost distribution in the Cordón del Plata, Cordillera Frontal, Mendoza, Argentina

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key words: rock glacier, Central Andes, Argentina, Andean permafrost, mapping and modelling

Creeping permafrost as expressed by rock glaciers is of particular importance in the Central Andes due to its ice content and cryogenic indicator function. This study presents an inventory of the periglacial and glacial environment of the Cordón del Plata (Andes of Mendoza, Argentina; 32° 40' to 33° 24' S, 69° 45' to 69° 12' W), and compares traditional mapping with statistical modelling techniques at a regional scale.

The periglacial environment of the study area comprises 1658 km² between the lower limit of 3450 m a.s.l. and the highest summit elevation of 6310 m a.s.l. at Cerro El Plata. This area includes the creeping permafrost with over 380 principal bodies of approximately 119 km². Creeping and high-elevation "quasi-continuous" permafrost are distinguished since these types adapt best to regional scales and visualization, and since technical limitations make a discrimination of quasi-continuous and other types of high-mountain permafrost very difficult. Degraded permafrost may be identified through the activation and enlargement of old thermokarst forms. Permafrost with very poor ice-content is also present in the study area.

Rock glaciers, thermokarst and glaciers were mapped from Landsat imagery, and regional permafrost distribution inferred from direct and indirect field observations including the use of geomorphological and geophysical methods. Furthermore, a predictive statistical model of rock glacier and glacier distribution that has been fitted to the entire Andes of Mendoza and Santiago (Argentina/Chile) was applied to the study area and is compared to the mapping results. The model reproduces very well the "rock glacier pattern" found in the Cordón del Plata, although this area is just a marginal part of the training area of the model. A comparison with the regional glacier inventory of 1981 also shows that predictive statistical modelling can efficiently produce satisfactory results in the assessment of permafrost distribution.

Cryogenic landslides as a source of natural lateral heterogeneity of the Yamal typical tundra

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key words: cryogenic landslides, lateral structure of the geosystem, granulometric composition, nitrogen and humus content in soils, willow shrubs

Natural lateral structure heterogeneity of the tundra geosystems appears due to exogenous geological processes. In typical tundra the most destructive process is landsliding. This metachronous process changes the surface of the upper Pleistocene marine plain, forming a specific relief of flat concave sliding surfaces alternating with lumpy sliding bodies. Soil block sliding outcrops the frozen salted strata changing the former geochemical conditions: plants, soils, water and the active layer become enriched in many chemical elements. Periodic landsliding results in burial of plant and organic layers and in permafrost depth changes.

Our new data shows, that slopes with landslides have high texture heterogeneity of the active layer. The hill tops and other automorphic surfaces of the upper Pleistocene marine plains are rather homogeneous in granulometric composition of the active layer: coarse silt and silty sand dominate (70 to 80%) through the whole cross-section. Landslide slopes are characterized by 4 texture groups separated by sand and clay ratio: **(1)** clay (>75 to 80%); **(2)** clay > sand (60 to 75%); **(3)** clay \approx sand (40 to 60%); **(4)** sand > clay (60 to 75%). The first group occurs on the young landsliding surfaces, while the last one is mostly found within the ancient sliding bodies. Vertical heterogeneity of the active layer soils is also high: 3 to 4 granulometric groups can be observed cross 1-meter deep-layer.

The nitrogen and humus content in soils of landslide area also shows high variability compared to background. The background soils of hill tops are characterized by weak acidity (pH=5.5 to 5.8), low nitrogen content (0.08 to 2.3%), and very low saturation with bases (4.5%). In 7 to 8 years after landslip the young shearing surfaces are still bare of soil; they show surface salt evaporates and are fragmentary covered by Gramineae and chamomile. Desalination of the frozen marine sediments involved in active layer causes soil saturation with bases (close to 100%, except for the top 10 cm to 50 to 60%) and alkalization (pH=7.5 to 8). Organic carbon content here is lower than that of background (0.2 to 0.7%), while nitrogen quantity is almost similar. In ancient landslides (over 1000 years old) the soil cover restores. Soils reduce both in pH (down to 6.5) and in base saturation (to 24.5%) that verifies gradual desalination of the active layer approximating background conditions. High willow shrubs covering ancient landslides increase organic carbon and nitrogen content in soil by 2 times on the average, thus improving its productivity. The latter observation corresponds completely with the data of the American scientists.

Surface displacements and surface age estimates for creeping slope landforms in Northern and Eastern Iceland using digital photogrammetry

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key words: surface displacement, digital photogrammetry, rock glaciers, surface age estimates, Iceland

In this study, three areas of different active slope processes in Northern and Eastern Iceland are investigated. Surface displacement of some glacier derived rock glaciers and a debris covered glacier in the Hólar area, a moving debris lobe close to Siglufjörður and a sheet flow at Seyðisfjörður are measured. The displacement fields are obtained by cross-correlation matching of multi-temporal orthophotos. Orthophotos are generated using a Z/I-Imaging digital photogrammetric workstation and various series of air photos from 1964 to 1994. Cross-correlation matching is done with the CIAS-software. The results are analyzed and used for rough surface age estimates. In addition, type and cause of movement are discussed. The velocity of debris covered glacier and the rock glaciers in the Hólar area average from 0.14 to 0.67 m a⁻¹. While the debris lobe at Almenningstöf close to Siglufjörður show an average displacement of 0.19 m a⁻¹ with a maximum value of 0.84 m a⁻¹. The displacements at Almenningstöf agree well with displacement surveyed by GPS by the Icelandic Road Authorities. The measured velocities in Seyðisfjörður, although using air

photos taken 30 years apart, turned out to be too small taking in account the accuracy of the method. Based on the surface age results all landforms are suggested to have developed during the late Holocene cooling period, with ages from around 1500 via 3000 to around 5000 years for the different landforms. This surface age estimates coincide with data from nearby moraine dating and Holocene climatic development.

Chapter 5

Session 4 - Permafrost as Analog for Extraterrestrial Systems

Session Conveners: Dirk Wagner, David Gilichinsky

Martian cryogenic conditions

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key words: Mars, permafrost, polygonal pattern, high-mineralized solution, thermal inertia, albedo

The adopted ideas about thickness of Martian permafrost in a view of the latest data are generalized and corrected. In our opinion, the thickness of Martian permafrost could change from 450 m in equatorial regions to 1500 m in high latitude's areas. This is based on the presence within Martian permafrost of high-mineralized solutions, the influence of the overlying soil layer pressure on the temperature and, hence, the beginning of freezing of water and the thermal resistance of the surface layer of dehydrated regolith. Application of a crater method allows to estimate the position of the top border of ice-content. The bottom of the permafrost is defined on the base of calculation, which has taken into account of above-mentioned corrections. The calculated thickness of permafrost is much less as was estimated earlier.

The report represent the Martian average atmosphere temperatures and their amplitudes, temperature conditions on a surface (mid-annual, daily and seasonal average temperatures and their amplitudes), values of albedo and thermal inertia, which are characterizing by temporary and spatial variability and have latitude distribution and altitude variability. The joint analysis of thermo-physical and optical characteristics allows to zone a surface of Mars. This analysis is based on the data of "The Mars Climate Database". The properties of the Martian upper layer received by a number of remote methods from orbital space vehicle and directly by Martian landed devices. It let us to make a conclusion about structure of upper layer. We divide this layer in two differ stratums. The first one is the fine, dust, loose sediments, characterized by andesite composition, high value of albedo, high porosity and low heat conductivity. The second one is from the medium size coarse-grained, dense, consolidated sediments to the bedrocks, characterized basalt composition, low value of albedo, low porosity and high heat conductivity. Our mathematical modelling shows, that the first layer, presented by the dry regolith, which possess greater thermal resistance, essentially reduces influence of temperature fluctuations on the surface and decrease the thickness of the layer of zero annual amplitudes. It is possible to analyze and to interpret the rocks of the Martian second subsurface layer due to the our experimental researches of some thermo-physical and mechanical properties of terrestrial sample-analogues which were carried out in a wide range of negative temperatures (from -60 to -120°C).

Volcano permafrost - terrestrial model for extraterrestrial systems

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key words: mountain permafrost, volcanoes, Mars surface ground analogue

Volcanoes on Mars are known a long time ago and, according the NASA point, one way to have liquid water on Mars at shallow depths would be through subglacial volcanism. The images of volcanic cones near polar caps from ESA Mars Express mission not excludes that such volcano-ice interactions could be going on beneath the polar caps of Mars today, or even within the adjacent permafrost around the margins of the ice caps. This is why one of the Earth's models, close to extraterrestrial environment, represented by the interaction between active volcanoes, ice and permafrost.

Kluchevskaya volcano group on Kamchatka peninsula is one of the largest modern regions, where in high-mountainous zone the permafrost and glaciers are widespread parallel with volcanic activity. This volcanic area characterized by high temperatures (up to 1400°C in lava), and near-surface temperatures are about 50 to 150°C. The dross-ash-gaseous volcanic piles (or huge clouds), formed during volcanic eruptions, are the powerful natural abiogenic "chemical reactor", synthesizes the main biological combinations: amino acids, hydrocarbons, etc. The total area of glaciations on Kamchatka is ~ 900 km². Glaciers near Ploskii Tolbachik volcano are distributed higher then 1400 to 1500 m with average thickness 30 to 40 m. Probably, most of glaciers which are distributed higher then 3000 m are cold type. Basal melting possible only in caldera area where the ice have maximum thickness, more than 120 m. On the base of air temperatures only, it was calculated that continuous permafrost is usually spread above 1800 to 2000 m and has thickness of 50 to 400 m. In Kamchatka river valley and below 900 m only seasonal freezing up to 2 m depth is possible. Mean annual ground temperature (T) in this zone is from +5 to 0°C. From 900 to 1100 m asl permafrost have sporadic distribution with T~ 0°C and thickness up to 60 m. Higher (1200 to 3000 m) permafrost have discontinuous and continuous distribution, T varied -2 to -8°C and thickness up to 350 to 400 m. At the top of volcanoes (4000 m asl) T=-15°C. Seasonal thawing layer thickness varied from 2 m at 900 m to 0.4 m at 2500 m. Some frozen tephra is diacryogenic type that has been freeze very rapidly (1 to 2 years) after been deposited during the eruption. Polygonal structures in volcanic deposits was found at altitudes 1100 to 1500 m. They have size about 10 to 30 m in diameter, and some of them have round shape. The main type of ground is the young volcanic deposits: tephra (cinder (0.5 to 10 mm in diameter), ash (0.01 to 0.5 mm)) and basalt lava flows, which may be considered as an analog of Martian surface ground. The main cryostructures are massive and ataxic, ice content varied 20 to 40% (up to 80%). Tephra is characterized by ph=6 to 8 and a very low TOC<0.4%.

The thermal-physical properties of volcanic tephra have been estimated in laboratory. This deposits have very low ability to heat transfer and high porosity:

1. scoria

$$\lambda_T = \frac{0.27(W = 10\%) - 0.44(W = 45\%)W}{m\kappa}, \lambda_f = \frac{0.34(W = 10\%) - 0.66(W = 45\%)W}{m\kappa} \quad (5.1)$$

2. ash

$$\lambda_T = \frac{0.30(W = 21\%) - 0.58(W = 43\%)W}{m\kappa}, \lambda_f = \frac{0.42(W = 21\%) - 0.82(W = 43\%)W}{m\kappa} \quad (5.2)$$

Due to this, it can preserve permafrost and buried ice from melting or sublimation. It is actual for harsh Martian conditions. From point of visual similarity, similar composition and properties, volcanic tephra is one of terrestrial model for Martian surface.

Geological interpretation of global map of epithermal neutron flux from Mars based on the search of correlation with different factors

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key words: Mars Odyssey, HEND, water on Mars, Martian permafrost

Global map of neutron flux from Mars according to orbital measurements on HEND onboard Mars Odyssey presents the most important and interesting information about hydrosphere and cryosphere of Red planet for today. This map allows us to understand role of water and permafrost in driving Martian geology. There are two main contributions of neutron measurements for present Mars science:

1. the map of epithermal neutrons displays two poleward regions of strong depressions of the leakage flux. The subsurface layer of these regions may contain tens of % of water ice by weight.
2. There are two regions at equatorial latitudes (Arabia and Memnonia) which have a water rich layer with about 10 to 19% of water covered by a dry layer of soil.

The possibility of preservation of water in equatorial regions under the present climatic conditions is probably the most important contribution of neutron measurements by HEND. Again we come back to a fundamental contradiction between the observed fluvial geomorphic records and current Martian climate, which does not allow water to exist on shallow subsurface due to present atmospheric temperature and pressure. To understand the origin of water in Arabia and Memnonia it is necessary to find out factors which control water maintenance. So as the first step of geological interpretation of HEND data we looked for correlation between neutron flux and such factors like Martian geology (age and type of rock), relief characteristics (altitude, exposition of a slope, inclination of a surface, roughness etc.), thickness of unfrozen layer, different characteristics of upper regolith layer (thermal inertia, albedo) and concentration of different chemicals. In this report we speculate that neutron measurements from HEND for the first time say that Mars is a cold water-rich planet with permafrost and present first results of our geological interpretation of HEND data based on correlation and factor analyses.

Cryopegs - The only opportunity for liquid water on Mars

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key words: permafrost, cryopegs, microorganisms, ecosystem, exo/astrobiology

Because of the distance from the Sun, the planet Mars is a cryogenic type at ultra low temperatures with the possibility of free water existing within subsurface permafrost only in the presence of high solute content. Therefore, it is important to find the terrestrial analogue of such aquatic system and test it on the presence of viable microorganisms. Most of the studied saline aquatic ecosystems on the Earth are open water reservoirs characterized by temperatures above zero. The only exception is the Antarctic lake Don Juan Pond, which has temperatures permanently below zero and due to 45% concentration of CaCl₂ salts, freezes only at -48°C. The largest Antarctic subglacial lake Vostok, at a depth of 4 km and an age of about 400000 years, also has temperatures above 0°C. The bottom layers of some Antarctic surface lakes with a permanent ice cover have temperatures below 0°C and salinity up to 200 g L⁻¹, but they are not impermeable to microbial penetration from the outside. At the same time, the Quaternary transgression and regressions of the Polar Ocean in the high Arctic against a cold climatic background favored the formation of unfrozen ground that is perennially cryotic. In these marine layers, usually defined as cryopegs, freezing is prevented by freezing-point depression due to the dissolved-solids content of the pore water. In some cases, because of pressure caused by freezing, the cryometamorphism of water saturated bottom sediments was accompanied by a freezing out of salts in the water. This process formed marine cryopegs - overcooled brines embedded within permanently frozen strata and defined as lenses of "cryosaline water". They are the only hydrological systems on the Earth with permanent subzero temperatures, high salinity and isolation from external factors throughout their geologic history. Such isolated lenses (0.5 to 5 m thick, 3 to 5 m wide) of sodium-chloride (250 g L⁻¹) brines remain liquid at the in situ temperature

-10°C and were exposed by boreholes in the tundra zone near the East Siberian Sea coast. The cryopegs are confined to a 20-m-thick mid Pleistocene marine horizon, which marks the border of the Polar Ocean before sea level decreased and regressed to the North in the late Pleistocene, and sandwiched between terrigenous non-aligned layers at depths of 40 m below the surface. From these cryopegs, anaerobic and aerobic, spore-less and spore-forming, halotolerant and halophilic, psychrophilic and psychrotrophic bacteria, mycelial fungi and yeast were isolated and their activity was detected below 0°C. Subsurface hydrogen on Mars indicates the existence of water, probably as cryopeg lenses within the permafrost. These brines, formed when Mars became dry and cold, just as their terrestrial models, hypothetically might record genetic signatures of preexisting life (viable cells concurrently adapted to both, subzero temperatures and high salinity) that has long since vanished.

Polygonal patterns in the high latitudes of Mars - phenomena of frost cracking

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key words: polygonal pattern, frost-cracking, comparative analysis, stable ice, two-layer thermo-elastic model

The recent fundamental data has expanded our view on existing representations about an atmosphere, a climate and surfaces of Mars. The regions found out in Martian high latitude covered by a polygonal net have caused discussions about genesis and character of these forms, about their interrelation with modern and pale environmental conditions on the planet. Obtained data have allowed to consider this question as an actual scientific problem. We reports our results of the comparative analysis of frost conditions and displays of process frost cracking at high latitude of the Earth and Mars. We represent the factual and analytic data: high-resolution images of polygonal relief of the Martian Orbital Camera (MOC); morphology data of a surface, structure and characteristics of rocks in near-surface layer, received during landing missions Viking 1,2; Mars Pathfinder; Spirit; Opportunity and remote sounding from devices Mars-3, Mars Global Surveyor, Mars Odyssey, had made by following equipment: neutron and gamma-spectrometer HEND, laser altimeter MOLA, thermal emission spectrometer TES and others; a database "the Mars Climate Database of the European Space Agency"; the database of terrestrial polygons, which have represent air photo of the Arctic areas of Russia (Novosibirsk islands, Yamal and New Land islands, Tasovsky peninsula, Kamchatka) and Antarctica areas. We have carrying of the comparative analysis on the basis of N.N.Romanovskii's Ratz's and Kaplina's classifications (its have considered both stages of development of ranges, and their geometry), and on the base of an factual material from MOC images. The comparative analysis of terrestrial frost cracking polygons and Martian polygons, has shown similarity of morphology and similar character of histograms of distribution of the sizes, however the sizes of Martian ranges it is much more (average terrestrial size to 100 meters, for Martian to 200 meters). In both cases they are characterized three and four ray crossings of cracks. Developing polygonal patterns are observed in high latitudes of Mars. They are indicated by the ridges along the cracks and intrapolygonal baths. Calculations of the sizes of the Martian ranges, which have lead within the limits of two-layer thermoelastic model, have shown satisfactory convergence with the sizes of the ranges estimated by polygonal morphometry. These results, and circumstantial evidences of stable H₂O-ice presence in high latitudes allow us to assume, that the Martian polygonal relief is a phenomena of frost cracking process, which is accompanying by growth of ice, ice-bearing or soil wedges.

Tolerance limits of methanogenic archaea from Siberian permafrost: effects of high salinity and low temperatures

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key words: methanogenic Archaea, extreme habitats, Mars

Extraterrestrial Permafrost is a common phenomenon within the solar system and the main centre of extraterrestrial research in Astrobiology, with focus on searching for extraterrestrial life. Mars is considered as one of the most similar planets to Earth of our solar system, even if it is characterized by extreme coldness and dryness today. When living conditions on Mars were similar to that on early Earth, the evolution of microorganisms had already started on Earth. Prokaryotic microfossils, found in early Archean rocks, implies that the earliest life forms probably date

from between 3.5 to 3.8 Ga ago. Therefore it is legitimate to assume that life also on early Mars emerged as on early Earth. The newest ESA Mission to Mars (Mars Express) determined water as ground ice on Mars, which is fundamental requirement for life initiation. Further investigations for the first time demonstrated the presence of methane in Mars atmosphere, which could be only of active volcanic or biological origin. Data obtained by the Mars Express probe show that water vapour and methane gas are concentrated in the same regions of the Martian atmosphere. This finding may have important implications for the possibility that microbial life could exist on Mars. It is obviously that Martian life, if present, must have adapted to drastically changing environmental conditions. One possibility of survival might be subsurface lithoautotrophic ecosystems, comparable to permafrost on Earth, in which microorganisms have survived for several million years. Methanogenic Archaea, which colonised terrestrial permafrost, are highly specialized organisms from the view point of metabolism. The capability these organisms to lithoautotrophic growth, whereby methane is gained by the oxidation of hydrogen and carbon dioxide is the only carbon source under strictly anaerobic conditions, tolerance to low temperatures and survival under extreme conditions of permafrost for several millions of years make methanogens to one of the most suitable keystone organism for the investigation of possible Martian life. The goal of this work was to examine the tolerances of these organisms under unfavourable life conditions of terrestrial or extraterrestrial permafrost. The borders of growth influenced by desiccation, temperature extremes and high salt concentration were analyzed for the organisms in pure cultures as well in their natural environment of Siberian permafrost. The investigation area is situated on Samojlov Island in the Lena Delta, Siberia. The influence of high salt concentrations, which occur while soil freezing, in combination with low incubation temperatures was determined. Methanogenic Archaea revealed methane production under in situ conditions (at temperatures between 0 and 2°C) and salt concentration up to 6 mol with a rate about 0.02 to 0.09 nmol CH₄ h⁻¹ g⁻¹. Further laboratory tests with isolated cultures confirm those results. Incubation of pure cultures with different salt concentration (from 0.1 to 6 mol) showed a significant methane production rate even at salt concentration 6 mol (0.6 to 1.3 nmol CH₄ h⁻¹). The ascendancy of temperature on the experiments was also analyzed. Methanogenic Archaea showed better adaptation to high salt concentration at low temperatures, 4°C, with methane production rate 0.9 to 1.3 nmol CH₄ h⁻¹ as at incubation temperature 28°C (0.59 to 0.7 nmol CH₄ h⁻¹). Consideration of methanogenic Archaea natural environments makes those results not surprising, but conclusive.

Cryobiosphere - a new habitat for *Deinococcus radiodurans*?

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key words: radionurans, Mars analogue, extreme environment, diurnal thermophysical conditions

The cryogenic ecosystem permafrost, an approved analogue for putative Martian habitats, shows broad spectra of cryogenic niches, e. g. halotolerant brines within the permafrost (terrestrial model: Arctic cryopegs) as well as high counts and a diversity of microorganisms. Next to being very radiotolerant to any kind of radiation, *Deinococcus radiodurans* is capable of surviving dehydration as well. This feature suggests that *D. radiodurans* could survive in cryogenic ecosystems, which correspond to arid environments. Having studied the resistance towards the full solar UV range of *D. radiodurans* and its tolerance to desiccation and even space vacuum, we have started to investigate its response to combined exposure to UV, vacuum and low temperatures. Combined treatment results in synergistic effects. When exposed to the diurnal temperature profile both investigated *D. radiodurans* strains exhibit similar tolerance, but additional stress and increase of the temperature gradient seems to make the wild type strain R1 more vulnerable than the mutant strain 262. This result confirms that the wild type strain R1 is susceptible to temperature shifts. Special focus is laid on both the single effect of each applied parameter on the viability and/or the physiological composition of *D. radiodurans* and the percent contribution of each parameter.

Concerning probable cryogenesis on the Mars

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key words: Mars, grounds, microscope, frozen, weathering

Thermodynamic conditions on the Martian surface point the frozen ground presence, at least in sub-polar regions. Temperature oscillation amplitudes on the planet surface allow water to freeze almost everywhere. It assumes the

possibility of various cryogenic processes development including the cryogenic weathering. Spirit and Opportunity images of Martian surface provide unique information regarding the cryogenic transformations of the rocks. Most of them are similar to the Earth. The space devices panoramic images display a major quantity of acute-angled rock fragments with multiple cracks. The images of the rock surface prepared by the driller with the microscope application are seemed to be the most informative. They reveal the wedging out by freezing solutions of both gas and liquid inclusions as a dominant rock destructive mechanism in the case of water absence (or deficit). Such mechanism appears on the Earth due of wide daily or seasonal temperature amplitudes in polar and mountainous regions. Microscope observation of the Mars surface showed the existence of iron spherical formations (several millimeters diameter). Some of them destroyed with formation of acute-angled rock fragments. Similar, but smaller formations were detected in syncryogenic deposits of Russian North-East. They was formed as result of composite minerals cryogenic transformation. At that on the some cross-section of syncryogenic siltstones, we observed relation between coefficient of cryogenic contrast and content of free iron. The striking similarity of Mars and Earth phenomena turns to a probable analogy in cryogenesis development on the Red planet, and much more intensive than on the Earth. This study was supported by Russian Foundation for Basic Research (project 03-05-64462) and INTAS (project 01-2211).

Seasonal changes of South Polar contraction cracks, observations from Mars' orbit

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key words: Mars, South Pole, thermal contraction cracking, carbon dioxide

Polygonal patterns on the surface of Mars have been interpreted as either thermal contraction cracks or mud-desiccation cracks since the Viking imaging instrument discovered these features for the first time. New insights into the distribution, scales and shapes of polygonal patterns on Mars have been provided through the high resolution Mars Orbiter Camera (MOC) onboard Mars Global Surveyor which mapped selected areas with a resolution of about two to three metres per pixel. The continuous mapping progress has led to a considerable coverage of the Martian surface and several overlapping image strips in the polar areas. Image analyses of over 150,000 images have shown that the polygonal patterns are visible within a 30°-belt in both hemispheres, mainly. These observations support the idea that the polygonal patterns are formed through thermal contraction cracking of the surface as several models predict the stability of near-surface ground ice at these locations. Furthermore, viscous flow features (or ice-assisted creep phenomena) at these locations have been observed as well. The sizes and shapes of polygonal patterns is in the range of their terrestrial counterparts suggesting similar mechanical properties of the surface and comparable temperature gradients. However, evidence for thermal contraction cracking cannot be provided without in-situ measurements. The analysis of the polar areas of Mars lead to more convincing results as desiccation processes of water can be ruled out here. From over 6000 MOC images of the south polar area of Mars, 1500 images show characteristic polygonal patterns. The variety of different polygonal patterns is larger than in mid-latitudes suggesting different forming processes and time-scales. At least six types of patterns could be distinguished which correlate well with topography and surface texture. The analysis of multi-temporal coverage (3 years of observations) of certain regions revealed considerable changes in polygonal patterns. The sizes and shapes are comparable in each year's observations. With the help of six overlapping images that cover a polar trough at 87° S it was possible to reconstruct the seasonal changes and the processes that have taken place as these images have been taken during different seasons of the year (solar longitudes between 196° and 315°). At the polar trough, polygonal crack patterns form underneath the seasonal carbon dioxide cover within a thin layer during fall or winter and are visible at late southern spring when most of the carbon dioxide sublimated. In early summer, parts of the area are covered by remnants of carbon dioxide ice but ice-free areas show a pristine pattern of polygonal troughs that are filled by a dark material. In late summer, the crack pattern completely disappears and the underlying polar-trough infill of dark material is visible. In fall, carbon dioxide deposits and covers the region again. It is suggested from estimations of the coefficient of linear expansion and from the observations that the cracks occur in a thin veneer of slightly different material that might at least partly be composed of water ice.

Chapter 6

Session 5 - Hydrology and Sediment Fluxes in Permafrost Regions

Session Conveners: Achim Beylich, Bernd Etzelmüller
in association with: ESF project SEDIFLUX

Five years of monitoring the front slope of the highly active Hinteres Langtalkar rock glacier using terrestrial laser scanning: A case study in the Central Alps, Austria

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key words: rock glacier monitoring, terrestrial laser scanning, digital elevation model, surface change

The Hinteres Langtalkar rock glacier in the Hohe Tauern National Park (Central Alps, Austria) has been monitored using terrestrial laser scanning during the last years beginning with 2000. The ongoing sliding process and the steepness of the rock glacier front slope prevent standard geodetic measurements as well as surface motion analysis by photogrammetric methods. Long-range laser scanners are able to acquire high-resolution 3D data of surface structures. We report on the sensor and software set-up, the logistics and the procedure for data evaluation for rock glacier monitoring, as well as the results of a long-term monitoring in terms of 3D motion and deformations. It is shown that the system (Laser Scanner LPM2k produced by Riegl Laser Measurement Systems, Austria, combined with software for scanning and data evaluation by JOANNEUM RESEARCH and DIBIT Messtechnik GmbH, Austria) is capable of updating the database for the surface change of the rock glacier within a single day's measurement campaign. Single time-of-flight measurements with distance accuracy of 5 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 differences between DEMs of subsequent measurement epochs are used to describe the 3D surface deformations. In addition matching based on DEM structure allows identifying both global (velocity field distribution) and local (debris flow, other mass movements) effects of creeping permafrost. The results gathered through 5 years of monitoring are presented and analysed. The accuracy gained is within a range of 10cm in elevation. The elevation change varies from -5.0 m to +2.5 m. The obtained results enable the access to high-resolution surface deformation data in all three dimensions. The proposed terrestrial laser scanning method is able to extend, complement and verify state-of-the-art remote sensing strategies for rock glacier monitoring.

The role of rock glaciers and slope processes for strandflat development

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key words: strandflat, rock glaciers, cliff-wall retreat, slope processes, thermo erosion

The strandflat is a low-relief landscape situated about 40 m below and 40 m above the present sea level, backed onshore by up to several hundred meter high cliffs. Strandflats are found along coasts that have been repeatedly glaciated during the Quaternary, and are particularly well developed along parts of mainland Norway and Svalbard. The genesis of the strandflat is disputed but has generally been attributed to a suite of processes including glacial erosion, marine processes and frost weathering, coupled with the role of changing relative sea levels throughout the Quaternary. During recent decades, focus has been on frost weathering along the shore in a permafrost environment. The possible role of slope processes and subaerial weathering of the backing cliffs have received less attention. We present a case study from the permafrost environment on Prins Karls Forland, Svalbard, in order to evaluate how the slope system may contribute to strandflat development.

While marine abrasion and alongshore frost weathering only attack a narrow zone at any instant, backwall weathering and slope processes can perform geomorphic work along a broader space. However, the slope system is only capable of transporting material to the foot of slope - somewhat further in the case of rock glaciers and large rock slides - and the transported material will then be stored unless or until it interferes with another sediment transport system. Close to sea level, such stores will interfere with the marine system repeatedly through time because of changing relative sea levels.

On Svalbard, a great number of rock glaciers are found along the inner part of the strandflat. Relict rock glaciers are also found on equivalent positions some places along the Norwegian mainland coast, proving former permafrost conditions. On the northwestern part of Prins Karls Forland, off the west coast of Spitsbergen, rock glaciers form a several km long continuous transition between the strandflat and the backing cliffs. These rock glaciers form a substantial store of debris, which reflects the minimum amount of cliff-wall retreat during the time of rock glacier development, considering that removal of material may have taken place by marine erosion during this time period. The debris volume of the rock glaciers studied at Prins Karls Forland imply Holocene average cliff retreat rates of 0.3 to 0.6 mm a⁻¹, depending mainly on the choice of rock glacier age. The marginal position of Prins Karls Forland with respect to the Quaternary ice sheets implies that subaerial cliff retreat may have taken place during the main part of the time interval when the strandflat is thought to have developed. This would explain a substantial part of the total denudation, but does require sediment evacuation through the marine or glacial sediment systems. Marine erosion is currently taking place on one of the Prins Karls Forland rock glaciers. Due to its ice content, thermoerosion forms part of this process and causes probably much more effective evacuation of debris than otherwise possible.

The European Science Foundation (ESF) Network SEDIFLUX: sedimentary source-to-sink-fluxes in cold environments (2004 to 2006) - Introduction

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key words: source-to-sink fluxes, interdisciplinary, cold environment, climate change, ESF

Climate change will cause major changes in the Earth surface systems and the most dramatic changes are expected to occur in the cold climate environments of the Earth. Cold climate landscapes are some of the last wilderness areas containing specialized and diverse plants and animals as well as large stores of soil carbon. Geomorphological processes,

operating at the Earth's surface, transferring sediments and changing landforms are dependent on climate, vegetation cover and human impacts and will be significantly affected by climate change. In this context it is a major challenge to develop a better understanding of the complex ecosystems and the mechanisms and climatic controls of sedimentary transfer processes in cold environments. More reliable modelling of sediment transfer processes operating under present-day climatic settings is needed to determine the consequences of predicted climate change. It is necessary to collect and to compare data and knowledge from a wide range of different high latitude and high altitude environments and to develop more standardized methods and approaches for future research on sediment fluxes and relationships between climate and sedimentary transfer processes. In Europe the wide range of high latitude and high altitude environments provides great potential to investigate climate-process relationships and to model the effects of climate change by using space for time substitution. The highly relevant questions to be addressed need a multidisciplinary approach and the joining of forces and expertise from different scientific fields. Especially a closer cooperation between geoscientists and biologists/ecologists is needed. The ESF Network "Sedimentary Source-to-Sink-Fluxes in Cold Environments" (SEDIFLUX, 2004 to 2006), is bringing together leading scientists, young scientists and research teams from different fields. The large number of projects run by the ESF Network participants demonstrates the high level of research activity of scientists working on sediment fluxes in different cold environments. The Network will form a framework for an integrated and multidisciplinary investigation of the research topic and will be a catalyst for strengthening and extending contacts and exchange. The Steering Committee of SEDIFLUX consists of scientists from seven countries: Achim A. Beylich (Co-ordinator of SEDIFLUX), Trondheim, Norway; Samuel Etienne, Clermont-Ferrand, France; Bernd Eitzelmüller, Oslo, Norway; Vyacheslav V. Gordeev, Moscow, Russia; Jukka Käyhkö, Turku, Finland; Volker Rachold, Potsdam, Germany; Andrew J. Russell, Newcastle, UK; Karl-Heinz Schmidt, Halle/S., Germany; Þorsteinn Sæmundsson, Sauðárkrúkur, Iceland; Fiona S. Tweed, Staffordshire, UK; Jeff Warburton, Durham, UK. Network activities include four Science Meetings in Sauðárkrúkur, Iceland (June 18th-21st, 2004), Clermont-Ferrand, France (January 20th-22nd, 2005), Durham, UK (December of 2005) and a final Science Meeting in Trondheim in October 2006, Steering Committee meetings attached to these Science Meetings, a Session co-organized by SEDIFLUX at the 2nd European Permafrost Conference in Potsdam, Germany (June 12th-16th, 2005), Journal Publications (Special Issues), Publication of Abstract Volumes, Publication of a SEDIFLUX Handbook, development of a SEDIFLUX Database, and the diffusion and dissemination of Network activities and outputs by using electronic media (webpages, newsletters, forum, etc.). A strong monitoring and operational data collection and more standardized methods will provide a baseline for the development of reliable models and for future research in the changing cold environments. Apart from further collaborations and collaborative research activities project and programme applications both at national and at the European level will be discussed and initiated. For further information see <http://www.esf.org/sediflux> or please contact the SEDIFLUX Co-ordinator: Achim.Beylich@ngu.no

Hydrological modelling of Innvait creek, Alaska's North Slope

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key words: hydrology, modelling, north slope, Alaska

A new process-based, spatially distributed Hydrological Model (TOPOLFOW) is used to quantitatively simulate the water and energy fluxes in an Alaskan watershed. Innvait Creek is a small watershed (1.8 km²) located in the northern foothills of the Brooks Range (68° 30' N, 149° 15' W) and drains into the Kuparuk river. Two peculiar characteristics: (i) Innvait creek is a beaded stream and (ii) water tracks are efficient at conveying water down the slope during snowmelt and rain storms. Continuous permafrost underlies the active layer which by the end of the summer season reaches depths between 40 to 60 cm. Tussock tundra is the typical vegetation. The organic layer varies from about 50 cm in the valley bottom to around 10 cm on the slopes and ridges. The model is run using a collection of field data: Hourly climate and soil data (precipitation, long wave and short wave radiation and profiles of air and soil temperature). Other field data collection includes discharge measurements (flume), snow survey for the calculation of snow water equivalent (SWE), soil physical properties and channel characteristics. The model simulates various physical processes including snow ablation, subsurface, overland and channel flow, soil thawing and evapotranspiration. Predictions are made for the discharge at the outlet and will later include spatially-distributed soil moisture. Results using TOPOFLOW are presented and compared to measured discharge and SWE. First results indicate that the onset of snowmelt does not correspond well with the measured data because the model does not include the snow damming effect. Simulated hydrographs for the summer runoff period 2001 with different settings demonstrate that the different components of the water circle are represented in the model.

Rock glacier: glacial or periglacial origin - solution to the problem

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key words: rock glacier, permafrost, ice

The analysis of 30-years research on rock glaciers carried out by the author shows that the problem of their origin remains in a state of deadlock. All types of rock glaciers were the subject of field research and theoretical analyses. They were described in detail, analyzed and classified by means of all methods available. Despite the knowledge of the structure and features of rock glaciers there is still no unanimously accepted standpoint concerning their origin, which proves the solution to the problem must be somewhere else. The question whether rock glaciers are of glacial or periglacial origin is beyond the scope of notions currently used in glaciology and periglaciology. The difficulty in solving the problem lies in:

1. The actual separation of the glacial and periglacial research scope, where the latter is the only one to use the term 'permafrost'.

2. The lack of precise definitions used in the above sciences, which results in erroneous perception of rock glaciers. The definition of ice arises doubt. If water is defined as liquid, ice cannot be defined as water since it is not liquid. Due to it, ice is not commonly recognized as a mineral, as it is in crystallography, and glacier is not recognized as monomineral rock. Thus, each type of ice is rock and therefore a rock glacier is a composition or mixture of two very different rocks. In nature ice belongs to lithosphere rather than hydrosphere, which means that the notion of permafrost can and should be extended to glaciers. The term "rock glacier" best applies to the described form. A rock glacier is a transitional form between the glacial and periglacial environment. The description of rock glaciers is beyond the scope of those two sciences, as this is where the two fields adjoin each other, especially in the genetic sense. The point is, that ice and rock material, no matter what their origin is, form a relief which integrate glacial and periglacial domaine. The summer isotherm of 0°C in ground and glacier is the pivot of this integration.

Dynamic modelling of regional rock glacier distribution: presentation of a prototype model

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key words: rock glaciers, modelling, GIS, Swiss Alps

Numerous inventory studies about rock glaciers yielded information about their characteristics such as form, geology, location, etc. In addition, detailed studies on individual rock glaciers helped to build up a profound knowledge basis about these landforms. A comprehensive understanding of intra-regional variability of rock glacier occurrence is, however, still lacking. The objective of the present contribution is the exploration of a dynamic modelling approach in order to model regional, spatio-temporal patterns of talus-derived rock glacier distribution. The prototype model allows the numerical simulation of the spatial and temporal distribution of rock glaciers (i.e. it is a 4D model). Its main goal is to help evaluate and increase knowledge about dynamics and distribution patterns of rock glaciers by detailed comparison of the model outcome with the actual occurrence of rock glaciers. The area considered is the Upper Engadine, eastern Swiss Alps; the represented time-scale is the Holocene (i.e. ≈ 10000 yrs BP to today). The dynamic model considers processes in the spatial and temporal domain and accounts for both external and internal processes, implemented by means of six modules (A to G). The external processes considered are: (A) rock-debris accumulation, (B) hydrology, (C) climate, (D) glacier extent. The internal processes are: (E) creep initiation, (F) advance rate, (G) creep termination. Comparison between field evidence and modelling results yields the following most important results:

1. Most active and inactive talus-derived rock glaciers are reproduced accurately by the model, and the extents they exhibit in nature are also shown, approximately, although deviations can be found.
2. Certain active rock glaciers are not reproduced by the modelling. Careful consultation of the inventory data reveals that (at least) some of these rock glaciers are moraine-derived forms, and thus cannot be reproduced by a model that is based entirely on the processes involved in the development of talus-derived rock glaciers.

3. In a model run for 10000 years, the modelled rock glacier fronts do not advance into regions where relict rock glaciers are found in the inventory. Based on temperature reconstructions and relative age dating on selected rock glaciers, it can be assumed that relict rock glaciers in the area evolved as early as the Alpine Lateglacial. These findings seem to be supported by the model results with 'virtual rock glaciers' not exceeding the extents of active (and some inactive) rock glaciers.

Generally, it can be said that dynamic modelling enables the simulation of spatio-temporal creep processes but proves to be highly dependent on the accurate modelling of the relevant parameters.

Permafrost degradation and resultant impacts on soil moisture and ecosystems

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key words: permafrost, active layer, hydrology, thermocarst, climate change

The delicate thermal balance imposed on the arctic land surface by the interaction of climate and the annual variations in albedo, insulation, summer ablation, water infiltration and other small scale processes of mass and energy creates two of the most unique and important features of arctic hydrology: permafrost and the active layer. These features are crucial to arctic hydrology. They both affect, and are affected by, surface and subsurface water flow, the plant cover, the snow cover, and the climate. Because of permafrost, unlike hydrologic systems further south, thermal conditions rather than mechanical properties often determine whether erosion will occur. When frozen, stream beds and channels can withstand flows of high erosive power unscathed. This leads to unusual stream patterns and channel morphology. On the other hand, thermokarst (subsidence due to the volume change that results when massive ice melts) is widespread throughout the Arctic and Subarctic. When it occurs, it can cause profound changes in hydrologic systems, turning well-drained areas into bogs or lakes. The permafrost feeds back to the climate, and ultimately traditional aspects of the hydrology, through its interactions with soil moisture, which in turn affects vegetation. The vegetation responds to the active layer thickness and temperature, but in turn filters the surface energy balance and ground heat flux in such a way that it can influence the active layer thickness. For example, increased shrubs, perhaps holding more snow in winter, can change the surface energy balance and promote increases in the active layer depth, leading to a warmer and thicker active layer that promotes more shrubs in a feedback cycle.

Avalanche-driven rock glaciers in Svalbard

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key words: rock glaciers, avalanches, Svalbard, Spitsbergen, climate

Talus sheets with high snow avalanche activity in Svalbard are mainly facing NW, as the dominant winter airflow across the mountains is from SE. At the foot of such slopes, 1 to 4 m avalanche snow diluted by rock debris deposits accumulate each winter and spring under current meteorological conditions. As ablation consumes accumulated avalanche snow during the following summer, incorporated rock debris is released on the snow surface, forming a protective layer gradually hindering further ablation. At the end of the summer, the snow avalanche deposit has attained the look of a normal talus slope, but often considerable volumes of remnant avalanche snow are still present at 10 to 50 cm depth. By this, a 0 to 100 cm thick layer of snow and rock debris is added to the original terrain surface each year, making modern permafrost aggrading rapidly at the terrain surface by sedimentary processes. When a critical thickness of such snow avalanche deposits is reached, depending upon dilution of rock debris and terrain slope, slow creep transforms the deposit into rock glaciers. As snow avalanches especially occur on downwind slopes, modern rock glacier formation in Svalbard is highly wind-controlled and mainly takes place along the foot of talus sheets exposed towards NW.

Current changes in mountain permafrost creep: possible causes and consequences

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key words: rock glacier, creep, climate change, modelling, hazards

Beside its thermal characteristics creeping mountain permafrost is substantially defined by its kinetics. Due to the - in general considerable - ice content of rock glaciers, their dynamics are believed to respond sensitive to climate forcing. For a number of rock glaciers in the European Alps a significant creep acceleration has been observed in recent years. Questions arise if these changes reflect current or recent climatic changes, and what the further consequences of such behaviour could be. In this contribution, we compile globally observed rock glacier speeds as a function of local air temperature. In fact, air temperature can be identified as a major factor determining rock glacier speed. The remaining scatter clearly points to other influences such as slope, ice content, thickness or liquid water. In a next step, we summarize current monitoring results on rock glacier speed from other authors and ourselves. A surprisingly large number of Alpine rock glaciers showed an increase in speed in recent years. The large number points to other than solely local influences but rather to some regional-scale impact such as the observed increase in air temperatures. Using a one-dimensional thermo-mechanically coupled numerical model we simulate the potential response of rock glacier creep to a change in near-surface ground temperatures. It turns out that variations in temperature could affect indeed rock glacier creep in the currently observed order of magnitude. Other influences, however, clearly act as well. Among these, the occurrence and complex influence of liquid water in the frozen debris might be the most important for permafrost close to 0°C, though difficult to model. Our monitoring and modelling work implies that 'warm' rock glaciers (i.e. close to 0°C) creep faster than 'cold' ones. Furthermore, the findings suggest that the creep of 'warm' permafrost 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. By means of three scenarios, we finally demonstrate the possible consequences of an increase in rock glacier temperature and subsequent acceleration: (1) increasing sensitivity of rock glacier creep to seasonal influences, (2) dynamic activation of so far stable debris slopes, and (3) non-linear instabilities or ruptures of rock glaciers. Thereby, special focus is on applied aspects and consequences for natural hazard management.

Documentation of the creep process of Weissenkar rock glacier (Central Alps, Austria)

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key words: rock glacier monitoring, geodetic survey, digital photogrammetry, Weissenkar rock glacier, Central Alps, Austria

Weissenkar (46° 57.5' N, 12° 45' E) is a glacially shaped cirque in the Schober mountains of the Central Alps which are built of crystalline rocks. These rocks tend to be weathered to coarse debris favouring the formation of permafrost ice under climatic conditions with a mean annual air temperature of approximately -2 °C in 2500 m a.s.l. Due to the vertical extent of the cirque ranging from some 2600 m to 3100 m a.s.l. and the steep slope in its upper part continuous deformation of the permafrost by force of gravity has created an active rock glacier as it is also the case in a great number of sites with comparable topography in this mountain group. The creeping permafrost body has actually reached a plateau where its motion is retarded due to low inclination resulting in a very pronounced surface topography. This poster is focused on the documentation of the kinematic state of Weissenkar rock glacier. Geodetic and photogrammetric measurements have been carried out in order to obtain quantitative information on surface deformation, in general, and creep velocity and surface height change, in particular. In 1997 a geodetic network consisting of two stable reference points located in the vicinity of the rock glacier and 18 observation points on the rock glacier was installed and measured with substantial support of the Institute of Navigation and Satellite

Geodesy of the Graz University of Technology. These measurements have been repeated every year until now, with one interruption in 2002. Annual horizontal creep velocities obtained are rather small and range between 5 to 11 cm a⁻¹. In this poster selected results of the measurements (1997 to 2004) will be presented numerically and graphically. Furthermore, a comparative analysis of the data will be given. Large-scale aerial photographs of three different epochs, i.e., 1974, 1998 and 2003, covering Weissenkar rock glacier were acquired in order to obtain area-wide information on the surface movement. Dense fields of three-dimensional surface displacement vectors were computed applying modern digital-photogrammetric methods. Results obtained for the time period 1998 to 2003 were compared with the respective values of the geodetic survey. The poster also comprises various thematic maps showing the mean annual creep velocity and surface height change for the time periods 1974 to 1998 and 1998 to 2003. As a basis of cartographic work a orthophoto map of the area of interest was compiled. Finally, the kinetics of Weissenkar rock glacier will be discussed in respect to its morphology and its specific topographic situation.

Studying the movement of the Outer Hochebenkar rock glacier: Aerial vs. ground-based photogrammetric methods

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key words: rock glacier monitoring, digital photogrammetry, ground-based (terrestrial) photogrammetry, Photheo 19/1318, Linhof Metrika, Rolleiflex 6006 metric, Nikon D100 digital camera

The Outer Hochebenkar rock glacier is situated in the vicinity of the village Obergurgl in the Oetztal Alps, Austria. This tongue-shaped rock glacier is about 1 km in length and 42 ha in size. It has a comparatively high but periodically changing flow velocity of up to several m a⁻¹. At the lower end of the rock glacier a landslide has occurred, which is caused by the rather steep terrain. The upper part is characterized by a steady-state creeping process. The maximum velocity can be observed right above the sliding zone (at about 2580 m).

In this work aerial as well as ground-based photogrammetric methods were used for deriving metric information of surface deformation and flow velocity. Aerial photogrammetry is a standard method for rock glacier monitoring tasks, whereas ground-based photogrammetry, being the historically older method, has not been used anymore. Nowadays, it might become a valuable tool for the monitoring of small scale periglacial phenomena again. This is due to the availability of high resolution digital consumer cameras and modern, fully automated digital-photogrammetric methods. The following aerial photographs have been acquired from the Federal Office of Metrology and Surveying (BEV): (1) a stereo pair dated from September 7th, 1977 (panchromatic film), (2) a stereo pair dated from September 11th, 1997 (panchromatic film) and (3) a stereo triplet dated from September 5th, 2003 (color film scanned with 20 micron). The ground-based photographs have been taken during three field campaigns using four different (metric and semi-metric) camera systems: (1) a stereo pair from September 23rd, 1986 (Photheo 19/1318), (2) stereo pairs taken on September 9th, 1999 (Linhof Metrika and Rolleiflex 6006) and (3) stereo pairs taken on September 19th, 2003 (Linhof Metrika, Rolleiflex 6006 and Nikon D100). Photogrammetric evaluation was done for the aerial case (1977 to 1997 and 1997 to 2003) and for the ground-based surveys (1986 to 1999 and 1999 to 2003). First, all analog images were scanned with the UltraScan 5000 photogrammetric scanner of Vexcel Imaging Austria with a resolution of 10 micron. Then an all digital photogrammetric workflow was implemented using the digital workstation ISSK of Z/I Imaging and various software tools. These have been developed for geometric and radiometric correction of the (terrestrial) images and for automatic measurement of digital terrain models (DTM) and 3D flow vectors. The results derived from the two different data sets are presented numerically and graphically. This allows to compare the ground-based method directly with the aerial case and to verify both of them with geodetic measurements provided by the University of Innsbruck. Finally the pros and cons of this two methods are discussed in detail.

Rock glacier acceleration: a case study in the Mont Gelé area (Swiss Alps)

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key words: rock glacier, dynamics, surface movements, GPS

A monitoring of surface movements with DGPS has been carried out since 2000 on two active rock glaciers (rgB and rgC) in the Mont Gelé area (Western Swiss Alps, 46° 06' N, 7° 17' E). Located side by side, these two rock glaciers display similar topographic characteristics. Electrical prospecting revealed however a great difference in resistivities: values measured on rgC are much higher (350 kΩm to 1 MΩm) than those measured on rgB (max. 40 kΩm). With a Differential GPS (Leica Geosystems), the position of 28 points and resp. 35 points is measured each year (mid-September) on rgB and rgC with an accuracy of about 1 cm. The total movement between two measurement campaigns is the combination of the horizontal component (x,y) and the vertical one (z). The surface movements of the two rock glaciers is quite different. While rgB creeps with velocities higher than 1 m a⁻¹ on a large part of the landform, rgC creeps much slower (less than 30 cm a⁻¹). The third and fourth measurement campaigns (2003 and 2004) evidenced a marked acceleration of surface movements. On rgB, both horizontal and vertical components increased by 93% between the periods 2000 to 2001 and 2003 to 2004. This means that the surface velocities have almost doubled in three years. On rgC the increase in surface movements reached 76% for the horizontal component and 65% for the vertical one. The analysis of the periods 2000 to 2001, 2001 to 2003 (no measurements could be carried out in 2002) and 2003 to 2004 shows a completely different behaviour between rgB and rgC. On rgB, only a small increase in surface movements was measured between the first two periods (8% for the horizontal component and 14% for the vertical one). On the other hand, the increase in surface movements between the periods 2001 to 2003 and 2003 to 2004 reached 80% (horiz.) and 68% (vert.)! On rgC, the increase is stronger between the first two periods (38% and 44%), than between the last two ones (22% and 1%). As encountered on other rock glaciers of the Swiss, Austrian and French Alps, an evident acceleration is affecting the two studied rock glaciers. Even if no measurements were carried out before 2000, it can be assumed, on the basis of geomorphologic evidences, that the acceleration began a few decades ago. The obtained results probably point to the large influence of climate warming on rock glacier dynamics. By reducing the amount of unfrozen water and maintaining cold temperatures in the permafrost body, latent heat consumed by the melting of massive ice identified in rgC probably contributes to maintaining relatively low velocities. The marked increase in surface movements measured on this rock glacier between the periods 2000 to 2001 and 2001 to 2003 may be related to the mild winter 2002 to 2003 and to the heat wave of summer 2003, which would have contributed to warming permafrost and to increasing deformation velocity. The higher velocities recorded on rgB can probably be related to favourable topographic situation, a lower ice content and/or warmer permafrost. Thus, the warm conditions of 2003 would have had less influence on the dynamics of the rock glacier. On the other hand, further measurements are needed to understand the extreme increase of surface movements between 2001 to 2003 and 2003 to 2004.

Formation and degradation of ice-marginal moraine belts at three Central Spitsbergen glaciers

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key words: Spitsbergen, ice-cored moraine, landform preservation, active layer processes, high-arctic glacial landscapes

Many polythermal glacier margins in Central Spitsbergen are covered by a relatively uniform spread of supraglacial debris protecting the underlying ice from melting where debris thickness exceeds that of the active layer. As a result, these glaciers have downwasted rather than retreated since reaching their Little Ice Age maximum around ca. 1900. The formation and degradation of three such moraine belts was investigated with the aim to develop a model of landscape evolution during de-icing progression. Such a model adds to the understanding of polythermal glacial landsystems and could form an important contribution to the understanding of glacier-permafrost interactions and glacier reconstruction if certain sediment-landform associations can be linked to specific processes. Englacial debris layers at all three glaciers that indicate a horizontal stratification within the ice appear to reach the surface in the frontal belts. Individual boulders and bedrock slabs of distinct lithologies that only crop out near corrie headwalls strongly suggest rockfall onto the ice in the accumulation area, burial by snow and subsequent meltout at the snout as

the dominant process of material transfer; evidence of englacial thrusting was not found. Striated clasts indicate that subglacial transport contributed to the formation of the supraglacial debris belts. All three belts presently degrade due to frequent debris flows leading to exposure of the underlying buried ice. Transfer of sediment to lower parts of slopes triggers successive debris flows upslope to balance instabilities. This mechanism is most obvious at the frontal margin of the moraine belts and adjacent to stream channels that formed by roof collapse of former englacial meltwater tunnels; along such channels, material is readily evacuated from the system. Comparisons with studies from other central Spitsbergen glaciers confirm that most of the supraglacial material is readily removed by fluvial activity leaving comparatively little evidence indicative of a formerly glaciated terrain. As a result of continuous permafrost, melting is concentrated in exposed areas or where the debris cover is thinner than the active layer. Material transfer is largely towards the front where the sediment wedge is thickest rather than into basins and troughs where the sediment cover is relatively uniform. A subdued (<5 m) outermost ridge might form as a result of 'front-melting' instead of hummocky terrain that characterises subpolar glacier forelands such as those in Iceland characterised by areal 'top-melting'. The limited preservation potential of glacial deposits and landforms indicated by our findings can also explain the scarcity of e.g. early Holocene glacial deposits elsewhere on Svalbard. Transferred to palaeo-environments, this resulting model is best applied to areas where sedimentological and geomorphological evidence of glaciation is largely lacking.

Studies on the hydrological processes in permafrost regions of Northern Eurasia

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key words: hydrology, East Siberia, frozen ground, runoff, evaporation

Global warming, its consequent influence to terrestrial conditions and related feedback to the global climate are of special interest. During the past 7.8 years, studies in Northern Eurasia related to such issues were advanced by Siberian study group of WCRP/GEWEX project GAME(GEWEX Asian Monsoon Experiment), and IORGC of JAMSTEC continuing these studies as an Institutional research work. Hydrological conditions are important considering the regional water cycle of the earth, but are also important for the development and change of sub-surface thermal conditions. The present paper discusses the main results on the hydrological studies under these projects based on in-situ observations, and future plan related to these works. Main studies related to permafrost/ active layer made are as follows. (1) Drainage study of tundra and change in conditions of frozen ground. (2) Hydrological characteristics of taiga region (heavily forested) and change in conditions of frozen ground. (3) Monitoring system of hydrological conditions and frozen ground in eastern Siberia and Northern Mongolia implemented by IORGC.

Surveying the (seasonal) variations in rock glacier activity using GPS technique (western Swiss Alps)

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key words: rock glacier activity, GPS, Swiss Alps

RTK/GPS is an efficient method for monitoring the surface motion of a terrain as 100 points can easily be measured in one day with a centimetre precision. Thus, large areas may be covered by the set of measurement points. The observation of the rock glacier flow pattern is possible. Several difficulties like an inappropriate topography (the horizon is not open enough) or a difficult site accessibility however limit the use of the GPS technique. Moreover, the period during which the snow cover does not prevent the measurements to be carried out, is usually reduced to a few months in summer and early autumn, what makes the observation of seasonal changes in rock glacier surface velocities challenging. The Becs-de-Bosson active rock glacier (BBrg) is part of the PERMOS (Permafrost Monitoring Switzerland) program (high resolution photogrammetry analysis at a 5-year interval). Since 2001, 61 blocks have been surveyed on the front of BBrg. Measurements were carried out in October 2001, October 2003 and then five times in 2004: July, August, September, November (partially) and December (very few snow!). Only one part of the rock glacier front is moving (about 1 m a^{-1}). Horizontal velocities, that were already about 50% greater than those observed by photogrammetry between 1986 and 1999), still increased of 10 to 15% between 2001 to 2003 and 2003 to 2004. In

2004, maximal velocities occurred during late summer before that a decrease (-5%) was observed between September and December. In addition to the front, 118 new blocks were marked in autumn 2004 in order to cover most of the rock glacier. Measurements on blocks emerging from the snow cover will also begin during winter 2004/05, what would allow to observe the year-round rock glacier activity in the future. At Aget-Rogneux, the back-movement of frozen materials deformed by the advance of a small glacier during Little Ice Age are measured since 2001. An increase of about 60% in horizontal velocities over the whole period (2001 to 2003 versus 2003 to 2004) has been detected. Further surveys concern the Lona glacier/rock glacier complexe, the Ignes isolated debris-covered glacier remnants (reference site for vertical movements), an apparently inactive rock glacier at Alpage de Mille and two active rock glaciers (Mt.-Dolin, Tsarmine, in collaboration with the University of Lausanne). On the Tsarmine rock glacier, the disposition of the blocks, which are all covered with lichens, is clearly disturbed, suggesting the recent reactivation of a former quasi inactive rock glacier.

Chemical weathering of basalts in Central Siberia under permafrost conditions

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key words: basalt, Siberia, chemical weathering, fluxes, mineralogy, mobility

Chemical weathering of basalts in the Putorana Plateau, Central Siberia, has been studied by combining chemical and mineralogical analysis of solids (rocks, soils, river sediments and suspended matter) and fluid solution chemistry. Altogether, 70 large and small rivers, 30 soils solutions and groundwaters and over 30 solids were sampled during July to August 2001. Analysis of multiannual data on discharge and chemical composition of several rivers of the region available from Russian Hydrological Survey allowed rigorous estimation of mean annual major elements concentrations and dissolved and suspended fluxes associated with basalt weathering. For rivers Tembenchi and Taimura, that drain monolithological basic volcanic rocks, the mean multi-annual flux of total dissolved cations ($TDS_c = Ca + Mg + Na + K$) corrected for atmospheric input is $5.7 \text{ t km}^{-2} \text{ a}^{-1}$. The fluxes of suspended matter were estimated as 3.1, 9.0 and $6.5 \text{ t km}^{-2} \text{ a}^{-1}$ for rivers Taimura, Eratchimo, and N. Tunguska, respectively. Based on chemical analyses of river solutes and suspended matter, the relative dissolved versus particulate annual transport of major components is $C_{inorg} = C_{org} > Na + K > Ca > Mg > Si > Fe > Mn > Ti > Al$ which reflects the usual order of element mobility during weathering. According to chemical and mineralogical soil and sediment analyses, alteration of basalt consists of (1) replacement of the original basaltic glass by Fe-Al rich amorphous material; (2) mechanical desagregation and grinding of parent rocks leading to accumulation of "primary" trioctahedral smectites; (3) transformation of these trioctahedral (oxy)smectites and mixed-layer chlorite-smectites to secondary dioctahedral smectites accompanied by removal of Ca, Mg and Fe and enrichment in Al. No vertical chemical differentiation of fluid and solid phases within the soil profile was identified. Fresh unaltered rocks, soil minerals, plant litter and the permafrost ice represent the major reservoirs releasing the elements to the groundwater and rivers. In spring and summer, with high discharge rate, plant litter and upper soil horizons provides the main contribution to the flux of major elements in river. The major elements and organic carbon concentration in sampled permafrost ice is very similar to that in soil solutions, groundwaters and rivers, as a result, the estimated flux of major elements and organic carbon associated with this process can contribute more than 50% of overall dissolved element flux during warm period of the year. During low water period in winter, all rivers become enriched in most mobile element, Na suggesting both its leaching from the rocks and soil minerals but also mobilization from deep highly-saline groundwater reservoirs. The effect of rock type, frost action and dissolved organic carbon on chemical erosion of Siberian basalts is discussed.

Permafrost-glacier relationships in an unstable sediment complex (Tsarmine, Arolla Valley, Western Swiss Alps)

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key words: rock glacier, glacier, push-moraine, geoelectricity

In Switzerland, numerous small lateral glaciers have deposited large amounts of loose sediments on steep slopes where torrents and debris flows are very common. These sediment complexes are often located in permafrost areas where debris flow hazards may grow in case of permafrost degradation. The lateral glacial cirque of Tsarmine located in the right side of the Arolla Valley (Western Swiss Alps) was investigated. Altitudes range from 2400 to 3000 m a.s.l. Geomorphology is dominated by a debris covered glacier and its morainic complex. The glacier variations have built a huge morainic bastion that dominates the bottom valley situated 1000 metres below. In the northern part of the glacier forefield, several push moraines located upstream a debris rock glacier show geometric modifications of frozen sediments due to Little Ice Age (LIA) glacier advance. In the southern part of the margin, a small proglacial lake is present above the frontal moraine dam. By using geoelectrical soundings and mapping, ground surface thermal measurements and geomorphological mapping, the study aimed to map and characterize the ice and permafrost distribution in the area and to evidence the relationships between the debris covered glacier, the debris rock glacier and the push-moraines in the glacier forefield. The possible presence of ice within the morainic bastion below the lake was particularly investigated. 6 DC resistivity soundings and 5 DC resistivity mapping lines were carried out in summer 2003. Ten mini data-loggers measured the ground surface temperature every two hours from September 2003 to September 2004. DC resistivity prospecting revealed that a large part of the glacier forefield contains ground ice. Two different types of terrains can be distinguished. On the upper part, resistivities ranging from 400 to 700 kΩm, outcrops of ice and other geomorphological evidences attest the presence of the buried Tsarmine glacier on a wide area covered with debris. Downstream, resistivities lower than 400 kΩm point to the existence of massive ice that could either be dead ice from Tsarmine glacier LIA position or older frozen sediments recovered by the Tsarmine glacier during the LIA. The area of the lake, and especially the frontal moraine dam that limits it, is free of ice (specific resistivities <7 kΩm). On the rock glacier, resistivities range from 10 to 100 kΩm, what is typical of permafrost bodies. Geomorphological evidences (steep front, absence of vegetation, numerous ridges and furrows) indicate that the rock glacier is probably still active. The presence of numerous push-moraines with resistivities higher than in the rock glacier shows that the rock glacier was disturbed and geometrically modified by the LIA advance of the Tsarmine glacier and that glacier ice was probably incorporated in the frozen sediments. In conclusion, large amounts of sediments are still frozen, but the area occupied by the lake is free of ice. This could have implication in terms of potential geomorphological hazards. The presence of the lake in the unfrozen morainic bastion may be a factor of debris flows triggering. Geophysical investigations combining seismic and geoelectricity are necessary in order to determine the structure and stability of the moraine dam.

Rock glacier “speed-up” throughout European Alps - a climatic signal?

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key words: rock glacier, speed-up, Alps, climate change, dynamics

At the PACE21 meeting in Longyearbyen, Svalbard in September 2004 an intense discussion on spatio-temporal variations in rock glacier movement and corresponding reasons began. Thus, an initiative started compiling an inventory of rock glaciers which show increased surface velocities from all over the European Alps in order to compare their characteristics and detail probable controls. Acceleration of rock glacier movement was observed in all parts of the entire Alpine arc from the Hautes Alpes, France, via Valais and Grisons in Switzerland, to the Austrian provinces

of Carinthia and Tyrol. For the quantification of kinematics and its variations, different methods (terrestrial geodetic survey, GPS and digital photogrammetry) were applied covering mostly periods between 1975 and 2004. The monitored horizontal surface velocities depicted accelerations of different magnitudes (5 to 350%), mostly starting in the 1990s. Additionally, distinct vertical changes were observed in some areas. Main objectives of the cooperation are first of all the differentiation of topographic (e.g., slope) versus climatic controls and thus the separation of local versus regional influences on rock glacier dynamics. Then, focus is given on the investigation of both regional and temporal differences in the amount of acceleration in order to define controlling parameters. Since variations in rock glacier movement are mostly discussed in the context of temperature fluctuations, horizontal and vertical velocities are correlated with Bottom Temperature of the winter Snow cover (BTS), Mean Annual Air Temperature (MAAT), etc. Finally, a uniform monitoring design for rock glaciers is demanded in order to set up an alpine rock glacier monitoring system and use these sensitive landforms as valuable environmental indicators.

Rock glacier acceleration in the Turtmann valley (Swiss Alps) - A discussion on probable controls

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key words: rock glacier, acceleration, climate change, dynamics, Swiss Alps

Temporal variations in mountain permafrost creep are analysed within a regional study on rock glacier kinematics. On all 16 active rock glaciers on the east side of the Turtmann valley an acceleration of horizontal velocities is ascertained, partially accompanied by distinct vertical changes. This signal of rock glacier speed-up was measured by digital photogrammetry for the period 1993 to 2001 and was confirmed by terrestrial geodetic survey in the years 2001 to 2004. Different topographic parameters (altitude, aspect, length of the rock glaciers) as well as climatic parameters (Mean Annual Air Temperature (MAAT), Bottom temperature of the winter snow cover (BTS), etc.) are correlated with the surface velocities, in order to separate local and regional controls. Since temperature is discussed to be the major parameter influencing rock glacier creep, the link between surface velocities and temperature developments is focused and is investigated on two different scales. The general increase in temperature in the Alps within the last century and especially since the 1990s fits well with the observed rock glacier acceleration. A different signal is revealed on the local scale, where BTS-values of the years 2001 to 2004 are correlated with horizontal surface velocities and depict a good coincidence. In areas with high velocities the BTS-values are clearly below -3°C and inactive parts show temperatures close to 0°C. Thus, the link of 'warming' and consequently accelerating rock glaciers, like it is shown in other studies, is not confirmed by our data. In general, the results do not deny the assumption that permafrost creep variations are correlated with climatic fluctuations. But, the relation between temperature and rock glacier dynamics seems to be much more complex and can not easily be described in simple correlations.

Thermal and physico-chemical characteristics of springs issuing from rock glaciers in the Ortles-Cevedale Region (Italian Alps)

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key words: rock glaciers, hydrology, spring water characteristics

The south and eastern sectors of the Ortles-Cevedale Massif (Peio, Rabbi and Ultimo valley, Italian Alps) are characterized by widespread and spectacular periglacial and permafrost-related landforms, like pattern grounds, ploughing boulders, solifluction lobes and block streams. Rock glaciers are very well developed, with lobate and tongue-shape landforms in some cases more than 1.5 km in length. The lower limit of active/inactive rock glaciers ranges between 2400 and 2900 m a.s.l. Thermal and physico-chemical characteristics of springs issuing at the base of the frontal slope of some rock glaciers have been examined. Temperatures and electrical conductivities of 16 rock glacier-related springs have been checked several times during field work in the Summer 2004 using an hand-held conductivity-meter.

For comparison, the same data have been collected from 4 springs which did not flow from rock glaciers but which were located near to the previous ones and at the same altitude. Water samples were collected both from rock glacier- and non-rock glacier-related springs and analyzed in laboratory. The temperature of 6 springs has been monitored every half hour from mid August until the end of September 2004 using data loggers. The water temperatures were almost constant and near 0°C during the whole summer period, with mean values ranging from 0.2 to 2.0°C for the rock glacier-related springs. Mean temperatures of non-rock glacier-related springs were also constant but higher than the previous ones, ranging from 2.0 to 4.2°C. No correlation has been found between water temperature and the springs altitude. We observed the maximum discharge in early Summer, when springs are fed mainly from snowmelt. In late summer and in autumn the discharge progressively decreased and many springs completely disappeared in late September. The mean water electrical conductivity of different springs is very variable and ranges from less than 10 $\mu\text{S cm}^{-1}$ to more than 250 $\mu\text{S cm}^{-1}$. The continuous monitoring with data loggers allowed us to achieve information not only about the thermal characteristics of the springs but also on their hydrological regime. From the temperature curve, indeed, it's clearly possible to recognize when a spring becomes dry and the data logger starts to record the air temperature between blocks instead of that of the water. We observed a strong correlation between spring water regime (recharge of the springs) and precipitation events recorded from nearby weather stations. The response time was very rapid, in some cases only a few hours. No variations were recorded in the temperature of the springs, that remained always near 0°C even after comparatively "warm precipitations".

Chapter 7

Session 6 - Mineralogy, Geochemistry and Isotopes in Permafrost Research

Session Conveners: Hanno Meyer, Ron Sletten

in association with: IPA WG on Isotope and Geochemistry of Permafrost

Distribution of C_{org} and C/N-ratio in the sediments of Ivashkina Lagoon

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key words: organic carbon, C/N-ratio, Ivashkina lagoon, sea-land interaction zone, Laptev Sea region

Arctic sea basin - Arctic lowlands interaction zone (Laptev sea region), is an area, characterized by originality of complex processes and faces. This includes transformation of organic and mineral substance in thermokarst lakes, "thermokarst lagoons", coastal faces of sea deposits, etc.; change of sedimentation, geochemical conditions, processes of freezing and thawing of the deposits.

The main objective of this work was a geochemical characterization of the sediments from the sea-land interaction zone, to investigate the variation in the conditions of accumulation and post-sedimentary transformation of sediments, to establish differences in the chemical content and distribution of organic carbon in the continental freshwater sediments flooded by sea water, and in the land sediments which are not affected by sea environment and freeze under the influence of a severe Arctic climate.

The material to this research work was obtained during the expedition in April, 2004 to the Bykovsky Peninsula which is situated between 71° 40' to 72° N and 129° to 129° 30' E. Several bore holes were drilled in the Ivashkina lagoon. The sites of the cores were in the transitional zone of sea-land interaction. In general 7 cores were taken and 4 were studied. Geochemical parameters such as C_{org} (%) and carbon/nitrogen C/N ratio and pore water anion, cation content of samples were measured in the Otto Schmidt Laboratory using C/N analyzer VARIO ELTRA III and ion chromatography. The C_{org} (%) content in all samples along the sections varies in a wide spectrum in different deposits and is relatively high till 4%. Thermokarst lagoon deposits were investigated by coring logs IV4-1 and IV4-2. Upper layer of the cores is presented by lacustrine-sea deposits (sandy silt), after 2.5 m it changes to taberal deposits (clay with organic matter inclusions). Cores IV4-1 and IV4-2 are characterized by uneven distribution of the C_{org} in different deposits and by terrestrial soil derived organic matter; C/N ratio in IV4-1, IV4-2 and IV4-4 varies from 10 to 15 along the section. Alas deposits were studied by core IV4-3, sediments on top consist of sandy loam they are replaced by lacustrine deposits and taberal deposits (fine grained sand). Core IV4-3 is characterised by terrigenous organic matter and a C/N ratio >15. Results on core IV4-3 which were obtained during the researches are comparable with the values of C_{org} which were got using another methodic of C_{org} determination and from another occurrence.

Chemical composition of water and sediments of Bolshezemelskaya Tundra lakes

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key words: water, lake sediments, Bolshezemelskaya Tundra, thermokarst lakes, glacial lakes

Investigations of chemical composition of water and sediments of the Bolshezemelskaya Tundra lakes were carried out in the frame of SPICE project. SPICE (Sustainable Development of the Pechora Region in a Changing Environment and Society) is the multidisciplinary research project funded for period of 3 years (2000 to 2003) by the INCO-COPERNICUS 2 Programme of the European Commission (contract no. ICA2-CT-2000-10018). During two summer field seasons (2000 and 2001) water and sediment samples of lakes on 4 watersheds of the Bolshezemelskaya Tundra rivers (Ortina, Neruta, Kolava and More-Yu) have been taken.

Distinctive feature of territory of the Bolshezemelskaya Tundra is permafrost development. The territory of the Bolshezemelskaya Tundra is covered with set of lakes of various origin - glacial, thermokarst and flood-lands. The lakes located within hilly relief have glacial origin and are characterized by well-defined deep hollows. Thermokarst lakes dispose usually on flat water-separate sites. These lakes are usually characterized by simple rounded outlines, small depth, peaty steep coast and a peaty bottom. The drain from thermokarst lakes is also very weak and marked only during spring raising of water level. The flood-lands lakes formed in result of separation from channel of branches and inflows are characterized by the small areas. They are usually connected by channels to the river, and their regime is determined by regime of water-current.

The sum of ions of water of investigated lakes was rather low - from 6 to 96 mg L⁻¹. Thermokarst lakes are characterized the lowest mineralization - 6 to 11 mg L⁻¹, then glacial lakes - 14 to 48 mg L⁻¹, in flood-lands lakes the mineralization reaches up to 96 mg L⁻¹. Thermokarst lakes are characterized as well by the minimal values pH - 5.14 to 6.36. In glacial and flood-lands lakes the value pH are close to neutral - from 6.46 to 7.40. The contents of the basic ions in water of investigated lakes was also rather low, that is typical for tundra lakes. The following decreasing sequence of concentration of the basic cations has been marked: Ca²⁺ > Na⁺ > Mg²⁺ > K⁺. Among the anions the following decreasing sequence has been marked: HCO₃⁻ > SO₄²⁻ > Cl⁻. Contents of Al, Fe and Mn in water of practically all researched lakes exceeded fishery permissible concentrations. Concentration of organic material and nutrients differ in lakes depending on origin of lakes. Contents of NH₄⁺, N_{tot}, PO₄³⁻, P_{tot}, as well as values of chemical oxygen demand as a rule were maximal in thermokarst lakes. Analyses of water on the contents of petroleum hydrocarbons have shown the excess of fishery permissible values (50 µg L⁻¹) practically in all investigated lakes (110 to 200 µg L⁻¹) owing to work on investigation and installation of oil and gas. The increase in concentration of Cd and Cu in surface layers of sediments of almost all investigated lakes, as well as Pb, Ni, Cu, Zn, Co, Mn, P, Sr, Hg, As and Fe in some lakes is revealed. The increase in concentration of elements and decrease of organic material contents in surface sediment layers of thermokarst lakes can speak about receipt of suspended material with high concentration of almost all elements in lakes from watersheds. Pollution by many elements (Cd, Mn, Sr, Cr, Cu, Co, Ni, Hg, As, Zn and P) of surface layers of sediments of deep glacial lakes is also marked. It is revealed, that such highly toxic elements as Hg, As, Cd and Pb are global polluting elements of the Bolshezemelskaya Tundra lakes.

Geochemistry of lacustrine sediments of terraces and alases in the Lena Delta (Siberian Arctic, Russia)

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key words: lake sediments, geochemistry, Lena Delta, erosion, fluvial hydrology

The Lena Delta is the largest delta in the Arctic and it is the main connection between interacting continental and marine processes within the Laptev Sea. In summer 2004 within the framework of the Russian-German project "The

Laptev Sea System" lacustrine sediment cores from the Lena Delta area had been chosen as targets for studies on erosion/accumulation and environmental conditions during the Holocene. Two lakes, located near the point of bifurcation of the Bulkurskay and Oleneskaya branches have been selected for estimating the rates of recent and latest Holocene erosion, accumulation, and hydrological conditions. One of them is located in a large alas (dry lake) depression, which is developed within the Ice Complex, and the other one is situated on the first river terrace about 8 m high. The alas lake has a maximum water depth of 8.1 m and a surface area of 0.5 km², the terrace lake is 4.6 m deep and covers an area of 0.05 km². Sediment cores (47.5 cm and 36 cm, correspondingly) were retrieved from the centre of each lake and the cores were analyzed for geochemical composition, grain-size distribution and TOC/TC content at 5 to 7 cm intervals. The following results were obtained:

- Sediments of the two lakes have close yet different characteristics; the alas lake sediments are quite homogeneous throughout, while the terrace lake sediments vary from bottom to top. The accumulation within the alas lake appears to be slower than that of the terrace lake.
- Sediments from the alas lake can be classified as medium silt with an average particle size of 25.4 μm. TOC/TC analyses have shown that carbon is dominantly organic and amounts to about 3 to 4%. The carbon-nitrogen ratio is about 8. The preliminary interpretation is that the organic carbon is mainly formed from autochthonous material deposited with the alas lake.
- The grain-size distribution of the terrace lake sediments varies from fluvial fine sand at the bottom to coarse silt at the top of the core. The properties of the sediments in the bottom section are close to the river-bed environment, while the upper section documents the lake catchment. It is suggested that the upper section of the core originates from weathering of the surrounding deposits, while the lower section is controlled by the input of riverine material. This is supported by the TOC content averaging 0.8% in the bottom and 4.5% in the top of the core.
- The distributions of the main elements are quite similar in both cores. These are aluminium, sodium, potassium, and iron compounds. However, there are subtle differences in the geochemistry of the two cores that can be referred to the conditions of sedimentation. The investigation of certain trace elements, which are known to be enriched in the Lena Basin, may be applied to reconstruct the chemical composition of the Lena River during different periods.

The analyses of sediment cores retrieved from an alas and a terrace lake provide new information on the basin erosion in the Lena Delta. ¹⁴C-dating of the lacustrine sediments, which are underway, will allow us to date the period when the area of the terrace lake was directly influenced by the river runoff. Therefore, the analyses of sediments cores taken from lakes that are situated in the river catchments provides a useful tool for recognizing erosion processes.

The specific properties of the quasiliquid film of the ice surface

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key words: quasiliquid film, ice surface, frozen systems, conductivity

Conductivity of frozen soils has ionic character. Their electrical resistance is determined mainly by the presence of an unfrozen water film and its amount, by the chemical composition of the solutes present, by the temperature of the medium and so on. Current-carrying ways in the frozen systems essentially differ in comparison with the unfrozen systems. Hence, it is possible to draw certain conclusions about the cause of ion migration in frozen soils by studying the dependence of the frozen soils conductivity on temperature and chemical composition of the pore solution. As a soil model, frozen sand was investigated. To prepare samples, river sand was washed following a standard procedure. The sand portions were saturated to moisture content of 20% with the solutions (0.05 mol l⁻¹) of the alkaline and alkaline-earth metal chlorides. They were frozen at a temperature of -20°C in an electrochemical cell. Electrical resistance of the cells was measured at temperatures from -2 to -15°C as the system reached equilibrium at each temperature.

The character of changes in electrical resistance of the frozen systems is practically identical irrespective of a salt cation. However, KCl and BaCl₂ usually form solid eutectics (microheterogeneous mixture of the solid phases of water and salt) in the examined temperature range. Therefore at temperatures below the eutectic temperatures of these salts (-10.6 and -7.7°C, respectively), full crystallization of both water and salt should have taken place and the electrical resistance of the frozen sands containing KCl and BaCl₂ should have abruptly increased. However, this was

not observed presumably because of the presence of mobile ions in the unfrozen water films, which consist of water adsorbed on the surface of mineral particles and a quasiliquid film on the surface of ice inclusions.

In our opinion, it is the quasiliquid film of the ice surface that promotes solute migration in the frozen systems. The additional experiments to study conductivity of the frozen KCl solutions with a waterproof filler at a constant negative temperature have confirmed this hypothesis. Water of the quasiliquid film differs on structure from bulk water, therefore water of the pore solution in the frozen substrate has the properties of a solvent, which differ from those of bulk water. It does not form eutectics with KCl and BaCl₂ (in a certain meaning of this word) up to -15°C. Hence, salt migration in the frozen ground can occur when the natural temperatures are lower than the eutectic temperatures of these salts.

Cs-137 distribution in tundra soils and landscape catenas as an indicator of modern processes in the active layer

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key words: active layer geochemistry, radiocesium, coastal tundra landscape

Long-lived technogenic radiocesium has been being involved in natural biogeochemical cycles and mass migration processes for more than 40 years since the time of nuclear weapon testing. Numerous investigations of the global radionuclide fallout have focused mainly on the large-scale and regional evaluation of its radioecological consequences and food chain contamination. Local studies with detailed investigation of radionuclides in soil-plant system and landscapes have been performed within the areas with considerable radionuclide contamination after several incidents and accidents at the enterprises and installations using nuclear fuel and radiochemical plants for monitoring and land management purposes (Nifontova, 1998; Barretzen et al., 2002; Korobova et al., 2004; Rikhvanov, 2004).

The main goal of our investigations carried out on the Yamal Peninsula, in the Pechora and Yenisey delta areas in 2002 to 2004 was to find whether Cs-137 can be indicative of natural landscape processes typical for permafrost areas with complicated landscape structure (Leibman et al., 2000; Shcherbov et al., 2000). The obtained preliminary data have shown landscape patterns of cesium-137 distribution in flood plain and terrace soils and sediments of different geomorphological positions (Korobova et al., 2004). Radiocesium concentration determined with the help of HPGe detector (Canberra, USA) varied in the studied Yamal landscape cross-sections from <0.1 to 195 kg⁻¹ dw that corresponds to (Nifontova, 1998; Barretzen et al., 2002; Rikhvanov, 2004). Maximum values were registered in the top organic soil and clay layers compared to sandy sediments. In landscapes with typical cryogenic landsliding and solifluction structure (Ukraintseva et al., 2004) maximum radiocesium contamination was detected in soils of the older sheared surfaces and landslide bodies of the catena lower accumulative level being now overgrown with high willow shrubs. Elevated local depressions were also noted for relatively enhanced radiocesium level while its variation in soils of the young landslide slopes was lower (45 to 85 kg⁻¹). Young shearing surfaces and deep frozen layers were practically clean of radiocesium. Permafrost can serve as natural barrier protecting from radiocesium penetration to the deeper horizons. In soil samples from the Lower Pechora including the Bolvansky Cape area Cs-137 activity ranged from 16 to 156 kg⁻¹ being higher on Cape Bolvansky. Revealed patterns are believed to reflect initial radioactive contamination and its secondary redistribution through landscape processes due to sorption and further solid and water mass migration and accumulation related to cryogenic phenomena. Local enrichment in Cs-137 of the lower soil layers may result from burial of the contaminated organic-containing surfaces and river deposition of fine sediments known for higher sorption capacity. Therefore Cs-137 distribution in tundra soils and landscape catenas can be used as an indicator of modern processes in the active layer.

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Geochemistry and isotopes of surface and ground ice in the Arctic

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key words: ions, trace elements, isotopes, tabular ground ice

A large-scale geochemical study of tabular ground ice is ongoing since 1998. Sections were sampled at the Kara Sea region (Yugorsky and Yamal peninsulas) and Far East region (Chukotka). Last years in addition to sampling ground ice and enclosing deposits, glacial ice and snow were studied and used as benchmarks for possible tabular ground ice formation. Kolguev Island was a key site for modern and buried snowpatches while Svalbard and Novaya Zemlya Archipelagos were key sites for glacial ice, icings, pingo ice and modern snowpatches. Several test techniques were used. Ionic and trace element study, isotope (³⁴S, ¹³C, ¹⁸O and D) study data are analyzed in this paper with more emphasis given to surface snow and ice geochemistry.

Ionic composition of snow and glacier ice is hydrocarbon-calcium with variable Mg content reflecting aerosol composition in the air precipitation of the Arctic. While cation composition shows source of soluble salts and thus source of water, anions show freezing conditions under which ice was formed. Proportion of chloride, bromide and sulfate ions in snow and glacial ice as compared with tabular ground ice shows that the last was formed under considerably lower temperature, which can be interpreted as higher salinity of the source water. Trace-element content is found to be much (up to an order of magnitude) higher for the moisture of an atmospheric origin (snow and glacial ice). Especially significant difference is in the content of Fe. This is resulting from the high content of trace elements in the Arctic aerosols, the same reason as for the cations content. Tabular ground ice of Chukotka is the only ice - if that type has a relatively high content of trace elements - which make us consider a different origin of this ice, probably initiating from the initially surface ice. Data obtained on Sulfur shows clear differentiation for moisture of various types. The highest content of heavy isotope ($\delta^{34}\text{S}$ average +15.7‰) is characteristic of tabular ground ice in Chukotka section. The lightest isotope composition is found in the snowpatches of Kolguev island. It is important to note that this value is close in both modern snowpatch and rather ancient, buried one (average $\delta^{34}\text{S}$ about -4.5‰). Other than Chukotka tabular ground ice sections showed intermediate values of $\delta^{34}\text{S}$, thick ones covered by clayey marine deposits being 2 to 3 pro mil heavier compared with thinner layers in the sand. Glacier ice with very low content of sulfate showed the lightest values of $\delta^{34}\text{S}$ (average +5.7‰). Icing and pingo ice were tested to show properties of ground water when frozen on or near the surface. Icing has the highest content of sulfate, proving its subsurface origin and has intermediate values of $\delta^{34}\text{S}$ (around 12.5‰). Pingo ice contains rather a big amount of sulfur, in core water and even a higher content in the ice out of this water, forming an icefall at the side of the pingo. As to $\delta^{34}\text{S}$ content it is very light in the ice (-4.2‰) while the heaviest of all the samples in the core water (+19.2‰). Oxygen and Deuterium isotope composition showed the following. $\delta^{18}\text{O}$ vary in a wide range in both surface and ground ice types, in the tabular ground ice being in average of lighter composition compared with modern surface snow and ice due to its formation in much colder times compared with modern climate. Excess Deuterium shows close relation of tabular ground ice to the meteoric water line, but when compared to the moisture originating from atmospheric precipitation, one can see that even averages for tabular ground ice are located below the meteoric water line, and ratio δD to $\delta^{18}\text{O}$ is notably higher for tabular ground ice than for surface ice. Thus geochemical-isotope studies of modern surface snow and glacier ice and tabular ground ice in the Russian Arctic showed the following. (1) Most tabular ground ice

bodies were formed under a low temperature, possibly out of rather saline water. (2) High content of trace elements is an evidence of initially surficial origin of the ice body. (3) Light isotope composition of Sulfur in sulfates points to initially snowpatch origin of the ice body. The study was supported by INTAS 01-2211.

Structure and composition of Late Quaternary permafrost sequences at Cape Mamontov Klyk, Northern Siberia, and the palaeoenvironmental and palaeoclimate implications

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key words: palaeoclimate reconstruction, stable isotopes, ice wedges, Northern Siberia, sedimentology

Research at Cape Mamontov Klyk, Northern Siberia, was carried out to reconstruct the palaeoclimatic and palaeoenvironmental history in this remote region. The investigated area is located in the Lena-Anabar lowland at the Laptev Sea coast. Generally, the cliff of Cape Mamontov Klyk (73° 36' N; 117° 10' E) consists of ice-rich sediments with a complicated depositional and cryolithological situation.

Samples of sediments and ice wedges of different generations were taken over the whole vertical profile of the cliff for sedimentological, hydrochemical and isotope-geochemical analyses. These include analyses of grain size, and C and N content in order to get information about the conditions of deposition. With the ice wedge samples hydrochemical analyses (major ions) and $\delta^{18}\text{O}$ and δD analyses were carried out for information about hydrological and palaeoclimatic conditions. A clear stratification of four units outcropping at the cliff can be found regarding the different sedimentological parameters. About 4 m thick bottom sands with ice-sand-wedges represent the oldest unit in this section (IRSL dated between 31.3 ± 4.2 and 56.2 ± 6.7 ka). It is overlain by a 5 m thick peat-sand-complex with small ice wedges radiocarbon dated 30 to 45 ka ^{14}C BP. Above that the Late Pleistocene Ice Complex as the main unit (about 9 to 20 m thick) is one of the most peculiar cryolithological formations in this region characterised by silty sands with huge syngenetic ice wedges. The Ice Complex is partly covered by a 2 m thick horizon of peat-rich, silty sediments of Holocene age. Besides this, two more subunits of Holocene age can be distinguished: deposits of thermoerosional valleys as well as fluvial deposits. First interpretations of these units indicate changing depositional conditions from a rather fluvial to an alluvial environment in the Pleistocene and thermoerosional destruction in the Holocene.

Recent ice wedges of the profile seem to be genetically correlated with snow patches as their isotopic composition is in the same range. Ice wedge growth is caused by the repeated cracking of the frozen ground, followed by penetration and refreezing of melt water of winter snow. Thus, the isotopic signal of wedge ice may reflect winter temperatures. Assuming this, results of the isotopic composition of the ice wedges indicate that today's climate seems to be the warmest for that area since recent ice wedges show the heaviest isotopic composition of all units. Winter conditions during the Holocene were similar, but slightly colder than today.

The Pleistocene ice wedges show a clear transition in the isotopic compositions which separate them clearly from the Holocene units ($\approx 5\text{‰}$ in $\delta^{18}\text{O}$ less) pointing to colder winter temperatures at that time. The peat-sand-complex shows extreme variations in the isotopic composition. It has to be solved if these variations can only be explained by fluctuations in the winter temperatures. The lowermost unit (bottom sands) represents a period that is characterised by cold temperatures and low climatic variability in the winter season.

Hydrochemical results for the ice wedges show that Holocene ice wedges are characterised by higher sodium and chloride contents and may therefore point to a stronger maritime influence whereas ice wedges of Pleistocene age show higher contents of calcium and hydrogen carbonate and may therefore be associated with a rather continentally affected environment.

Dating of permafrost by cosmogenic radionuclides

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key words: permafrost, ³⁶Cl, ¹⁰Be, Chronosequence

The paper for the first time focuses on the fundamental geocryological goal - direct determining of permafrost age with implications in many fields of geo- and bioscience. In general, the duration of the permafrost existence does not coincide with the age of the sediments. Therefore, a cross-section of the cryolithosphere (except the syngenetically frozen layers, that were frozen upon deposition and never had thawed) represents a sequence with known age of the sediments and with permafrost age, which is unknown or different to the sediment ages.

Theoretically, the problem could be solved using the approach of nuclear physics. We present a method of permafrost dating with the cosmogenic radionuclides ³⁶Cl and ¹⁰Be in ice as a natural chronometer. The principal advantage of the proposed dating method for permafrost studies is based on the determination of the time of ³⁶Cl and ¹⁰Be fixation that corresponds to the age of the ice. As the first application, ice wedges are dated. As signals, the ³⁶Cl and ¹⁰Be ratios are used. ³⁶Cl and ¹⁰Be are produced in the atmosphere by nuclear and spallation reactions of cosmic rays with argon and nitrogen or oxygen, respectively. Stable chlorine enters the atmosphere from the oceans and is contained in the precipitations. The ratio does not depend on chloride concentrations in precipitations and on sublimation of snow. *In-situ* production of ³⁶Cl in ice via neutron capture reactions on chlorine and of ¹⁰Be via cosmic ray induced reactions on oxygen are calculated.

Preliminary analysis of the results supports feasibility of the permafrost dating. ³⁶Cl/Cl ratios in late and middle Pleistocene Icy Complexes samples from the cape Svjatoy Nos on the Laptev Sea coast (72° N, 140° E) were measured by accelerator mass spectrometry. The time difference between the formations of these Complexes was estimated as 0.4 million years. This time difference compares reasonably well with a time difference estimated by traditional geological methods. Dating limit based on the presented method corresponds to an age limit of 3 million years. This interval covers all possible Arctic permafrost horizons and the significant (from late Pliocene) part of Antarctic permafrost. As a next approach step, ³⁶Cl and ¹⁰Be in ice-cement and segregated ice will be dated. To develop the cosmogenic dating of permafrost age, it is necessary to correlate these data with the geological and permafrost history.

Geochemistry and mineralogy of tabular ground ice, Yugorsky peninsula, Russia

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key words: tabular ground ice, granulometric composition, mineralogic composition, cryo-metamorphic process, cryogenic construction

Tabular ground ice is a unique natural object which origin is not finally determined. During the period 1998 to 2004 tabular ground ice was under study on Yugorsky peninsula, Shpindler section. This study generalizes the results of field and laboratory studies as well as geochemical modelling. Studying cryolithological structure and especially the lithogenic component of the main stratigraphic units in the natural exposures at Yugorsky peninsula along a 45-km coastline allowed to determine the pattern of tabular ground ice position in the sequences. The tabular ground ice is linked to the interface marine clay/pro-deltaic sand-silty clay-peat interbedding (upper ice body), and pro-deltaic interbedding/fluvial granule-pebbly sand (lower ice body). In addition, these interfaces separate overlying aquifuge and underlying aquifer.

It was for the first time that the granulometric and mineralogic analyses of impurities in the tabular ground ice were performed. These analyses showed that tabular ground ice is a unified geological body related to enclosing sediments. This relation is manifested in the specific granulometric composition of the lithogenic impurities distributed in different parts of the ice body and in the down-directed change in granulometric spectrums from ice toward the underlying sediments. The cation-anion composition of the ice depends on the amount of lithogenic impurities or on the proximity to underlying sediments. This pattern evidences in favour of relation between tabular ground ice and underlying sediments. Distinctive features of lithogenic impurities in tabular ground ice in comparison with enclosing sediments were revealed. The tabular ground ice comprises a separator between covering and underlying sediments at which noticeable change of numerical indices for mineralogical associations is observed. The same change is noted when analyzing coefficient of cryogenic contrast (CCC). CCC shows that these changes are caused by transition from thermochron to cryochron. The cation-anion composition for tabular ground ice rich in lithogenic impurities, as well as for overlaying sediments, probably, were formed under cryo-metamorphic processes. The increased content of mirabilite ions in the marine clay unit and the systematic transition of mirabilite concentration from thermochron to cryochron is in favour of cryo-metamorphic process.

The main result of the study is numerical justification of the assumption that tabular ground ice at Shpindler section was formed intrasedimentally. Sources of water and impurities in the ice were underlying sediments. The study was supported by grant INTAS 01-2211.

Thermal and geochemical investigations about some ice wedges of Northern Victoria Land (Antarctica)

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key words: ice wedge, thermal regime, oxygen isotopes, hydrogen isotopes, tritium activity

During the XIV, XVI and XIX Italian Antarctic Expeditions (1998 to 99, 2000 to 01 and 2003 to 04, respectively) geomorphologic surveys of permafrost-related polygons were carried out in the Northern Victoria Land. Ice wedges were found in sites with different altitudes and climate conditions in a vast area extending from the Terra Nova Bay up to the Freyberg Mountains. They were placed at depth ranging between 10 to 15 cm and 60 to 65 cm from the surface. Their width ranged from 5 to 7 cm to 155 cm at the top, and their extension into the ground ranged from more than 50 cm to over 150 cm. The ice of the wedges was milky white in colour, mainly free of sediments and with numerous oriented and clearly visible gas inclusions forming vertical foliations. A vertical fissure, 2 to 5 mm wide, filled with small loose ice grains, was present in the centre of most ice wedges.

The ice was sampled by inserting an ice screw, with an internal diameter of 14 mm, into the ice wedge in vertical sequences. All the samples were measured for their oxygen isotope ratios (reported as delta units in per mil, versus V-SMOW) while in some cases a co-isotopic study was performed, measuring both oxygen and hydrogen isotope compositions. Tritium activity measurements were also carried out. This isotopic study aimed to define the origin and the growing processes of the ice forming the wedges. Indeed, co-isotopic studies are widely used in order to determine whether melting-refreezing and/or sublimation processes have affected a ground ice body. The same authors have already suggested that sublimation phenomena could have played an important role during the growth of an ice wedge located at high elevation in an inland site in the Terra Nova Bay area.

On February 2004 two data loggers for monitoring ice wedge thermal regime were installed at two selected sites located respectively at 18 and 870 m a.s.l. The data loggers (Testostor 171/4) recorded top and bottom ice wedges temperature, surface ground temperature and air temperature, by means of NTC sensors. The temperature of the ice wedges ranged from -3.4°C and -6.3°C at their top in February, to -27.2°C and -32.8°C at their bottom in July. At the site located at 18 m a.s.l. high thermal gradient more than 21°C between air and top of ice wedges were measured on June 2004. Such high gradient was connected to a sudden and remarkable increase of air temperature which reached +1°C in a few hours. The high thermal gradient coupled with the presence of hoarfrost crystals more than 20 mm in diameter, observed in the contraction crack of one ice wedge during field surveys, corroborate that sublimation processes may control the formation of ice in the growth processes of some ice wedges.

Mineral formation in sediments formed in permafrost landscapes

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key words: cryolithology, mineral formation, environmental conditions

During the cryolithological investigation of numerous Quaternary permafrost sequences in northern Siberia many data were obtained on peculiarities of mineral formation in sediments and soils that were formed in permafrost landscapes. We achieved the results using a complex of mineralogical methods. They show the potential of newly formed (authigenic) minerals to indicate environmental conditions under which sediment was accumulated and frozen.

Processes of mineral formation in permafrost landscapes are restricted to the active layer and taliks. But the most significant and varied associations of newly formed minerals can be found in horizons affected by seasonally freezing. Strong seasonal temperature variations favor energy and mass transport in these freezing-thawing systems and lead to cryogenic precipitation and the dehydration of colloids and to the formation of well-crystallized minerals.

The concrete association of authigenic minerals depends on the environmental conditions of the cryolithogenesis. But geochemical landscape character and the stage of climate continentality also determine the specific features of mineral formation in sediments and soils. Humid climate conditions favor peat accumulation and a reducing acidic environment. Under such conditions lepidocrocite and vivianite are the most characteristic authigenic minerals. In extreme continental climate regions, for example in Central Yakutia, low precipitation and high summer temperatures lead, on the one hand, to the humification of organic matter, but also to salt accumulation in soils and water bodies due to intensive evaporation and transpiration. Alkaline environments with different oxidation stages dominate here. Characteristic authigenic minerals for reducing environments are iron sulfides of the greigite- mackinavite group mostly in association with Fe-Mn-bearing carbonates or Fe-hydroxides. Under oxidizing and dry conditions oxides and hydroxides of iron and manganese carbonates (calcite and dolomite group) as well sulfates and other ephemeral readily soluble minerals are typically created minerals. In areas with clay-rich rocks in the denudation area relatively high concentrations of soluble Al in surface waters and soil pore solutions lead to the formation of very specific cryogenic authigenic forms of corundum and other modifications of aluminas. Examples of the occurrence and distribution of authigenic minerals in permafrost deposits developed in different environments will be given.

An oxygen isotope record from the Foscagno rock glacier ice core (Upper Valtellina, Italian Central Alps)

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key words: rock glacier, oxygen isotopes, glacier ice, permafrost, paleoclimate

Here we present a new oxygen isotope record obtained from the Foscagno rock glacier ice core drilled in June 1998 at 2510 m in Upper Valtellina (Italian Central Alps). The drilling was carried out in the frontal part of the right lobe of the active Foscagno rock glacier. The borehole reached a depth of 24 m and massive ice was found between 2.5 and 7.65 m. The massive ice can be divided into two parts according to its macroscopic characteristics: the upper core between the depths of 2.5 and 4 m, and the middle core between the depths of 4 and 7.65 m (Guglielmin et al., 2004). Crystallographic and chemical analyses (Guglielmin et al., 2004) have already suggested that the ice characteristics between 2.5 and 4 m, are consistent with superimposed ice that formed as a consequence of melting and refreezing processes. On the contrary, the ice between 4 and 7.65 m can be considered as a relict glacier ice body. Oxygen isotope measurements (reported as delta units in per mil, versus V-SMOW) were carried out in the massive ice with a mean sampling resolution of about 15 to 20 cm and 3 cm in the depth intervals between 2.5 and 4 m and between 4 and 7.65 m respectively. The oxygen isotope data suggest a clear division between the upper and the middle core. The upper core shows quite homogeneous data gathering around a mean $\delta^{18}\text{O}$ value of -12‰, while the values obtained from the middle core (4 to 7.65 m) range between -16.3 and -10.1‰. These variations can be considered as seasonal fluctuations preserved after the firnification process, similarly to what observed in the chemical profiles (Guglielmin et al., 2004). Guglielmin et al. (2004) indicated a minimum age of 2200 ± 60 yr BP (uncalibrated ^{14}C ages) for the

rock glacier although the possibility for an older age cannot be excluded. On the basis of the isotopic composition of modern precipitation in northern Italy (Longinelli and Selmo, 2003), the mean annual $\delta^{18}\text{O}$ value expected for the precipitation in the area of the Foscagno rock glacier could range between -12 and -12.5‰. We obtained a similar value (-12.5‰) averaging the data obtained from the massive ice between 4 and 7.65 m, suggesting a climatic period similar to the present day or at least slightly cooler. The new isotopic data presented here are further confirming the interpretation of the massive ice as a relict of glacier ice preserved within permafrost. Moreover, we want to emphasize the importance of rock glacier as a source of paleoclimatic information.

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Structure and isotopic composition of snow cover in Yakutsk region

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key words: snow cover, isotopic composition of snow, horizon of depth, hoar, snow metamorphism processes, modern ice wedge

According to the present opinion the stable isotope composition of ice wedges is mainly determined by average isotopic composition of winter precipitation and reflects well winter climatic conditions. The starting point for these investigations is the study of the isotopic composition of modern winter precipitation and its relationship with isotopic composition of modern ice wedges in the region. In 2000 to 2004 the isotopic composition (^{18}O , D) of both fresh snow, snow cover during winter and spring and recent ice veins of ice wedges were studied in detail near Yakutsk at a special polygon in the frame of Russian-German scientific cooperation. The structure of snow cover and its changes during winter and spring were studied in parallel.

One of the main features of snow cover structure in the region is the horizon of depth hoar - the result of snow metamorphism processes due to high temperature gradients. Other important feature of snow cover is the intensive evaporation of upper part of snowpack in spring. All these processes may cause the isotopic redistribution in snow cover and considerably change the initial isotopic composition of fresh snow. In the result the isotopic composition of snowmelt which is the main source of modern ice veins may differ from average isotopic composition of winter precipitation. In this report we present and discuss the results of field studies of accumulation and melting of snow cover, possible changes of isotopic composition formation, processes of modern ice wedge formation in the region. The investigations of snow cover structure and isotopic composition, as well as modern processes of ice wedge formation in the Yakutsk region will be continued.

The research of phase balance parameters and formation temperature for cryopegs

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key words: cryopeg, hydrochemical analysis, phase balance parameters

The research results for phase balance parameters of cryopegs water with the help of various experimental and computational methods are presented. The calculation of phase balance parameters is especially difficult for cryopegs, because of their high mineralization and chemical reactions under temperature variations. The hydrochemical analysis of cryopegs, formed in soils, allows restoring the temperature of their formation. S.M. Fotiev developed the graph-analytical method using Gitterman's experimental data about consecutive change of salt composition of seawater during its freezing-out. Using this method it is possible to estimate the temperature of formation of cryopeg ionic

composition, assuming the total mineralization or the chlorides content. This method is applicable only for cryopegs that were formed in soils with the marine type of salinization.

The method is offered that allows to estimate the temperature of cryopeg's formation using the temperature point of the beginning of sulfate falling out with the help of program FREZCHEM2, which has no restrictions connected to chemical composition of cryopegs and to concentration of ions. It allows estimating the diluting of cryopeg solution under temperature increase after its formation. The simulation of cryometamorphism of cryopeg solutions has been carried out, and the data on temperature of ionic-salt composition formation have been received, as well as freezing-point temperature of cryopegs water. The paper presents the results of comparison of calculated and experimental data on freezing-point temperature for samples of quartz sand, salted by mixes: NaCl+KCl, NaCl+CaCl₂, NaCl+MgSO₄. Using the data on consecutive changes of salt composition of seawater during its freezing-out in the range from 0 to -30°C (obtained with the help of program FREZCHEM2), the curve has been constructed that allows to determine the temperature of formation of ionic-salt composition depending on the content of chlorides. The comparison of the cryopegs formation temperature values received by the discussed methods had shown that their differences were less than 1 to 2°C.

Chapter 8

Session 7 - Permafrost Monitoring and Modelling in the Context of Climate Change

Session Conveners: Charles Harris, Wilfried Haerberli or Danni VonderMühl, Lorenz King
in association with:

Studies of seasonal freezing layer dynamics formation processes on the Oka River middle stream Site

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key words: seasonally frozen grounds, landscape, dynamics

The impact of seasonal freezing layer onto ecosystem functioning is discussed as the site area is typical for Russian plain forest geographical zone.

The results of a four-year stationary seasonal freezing research programme in the Protva River (left tributary of Oka River) valley 120 km southeast from Moscow are presented as a map. Spatio-temporal variety of ground characteristics, vegetation cover, snow depths are observed twice a winter: in the beginning and the end of the existence of the seasonally frozen layer corresponding with the beginning of December and the end of February. Winter 1999 to 2003 meteorological conditions vary as indicated by the air temperature, the snow cover depth, the prevailing winds. In addition, landscape, both ground composition and humidity also varied at the beginning of freezing, affecting the seasonally frozen layer thickness and distribution. Multifactor analysis revealed snow depth as the dominating influence. The vegetation cover role is taken into account by determining the surface factor of snow cover thickness variation. On the basis of statistical analysis of each seasonal freezing depth distribution, the map of seasonal freezing of the Site was prepared. The site seasonal freezing map corresponds well with the landscape map. Anthropogenically modified landscapes are inseparable components of the ecosystem on the site area as well as in the central region of the Russian Plain. The anthropogenic impact on the seasonally frozen layer was assessed by comparing it to natural areas with similar ground, snow and microclimate features. Seasonal freezing is associated with a series of negative processes including cryogenic weathering, heaving forces and thaw subsidence affecting low-load in basements of buildings and constructions that are widespread in rural area. The minimal depths of basements necessary in different landscapes are outlined. The impact of the seasonal freezing layer on ecosystem functioning is discussed as the site area is typical for the Russian forest plain geographical zone.

Changes in permafrost in relation to climate change and its impacts on terrestrial ecosystems in the Subarctic, Sweden

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key words: permafrost, active layer, climate change, sea ice variations

In 1978, a long-term permafrost monitoring programme was established (within the framework of IPA) in an east-west transect in the Abisko area, northern Sweden. Continuous annual measurements have been carried out, resulting in the longest still running permafrost data series in the Arctic. The transect cover a strong climatic gradient, ranging from a maritime climate in the west to a more continental climate in the east. In general, regional precipitation decreases (ranging from approximately 1000 mm a⁻¹ to 300 mm a⁻¹) and seasonal temperature differences increase to the east.

At Abisko Scientific Research Station, which is located along the transect, climate monitoring has been ongoing since 1913. As in many other part of the Arctic, an increase in air temperature has been observed at Abisko during the last decades. During the same time period, changes in the depth of the active layer and the distribution of permafrost have been observed in mire ecosystems especially in the sites with maritime climate conditions. The active layer variability correlate well with the summer climate - June to August mean or DDT. The active layer follows the same general pattern and has deepened considerably. The months of May and September have also become warmer which have an effect upon the thawing and growing season. There are several surface indications as a response to the deepening active layer in the bogs. Thermokarst depressions appear frequently and many of the palsa like mounds and pounus have disappeared. The mean active layer in the bog sites varies between 0.48 m and 0.80 m during the period. Individually the deepest active layer is found in the westernmost bogs, where during the last years, the permafrost is almost completely disappearing. Remnants of permafrost are here only found in the few surviving mounds our pounus The soil temperatures are increasing at the -2 m level and in lower layers of the permafrost (-12 m). A deeper active layer and a warming of the permafrost leads to changes in conditions that are of major importance for the ecosystems. In general, extensive permafrost thaw is considered to lead to wetter conditions and replacement of forested communities by peat moss communities. At one mire along the transect observations have shown that vegetation has shifted the last decades. Here we present the current and past (back to 1978) extent of permafrost along the transect and we discuss what has caused the observed changes (geophysical, biologically, anthropogenic causes etc.) in permafrost that has occurred over the last decades. We will also discuss the observed changes in vegetation.

Reaction of the cryosphere objects on global climate change and local technogenic impacts in Atlantic-Eurasian sector of Arctic

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key words: permafrost thickness forecast, active layer mapping, active layer modelling, cryosphere reaction

The Arctic cryosphere includes atmospherogenic, hydrogenic, lithogenic and glaciogenic components, all of which show strong interactions and connections with other natural parameters. Monitoring of permafrost and cryogenic processes is widely used for ecosystem development forecast and for the organization of the most appropriate strategy of Northern development. In connection with complex processes which are taking place in permafrost regions, the cryosphere could be considered as a specific environment. Recent investigations underline the Global Climate Warming trend. The reason for this trend is complex - natural climate fluctuations together with anthropogenic impact. Ice as a mineral with high melting temperature is a very good indicator of climate changes. Permafrost regions show different types of impacts. One of the most important and sensitive elements of the permafrost system is the active layer. There is a significant feedback between cryosphere reaction and formation of new climatic situations, for example changes in distribution of sea ice became the reason for ocean stream redistribution, which caused the development of a new weather regime in the Atlantic-Eurasian part of Arctic. In this report climatic trends for the last 50 to 100 years were analyzed for 15 large Arctic regions (from Greenland to the Chukchi Sea). The regions with warming and cooling trends, and stable temperature regions are found, and cryosphere processes are evaluated. It is concluded that the most sensitive and rapid reaction to climate changes are the snowpacks of the Putoran Plateau and Polar Ural. Changes of active-layer depth are calculated by the year 2050 for 25 points in the Russian Arctic using climatic trends

of temperature and precipitation. The map of active-layer depth changes in sandy soils in Arctic regions of Eurasia was also made. For three regions using the “Teplo” software the permafrost thickness forecast was made by 2050 year. It was found that in the Bolshezemelskaya Tundra the mean thickness of permafrost would decrease from 70 to 67 m, in Pur-Tazovskiy Peninsula from 176 to 168 m, but increase from 245 to 260 m in the Lena-Amginskoe interfluvium. Reaction of cryosphere elements to global climatic fluctuations and regional technogenic impacts are different in terms of the speed of changes in different regions. At the same time dynamics and evolution of cryosphere elements have a significant impact on natural and anthropogenic systems.

The effect of the summer heatwave 2003 on the temperatures of the rock glacier Muragl, Swiss Alps

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key words: active layer, temperature monitoring, thermal properties, soil temperatures

In 1999, four boreholes with depths of about 70 metres were drilled into the active rock glacier Muragl, Swiss Alps. Temperatures were recorded in all boreholes at various depths. One borehole is located at the edge of the rock glacier, where no permafrost was recorded and the other three boreholes show that the lower base of the permafrost is found at a depth of about 20 metres. In order to quantify the effect of the climate on the changes in the permafrost temperatures with time, a new value, the active layer index, was introduced. This index adds up the thickness of the active layer during one year. Since conductive and convective heat fluxes within the active layer control the thickness of the active layer, this new index is thought to be an important value when comparing the effect of climate change with time. The record-breaking heatwave that affected the European continent during the summer 2003 had a significant effect on the ground temperatures, resulting in the largest active layer index recorded since measurements began. On the other hand, the late snowmelt in 2001 resulted in the lowest value measured. The index clearly shows that air temperatures and the snow cover are the decisive factors to control the thermodynamics within the permafrost. The porous material below the permafrost base of the rock glacier Muragl further allows air circulation and seasonal variations could be recorded at greater depth. The warmer temperatures during the summer 2003 also resulted in warmer temperatures at the permafrost base. Even though the heatwave in 2003 has exceeded the 1961 to 90 mean temperature by about 3°C, the changes in the ground temperatures within the rock glacier were much lower, showing the important role of the active layer and that ground temperatures respond very sluggishly and with retardation.

ANTPAS - Antarctic Permafrost and Soils: A contribution to understanding the Antarctic terrestrial cryosphere

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key words: Antarctica, mapping, monitoring, boreholes, data management

Antarctic permafrost forms an integral part of the terrestrial cryosphere, yet information on its distribution, thickness, age, and physical and geochemical properties is highly fragmented and absent for large sectors of the region. At the same time, active layer and permafrost conditions are increasingly recognised to be highly sensitive to climate change. Such changes can create important responses in regional hydrology, ecosystems functioning, landscape stability and human environmental impacts. Furthermore, Antarctic permafrost and soils hold potential to archive high resolution long-term (Ma) records of past environmental change and biological activity.

The combined IPA and SCAR GSSG working groups on Antarctic permafrost and periglacial environments, in close working relationship with the IPA Cryosols and Permafrost Astrobiology working groups, have launched the ANT PAS project to address some of the current shortcomings and research needs. The overall aim is to develop an internationally coordinated, web-accessible, database and monitoring system on Antarctic permafrost and soils. Specific objectives are:

- Integrate existing datasets on permafrost, ground ice, active-layer dynamics and soils into a common, web-accessible, database system.
- Produce a set of thematic maps on Antarctic permafrost and soils as models of our current scientific understanding of the region.
- Utilize non-invasive imaging methods including remote sensing/photogrammetry/GIS, as well as imaging sub-surface conditions with geophysical methods.
- Implement a network of boreholes and collect intact cores (up to >100 m at select sites) along selected environmental gradients to measure chemical, physical and biological parameters in permafrost as proxies for past environmental conditions, as well as to record permafrost responses to climate change. This forms the Antarctic component of the IPA Thermal State of Permafrost (TSP) project, and extends the current Circum-polar Active Layer Monitoring (CALM) network to the Antarctic region (CALM-S).
- Implement a monitoring network of active-layer and periglacial conditions and process responses to climate change coupled to the borehole network (CALM-S).

Proposed to be launched as an IPY activity the database and monitoring project will continue as an ongoing activity of the supporting associations.

Soil temperature and solar activity dynamics in the Western Siberia Plain

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key words: Western Siberia Plain, solar activity, soil temperature, time series

Recent research has demonstrated a correlation between dynamics of solar activity and other meteorological parameters, air temperature in particular. However, soil is directly influenced by solar radiation, and hence dynamics of soil temperature should be strongly dependant on solar activity. We studied the relationship between dynamics of soil temperature (annual, winter and summer time series at depths of 40 and 80 cm) and solar activity for the period 1960 to 1990 for various landscapes of permafrost and non-permafrost zones of the Western Siberia Plain (20 stations). The solar activity was measured as a sum of the number of individual sun spots and ten times the number of groups. Influence of snow depth dynamics on this relationship was also checked. High-frequency fluctuations in the soil temperature time series departures were first filtered. A method of moving linear regression was applied as a filter. This approach provides the curve smoothed, and it allows us to assess the value of heating/cooling for corresponding periods. Generally, the main periods of heating/cooling in the annual soil temperature time series departures did not coincide with the dynamics of snow depth but were coincident with periods of increase/decrease in solar activity.

Contribution of ground surface temperature mapping and monitoring in mountain permafrost studies

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key words: ground surface temperature, BTS, mountain permafrost, monitoring

Measuring the ground (sub-)surface temperature is a widely used method for prospecting mountain permafrost. Main techniques are the year-round continuous logging of the ground surface temperature (GST) by means of mini-temperature logger and the instantaneous BTS (bottom temperature of the snow cover) mapping in wintertime. Numerous questions have been raised about the reliability of both BTS and MAGST (mean annual ground surface temperature) values as permafrost indicators. Indeed, both data only represent indirect information on permafrost (active layer thermal offset) and significant variations in ground surface thermal conditions are likely to occur from year to year, making data interpretation difficult.

Working in marginal mountain permafrost areas, where permafrost, if present, is close to 0°C and widely discontinuous, we now have established a database containing more than 5000 BTS measurements and about 1000 annual GST curves. In several cases, a monitoring strategy has been applied during the last 5 to 10 years. Our experience makes it worthwhile to revisit and discuss the potential of both BTS and GST methods. BTS and MAGST reflect the thermal state of the ground surface at (or during) a certain time, which must be then be carefully interpreted taking account of surface characteristics (grain-size, porosity,...), snow conditions, weather, etc.

Significant inter-annual variations in BTS and MAGST can occur depending on climate conditions. They are moreover larger on coarser and/or colder terrain. Raw single-year BTS and MAGST values cannot be used as direct permafrost indicators. The probability for permafrost to occur is however higher where BTS and/or MAGST are colder. MAGST behaviour over many years is a key factor controlling the temperature evolution of the subjacent (permafrost) ground at depth. Inter-annual changes in MAGST appear to be rather homogenous at a regional scale but may differ drastically at a local scale. The latter could reflect for instance inter-annual changes in snow cover repartition (due to avalanches or predominant wind). Air circulation within porous material may strongly affect the evolution of GST during winter time. In consequence, it is locally possible that BTS do not reflect the thermal state of the subjacent ground. BTS mapping was successfully applied in some studies for detecting the efficiency of a ventilation mechanism (chimney effect). A monitoring strategy (measurements over several years) has to be envisaged in most studies where BTS and GST methods are applied. Both reliability and originality in the results may thus be significantly improved. Simultaneously, a regional monitoring of BTS and GST is worthwhile since it furnishes a reference for the temporal evolution of ground surface temperature (and therefore permafrost) as well as allowing reliable interpretation of single-year BTS mapping and GST measurements.

Witnessing global change in the Arctic: a four year record of the slow thermal decay of a palsa

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key words: palsa, permafrost monitoring, permafrost decay rate, Hudson Bay, Umiujak

The response of the frozen core of a palsa to climatic changes has been jointly monitored since July 2000 by the Université Laval (Quebec) and BGR. The palsa site is located east of the village Umiujaq, Quebec, Canada near the eastern shoreline of the Hudson Bay in discontinuous permafrost terrain. The monitoring operation was initiated by drilling six boreholes through the palsa. The palsa has a diameter of 50 m and features steep slopes, rising by 2.1 m to 3.4 m above the surrounding permafrost-free wetland. The boreholes have been instrumented since July 2000 with temperature sensors to monitor temperature changes in the soil. Now available is a four year record of the slowly advancing decay of the permafrost, being slowed down currently by the effect of the harsh winter seasons of 2002/03 and 2003/04. Several significant observations were made by our monitoring program. Temperature recordings from the base of the permafrost (as well as the measurement of fluctuating pore pressure near the freezing front) suggest episodic cracking of the frozen basal soil, causing influx of groundwater into the permafrost body. Secondly, our temperature recordings demonstrate the strong thermal influence of slowly intruding fluids. Groundwater from the unfrozen surrounding terrain migrates laterally at various depth levels into the permafrost body, whose overall temperatures are close - as consequence of climate change - to the melting point. It appears that the thermal decay of permafrost in discontinuous permafrost terrain cannot be described as a stepwise downward enlargement of the active layer with each annual cycle in consequence of surface warming. Our observations suggest that permafrost near the melting point will decay along all boundaries: from above (surface warming due to climate change), the bottom (influence of terrestrial heat flow) and from the sides (intruding groundwater). This observation suggests that the rate of decay of permafrost might be significantly higher than predicted by numerical models, which consider conductive heat flow and uptake of latent heat alone. It is anticipated that this monitoring program will be extended in 2006 by the installation of additional permafrost monitoring stations, which will be positioned on a south north trending transect along the eastern shoreline of the Hudson Bay.

Preliminary geophysical mapping of a massive ground ice body using a combination of resistivity and ground penetrating radar Western Canadian Arctic

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key words: massive ice, geophysics, resistivity, GPR, ground ice

The nature and distribution of ground ice is one of the most unpredictable geological variables in near-surface sedimentary deposits characterized by continuous permafrost (Pollard and French, 1980). Subsurface information about ground ice distribution at any site can be obtained by drilling boreholes and by geophysical investigations. In this study, two geophysical tools, capacitive-coupled resistivity (CCR) and ground penetrating radar (GPR) were utilized to map a massive ice body on Richard's Island in the Canadian Western Arctic. Richards Island forms part of the Pleistocene Mackenzie Delta and consists of undulating tundra terrain, usually less than 50 m a.s.l. The volume of ground ice present in the upper 10 m of the Island has been calculated to be 10.27 km³ (Pollard and French, 1980). This enigmatic occurrence of massive ice is significant for two reasons, first from the scientific perspective because the analysis of its origin will provide insight into a poorly understood aspect of permafrost and ground ice geomorphology. And second, from the engineering and environmental management perspectives knowledge of massive ice distribution will be useful as ice-rich ground are difficult and expensive to develop on due to problems with thermokarst. After collection of the geophysical data, the interpretation of two-dimensional CCR and GPR surveys benefited from a natural section adjacent to the massive ice body. Resistivity values up to 50,000 Ohm.m were recorded in the surveys with areas of known massive ice being resulting in values between 10000 and 30000 Ohm.m. A maximum depth of resolution of 17 meters was achieved using the CCR system. For GPR data, a dielectric constant of 6 was assumed for frozen materials with a corresponding velocity of 0.12 m ns⁻¹. 200 MHz GPR penetrated to a depth of 9 m. Both the CCR and GPR systems were portable and effective in collecting data in very cold temperature (-40°C) although the cold caused minor problems with the CCR batteries. The detection of different layers in the GPR data would have been difficult without the CCR data. It must be stressed that the quality of the data collection was enhanced because the cold temperatures allowed for very deep depths of investigations. The complementary nature of these two geophysical tools led to the accurate detection and mapping of a massive ice body. These two portable, easily operated tools yield accurate, rapid and inexpensive results about ground ice distribution without disturbance to the study site. The use of both systems was essential for the interpretation of the data. Future studies could use a grid of 2D survey lines to map 3D volumes of the massive ice bodies. These techniques may lead to limiting developmental thermokarst.

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Permafrost distribution and dynamics in oceanic (northern Iceland) and continental (northern Mongolia) mountain environments

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key words: mountain permafrost, ground temperatures, bore hole, DC resistivity imaging, Iceland, Mongolia

Permafrost in high-mountain environments is extremely heterogeneous, and its distribution depends on topo-climatic factors in addition to snow and vegetation cover. The presentation gives examples and new data from mountain environments being on the fringe of permafrost existence, namely from Iceland and northern Mongolia. Iceland is governed by an oceanic climate type, with low temperature amplitudes and high precipitation. However, simple air temperature modelling and new bore hole temperature measurements revealed warm, thin, but wide-spread mountain permafrost at altitudes above 850 to 900 m a.s.l. Northern Mongolia is dominated by a continental climate type and lies at the southern edge of Siberia, forming the southern-most fringe of the Siberian continuous permafrost zone. Temperature measurements on the surface and in the ground together with DC-resistivity tomography and

topographic analyses revealed a highly heterogeneous distribution pattern with respect to permafrost and active layer thickness. Both environments are dominated by warm permafrost, and thus will possibly react quickly to changes of the environmental boundary conditions, which are totally different within the two sites. The presentation will discuss the measurement in the study areas in the light of geomorphological consequences.

Permafrost boreholes in Iceland

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key words: mountain permafrost, boreholes, thermal monitoring, Iceland

Iceland lies between the Scandinavian peninsula and Greenland, governed by an extreme maritime climate type. With respect to permafrost, Iceland is a link between the Scandinavian mountain permafrost and the Greenlandic arctic permafrost. Furthermore, Iceland is an area of high volcanic activity, influencing the ground thermal regime. The major aims of this study is to delineate the mountain permafrost distribution in the northern and eastern parts of Iceland, and try to estimate permafrost thermal regimes and thickness in areas of high geothermal gradients. In this context, four shallow boreholes have been installed with UTL-1 temperature miniloggers. One of the boreholes is situated in the inland of Iceland (Hágöngur, 899 m a.s.l.), while the others are situated in the east (near Snæfell, 918 m a.s.l.; at Gagnheiði, 952 m a.s.l.; near Vopnafjörður, 895 m a.s.l.). These boreholes represent areas within the volcanic rift zone as well as areas outside with decreasing heat flow in the ground. Although temperature measurements in the boreholes just started August 2004, thereby lacking any solid proof of permafrost by definition at this point, the measurements clearly indicate warm permafrost in all places except for the Vopnafjörður borehole. There, temperatures measured in September decrease with depth down to the bottom of the hole, 22 m below surface, where stable temperatures of 0.08°C are found. It is suspected that this temperature inversion is not solely due to a winter cold wave, but also represents warming due to climatic change. Thus, permafrost might exist further down in a degrading state. The borehole temperatures combined with preliminary regional modelling based on altitude of the MAAT = -4°C indicate that mountain permafrost is a quite widespread phenomenon in northern and eastern parts of Iceland with lower altitude limit of discontinuous permafrost of roughly 800 to 900 m a.s.l. in the study areas. This is supported by DC resistivity tomography measurements and geomorphological indications. Iceland is an area with anomaly high geothermal fluxes. Thus, the anticipated permafrost areas probably constitute relatively low thicknesses and are, thus, likely sensible to potential (and likely ongoing) climate changes.

Historical soil temperature changes in northeastern Siberia

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key words: soil temperature, climate change, permafrost, Siberia, warming

Soil temperature is an important indicator of climate change, especially in high-latitude environments. It is linked to the climate through the ground surface, vegetation, snow cover, and the active layer. Long-term soil temperature measurements at five depths (0.2 m, 0.4 m, 0.8 m, 1.6 m, and 3.2 m) are investigated for the continuous permafrost region of the Russian Arctic, from approximately 115° E to 160° E and 60° N to 70° N. These in situ measurements are based on station records from 31 sites, dating as far back as 1915 and extending through 1990. However, the 1956 to 1990 period is more reliable, and is thus the focus of this investigation. We find that across all depths, on an annual basis permafrost temperatures have been experiencing a statistically significant increase, with greatest changes near the surface (0.72°C/decade) and smallest change at 3.2 m (0.46°C/decade). On a seasonal basis, changes are greatest during winter (0.50 to 1.34°C/decade), followed by spring, then summer, and the smallest temperature changes are observed during autumn (<0.25°C/decade). We next evaluate the degree to which these changes are driven by air temperature, freezing/thawing index, snow depth, as well as warm-season precipitation. Preliminary findings suggest that during winter, soil temperature increases are driven by air temperature and snow cover, while summer increases are related to air temperature and precipitation. Cold-season permafrost temperature increases are therefore partly due to the insulating effects of increased snow depths in northeastern Siberia, while the warm-season soil temperature increases illustrate the importance of soil moisture on the thermal regime. However, part of the summer time changes are likely also due to soil “memory” effects, related to the higher winter soil temperatures.

Impacts of climate change on the distribution of palsas in the discontinuous permafrost zone of Northern Europe

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key words: palsa, climate change, scenario, 21st Century, Global Circulation Model (GCM)

Palsas are peat mounds with a core that is frozen throughout the year. They are located at the edges of the permafrost zone. They support a rich diversity of flora and fauna but are currently thought to be in decline due to climate warming. We develop a statistical model describing the distribution of palsas in the discontinuous permafrost zone of Northern Europe using climatological explanatory variables. The model is studied with respect to its climate-sensitivity and climate change scenarios are applied to assess possible impacts on the palsa distribution during the 21st Century. The model explained more than 88% of the palsa distribution and therefore suggests a strong dependency on climate. Already small increases of temperature and precipitation resulted in considerable losses of areas suitable for palsa development. The model predicted the total disappearance of palsas with an increased mean annual temperature of +4°C. The application of the model to climate change scenarios based on seven Global Circulation Models (GCMs) showed that the degradation of palsas might proceed very quickly. The area suitable for palsas in Northern Europe was reduced to only ca. 10 to 50% for the 2020s, depending on the climate model and scenario. All except of one climate scenario resulted in the total disappearance of palsas by the 2080s.

Change of the permafrost lower limit in 1973 to 2004

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key words: Nepal, Himalaya, mountain permafrost, mean annual air temperature, greenhouse warming

We researched the permafrost distribution in Khumbu region, Nepal Himalaya in 1973. We estimated that the permafrost lower limit in 1973 was 5200 m in flat terrain or south-facing slope of Khumbu region based on ground temperature measurements. In order to clarify the altitudinal difference of permafrost lower limit between 1973 and 2004 in Khumbu region, we researched the permafrost distribution in Khumbu region in 2004. We estimated that permafrost lower limit in flat terrain or south-facing slope of Khumbu region in 2004 is 5400 to 5500 m based on ground temperature measurements. Thus, the permafrost lower limit in Khumbu region has risen 200 to 300 m between 1973 and 2004. Since the lapse rate of air temperature in Khumbu region is about 0.4°C/100 m that is calculated with air temperature data at Syangboche (3833 m) and at Lobuche (5050 m) between 1994 and 1998, it is likely that the mean annual air temperature in Khumbu region has risen about 0.8 to 1.2°C for recent 30 years.

Winter thermal regime of ground surface in the zone of sporadic permafrost occurrence in Tatra Mountains

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key words: ground surface temperature, permafrost, BTS, Tatra Mountains

Monitoring of ground surface temperature (GST) with application of miniature loggers in the zone of sporadic permafrost occurrence (above 1850 m a.s.l., MAAT 0 °C) started in autumn 2003. The aim of measurements is the determination of conditions of ground thermal regime and the verification of results of permafrost mapping using BTS method. The measurements are carried out in glacial cirques in High Tatras both in locations with permafrost occurrence (confirmed in outcrop, DC resistivity soundings and infrared imaging) and permafrost free. Because of the strong relationship of topographic conditions, snow cover and permafrost, winter measurements are especially valuable. The obtained results indicate three stages of development of ground surface temperature in winter period, which are similar to the development of snow cover in sites studied:

- The stage of origin and slow growth of snow cover and large short-term temperature oscillations of its substratum. At the end of this stage, GST reaches the smallest values. In the places of permafrost occurrence, they are usually minus dozen or so °C and in other places minus several °C.
- The stage of high snow cover and stabilisation of its substratum temperature. In the places of permafrost occurrence, the ground surface temperature is usually in the range from -5 to about -10 °C. In the permafrost free places it is from 0 to about -5 °C. Some short term thawings may also occur, which cause permanent increase of GST values.
- The stage of snow melting. The temperature of snow cover substratum percolated with melting water reaches quickly 0 °C.

In the light of the obtained data, the monitoring of ground surface temperature, which is, at the end of the second stage of snow cover development, extended by individual BTS measurements, seems to be a relatively cheap, simple and precise method of permafrost mapping. The work was carried out in the frames of research project 3 P04E 045 23 financed by Polish Committee of Scientific Research.

Electrical resistivity measurements of the modern glacial and glacial deposits

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key words: resistivity, sounding, Spitsbergen

Geoelectrical method was applied for studies of modern glacial deposits in contemporary glaciated area on Spitsbergen in Norwegian Arctic. Electrical resistivity measurements were conducted in marginal zones of two Arctic glaciers: Ebbabreen and Hörbybreen, located in vicinity of Petuniabukta in the central part of Spitsbergen. The objectives of the research included geoelectrical characteristic of different types of glacial and glacial deposits, providing evidence of glacier ice presence beneath sediment cover and of permafrost, and testing applicability of Vertical Electrical Sounding (VES) technique to study modern glacial environments. Twelve soundings in four settings were performed with automatic-multielectrode-sounding system with resistivity meter. On the basis of the results, diagrams of apparent resistivity plotted against electrode array in a log-log scale were made and typical values of electrical resistivity and thickness of the particular strata were determined. The interpreted curves refer to two, three and four layer models. Three-layer curves are of A and H types, four-layer curves are of AA and HK types. Interpretation was based on the values of electrical resistivity as well as on the direct field survey. The method allowed to verify presence of ice cores in moraine ridges, depth of active layer in permafrost region as well as estimation of thickness of clastic sediment infill in the studied valleys. The presented results revealed that despite some limitations of this technique, electrical resistivity is helpful property of rocks in the permafrost region and may serve as tool in many investigations.

Spatial and temporal variation of soil temperatures in the Kuparuk River Basin, Alaska

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key words: Kuparuk River Basin, Alaska, soil temperature, permafrost warming

A series of environmental studies have been carried out in the northern foothills of the Brooks Range and the Arctic Coastal Plain in the Kuparuk River Basin, Alaska to develop a better understanding of the physical and climatic dynamics of an arctic ecosystem. As part of these studies, soil temperature measurements were made continuously at eight locations along a transect from near the Beaufort Sea coast across the coastal plain to the Brooks Range foothills. Soil temperatures measurements were made in the active layer and permafrost to depths exceeding 10 m. Data collection began at three of these sites in 1986 with other sites being added until 1994. These data sets are of sufficient length to begin showing long-term trends in arctic soil temperature. All locations show a trend to warming soils over the period, especially in the deeper permafrost soils. Soil temperatures at all sites indicate warming of the permafrost. Summertime soil temperatures within the active layer do not indicate warmer soils. This paper summarizes trends observed in soil temperature spanning the last 18 years in the Alaskan Arctic.

Deriving proxy variables for frequency and magnitude of rock fall induced by permafrost thaw using Monte-Carlo simulation of surface and sub-surface heat transfer

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key words: mountain permafrost, rock fall, modelling, natural hazard, climate change

Permafrost degradation has been hypothesized and demonstrated to influence rock-wall stability. Both thaw and warming of permafrost (entering the range of -1.5 to 0°C) have been shown to cause a corresponding reduction in strength of ice-bonded rock joints. Quantitative information on the spatial distribution of this additional, warming related stability factor is desirable to support the assessment of natural hazards in mountain areas. This contribution proposes variables that describe this effect and explores a way to account for the uncertainty that exists in current approaches for regional-scale modelling.

The most important variable to delineate zones of possible rock fall induced by permafrost degradation is the occurrence of permafrost below the surface. The degradation of a permafrost body will take place along its boundary. This can be at the permafrost table, the permafrost base and also result from lateral heat fluxes in complex topography. The depth of the degrading boundary of the permafrost body corresponds to the magnitude of a rock fall induced by thaw. The heat flow at the boundary strongly influences the frequency or likelihood of an event taking place as a consequence of warming as it is proportional to the volume of material that can be warmed or the volume of ice melted. For any given warming scenario, the resulting frequencies and magnitudes change over time. Especially for regional-scale modelling, sub-surface thermo-physical properties and water/ice contents are unknown and can thus vary over a wide range and influence the subsurface temperature field accordingly. Additionally, the surface temperature boundary condition simulated by energy-balance models has a high uncertainty in complex topography. The uncertainties of both effects are propagated using Monte-Carlo techniques. Results are interpreted in a probabilistic way with the aim of displaying them on ordinary maps.

New data on permafrost distribution and thermal regime in the Italian Alps

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key words: permafrost, active layer, climate change, long-term monitoring, Alps

In the last three years new projects have developed focusing on the improvement of knowledge of permafrost distribution and thermal regime in the Italian Alps, especially in respect to climate change impacts on the slope stability and ecosystems. 9 new shallow and intermediate deep boreholes (ranging from 5 to more than 40 m depth) were drilled in the Central and Western Italian Alps. Three main sites were chosen: Foscagno Valley, Zandila Valley, both in Upper Valtellina, and Cervinia- Cime Bianche (Valle d'Aosta). Geomorphological surveys, BTS measurements and new geophysical investigations (vertical electrical soundings and electric tomography) have been carried out in all sites to select the most suitable locations for boreholes drilling. Permafrost distribution was also estimated through permafrost modelling (Guglielmin et al., 2003). In addition in the Cervinia-Cime Bianche site a CALM-GRID with partially automatically monitoring has been installed. Geomorphological surveys, geophysical investigations and BTS measurements have been carried out in another four areas in Valle d'Aosta (Gressoney Valley, Ayas valley, M.Emilius area and La Thuille area) and a couple of other areas in Upper Valtellina (Santa Caterina Valfurva and Val Quintena) to analyse permafrost and ground ice distribution as well as to calibrate the used permafrost models. Permafrost thermal profiles both measured once per year by a thermistor string in boreholes and automatically logged with fixed equipment according to the PACE protocol (Harris et al., 2001) show a general "warm and degraded" permafrost with temperature always higher than -2°C and the occurrence of relict permafrost bodies with ground ice lying at depth of more than 10 m and thicker than 20 m. Permafrost distribution reflects primarily the snow distribution that represents the most important climatic factor in determining also the seasonal changes of active layer thickness and its monitoring

may provide significant information on the eventual changes of the precipitation regime (particularly snow) which are among the expected impacts of climatic change.

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Heat transfer of active layer at the Dasan Station, Svalbard

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key words: permafrost, geodatalogger, borehole temperature, heat flow, thermal diffusivity

Borehole temperature measurements at the Dasan station were made by Baroo-Diver geothermal datalogger. During September 28, 2002 to August 12, 2003 three temperature data (at the depth of 0.25 m, 0.5 m, and 0.75 m) were obtained by EnvironMon every thirty minutes. The thermal dynamics of active layer at the Dasan Korea Arctic Research Station, Svalbard (78° 55.5' N, 11° 56.0' E) is represented in the soil temperature which can be measured with high accuracy and high temporal resolution. Using the continuous data over a period of 318 days at the Dasan site, Svalbard, we deduce and quantify the processes which constitute the thermal dynamics. Conductive heat flow, migration of water vapor, and heat generation from phase transition are analyzed. Average thermal diffusivity indicates the range of thermal diffusivity 4×10^{-7} to about $6 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. The Dasan experiment is a good test of the geothermal method of climate reconstruction because the permafrost is a valuable recorder of climate change.

Resistivity structure of permafrost by transient electromagnetic method in Siberia and thermal historical processes

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key words: transient electromagnetic method, resistivity, permafrost history, numerical experiment, Siberia

In the continuous permafrost area of Siberia, deep resistivity structures were investigated using a transient electromagnetic (TEM) method in order to supply basic information for the interpretation of permafrost development. The TEM surveys were carried out at Magan and Neleger near Yakutsk. In Magan, the interpreted resistivity structure was compared with the temperature profiles, which suggested the existence of a talik below the shallow frozen layer, with a thickness of ca. 23 m. The resistivity structure derived from layered earth inversion revealed obvious resistivity contrast at the bottom of a resistive sub-surface layer, with a resistivity exceeding 300 Ωm ; the depth corresponded to the boundary of the surface frozen layer and talik, which were measured by temperature profile. At Neleger, we carried out TEM measurements every 20 m along a profile with a length of 860 m from alas to the taiga forest. An upper resistive layer (>200 Ωm), which corresponded to ice-rich permafrost, was revealed at all stations. Below the resistive layer, a thick conductive zone was observed, and was considered to be talik. Furthermore, a resistive layer (>100 Ωm) was observed below the talik, which may have indicated permafrost. The lower boundary of this layer (depth: >400 m) may have reflected a permafrost base that corresponded to the permafrost depth observed in this area by drilling. Finally, numerical experiments were carried out based on the interpretation of the resistivity structure, and these studies indicated that talik on a scale of 100 to 200 m could have been produced by the overlaid thermokarst lake. The estimated period following the initiation of alas formation agreed with the radiocarbon dating. In combination with the results obtained by the numerical method, the geo-electrical information estimated by TEM survey can provide a basic model for reconstructions of the historical process of permafrost environment.

A new model for quantifying subsurface ice content based on geophysical data sets

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key words: ice content, geophysical modelling, electrical resistivity tomography, seismics, 4-phase model

In partly or permanently frozen ground subsurface material may consist of four different phases: solid (rock, soil matrix), liquid (unfrozen pore water), gaseous (air-filled pore space and cavities) and frozen liquid (ice). Except for the analysis of borehole data, which are difficult to obtain in high mountain regions, the composition of the subsurface material can only be inferred through indirect geophysical investigations. Due to the complexity of the subsurface a combination of complementary geophysical methods (e.g. electrical resistivity tomography and refraction seismic tomography) is often favoured to avoid ambiguities in the interpretation of the results. The indirect nature of geophysical soundings requires a relation between the measured variable (electrical resistivity, seismic velocity) and the respective parts of the material composition (rock, water, air, ice). In this work we would like to present a model which determines the volumetric fractions of these four phases from tomographic electrical and seismic data sets.

The 4-phase model is based on two well-known geophysical mixing rules for electrical resistivity and seismic P-wave velocity, Archie's law and Timur's equation. In addition to prescribing the material dependent free parameters in Archie's law, the resistivity and P-wave velocity of the rock material and the pore water have to be known. Besides, one of the volume fractions has to be explicitly prescribed (usually the porosity). The model was tested using several electric and seismic data sets from various frozen and non-frozen field sites in mountainous terrain. First results confirm the good model performance for various field cases in permafrost research. Especially the detection and confirmation of the presence of ground ice was substantially improved. Furthermore, a quantitative assessment of the respective volume fractions (e.g. the ice content) can be conducted if the porosity of the ground is known. Analysis of the spatial variability of the subsurface, e.g. the detection of isolated air cavities or the differentiation between regions with small and large ice contents, is facilitated, as the two abstract geophysical data sets (resistivity, velocity) are combined to give 2-dimensional profiles of ice-, water- and air content. Extensive validation using a series of shallow boreholes is needed to further analyse the performance of the model for different environments.

Quantifying permafrost thaw on Schilthorn, Swiss Alps, based on a 5-year geophysical monitoring data set

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key words: permafrost degradation, geophysical monitoring, electrical resistivity tomography, seismics, Schilthorn

Monitoring the amount of permafrost degradation in mountain regions is one of the foremost tasks in current permafrost research, especially in the context of climate change and the increased rockfall activity in the European Alps during the anomalously warm summer in 2003. Apart from direct, but singular and costly temperature measurements in boreholes no operational monitoring system exists to date.

A surface-based geophysical monitoring system using electrical resistivity tomography has been initiated in 1999 to monitor the long-term change in electrical resistivity of the subsurface at the PACE21 (Permafrost and Climate in the 21st century) permafrost monitoring station Schilthorn, Swiss Alps. The electrical monitoring system was installed to determine the amount of freezing and thawing along a 60 m long and 10 m deep profile line on a regular basis. Two boreholes (13 m and 100 m deep) equipped with thermistor strings are situated close to the profile line. In addition, an energy balance station provides radiation balance measurements as well as meteorological parameters like air temperature and snow cover thickness. Resistivity monitoring proved to be an excellent method for the detection of freezing and thawing processes in the subsurface as long as no additional water sources like snowmelt and rain are present. Seasonal freezing and thawing as well as processes on time scales of a few days could be detected and

visualised. In combination with borehole temperature data the amount of freezing and thawing could be quantified for initially saturated material. However, a quantitative assessment of the amount of subsurface freezing and thawing is difficult using resistivity data alone.

In this contribution we present an improved monitoring approach using additional seismic data to calculate the evolution of the ice content at Schilthorn from 1999 to 2004. Ice-, water- and air content are calculated using a new model approach based on a combination of two well known geophysical mixing formulas for electrical resistivity and seismic P-wave velocity. Results from the 5-year resistivity data set in combination with additional seismic measurements show a decrease in ice content between 1999 and 2004 corresponding to an increase in active layer depth from 5 m to 7 m as determined from the borehole measurements. The results suggest that geophysical monitoring systems combining different methods may indeed be used to quantify the amount of permafrost degradation over larger areas as well as its spatial and temporal variability.

Estimating lower permafrost limit and snow cover importance using regional temperature maps

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key words: regional models, Southern Norway, surface temperatures

Regional permafrost models for Southern Norway based on mean annual air temperature (MAAT) maps (Tveito et al., 2000) have been generated earlier by for instance Ødegård et al. (1996) and Etzelmüller et al. (1998). To better quantify the influence of climate changes from the outer coast near maritime sites, to the inner, continental sites, an estimate of equal frost and thaw (DEFT) was calculated from freezing and thawing degree days maps (Tveito et al., 2001). The DEFT shows at what time during winter that the number of freezing degree days equals the summer thawing degree days. That means, a thick snow fall before this date may block frost penetration before enough freezing has occurred to form permafrost. Snow cover is a main important factor controlling permafrost formation and analyses of the DEFT helps to understand the regional distribution of permafrost. The regional permafrost models derived from the MAAT map and the DEFT are compared to field observation at 7 sites in Southern Norway.

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The influence of substrate and surface characteristics on the ground thermal regime and mountain permafrost distribution - Examples from the Matter Valley, Valais, Swiss Alps

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key words: mountain permafrost, surface characteristics, Matter valley

Shallow ground temperature measurements in the discontinuous permafrost belt of the Matter Valley demonstrate, how the ground thermal regime is influenced by a combination of various site characteristics on a local scale. Especially surface characteristics play a major role in this context besides the highly differentiating relief factors aspect and slope. The high variability of these influence factors causes an equivalent small-scale permafrost distribution pattern with sharp changes between permanently frozen and unfrozen areas.

Cumulated temperatures for Freezing and Thawing Degree Days allowed a clear separation of the thermal behaviour of coarse block layers and fine grained substrates. Varying textures of subsurface material in fine sediment govern the ground thermal regime due to their influence on soil moisture content. A blocky surface texture leads to a shift of heat transfer processes from conduction to convection. Unlike convective processes in finer grained substrates, where above all the movement of soil water and water vapour in soil pores and related latent heat effects participate in heat transfer, it is the convection of air, which plays a major role in the thermal regime of this substrate type. A maximum surface offset of up to -7°C was induced by coarse surface substrate combined with reduced snow cover, which can be ascribed to a double net cooling effect caused by air convection in the void system.

BTS measurements in the two test areas matched the continuous recordings well and allowed an areal extrapolation of this point information. In both areas, permafrost can be expected only beneath surfaces consisting of coarse debris. Even at an altitude of around 3000 m a.s.l. permafrost seems to be absent in soil substrate. A high resolution model of permafrost distribution for the investigated test areas incorporates the insights gained during the measurement campaign.

Mountain permafrost: Are we able to model the real distribution?

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key words: mountain permafrost, modelling, permafrost distribution patterns

Permafrost distribution modelling in densely populated mountain regions is an important task in relation to different natural hazards. As the heat wave of the summer 2003 in the middle of Europe (including the Alps) has indicated, hazard events, such as rock falls, will probably increase under a changing climate. Therefore, fast progress towards a better determination of sensitive areas in mountain regions is urgently needed. Beside the general local atmospheric conditions, the permafrost distribution in cold high-mountain areas is in addition highly influenced by the effects from complex topography. Surface conditions like slope, aspect, altitude, ground properties or humidity, and factors influencing the energy fluxes across the earth surface such as solar radiation, air temperature, precipitation, wind, snow cover, etc. often greatly vary over extremely short distances. Spatial modelling of permafrost distribution patterns and potential changes with time is a serious challenge under such conditions. In recent years several approaches have been developed and applied and many different model types are currently used both in science and practice. Several of these models were developed with the focus on individual surface characteristics, such as coarse debris, fine material or bedrock. All these model approaches are very useful simplifications of the real conditions in nature. These models helped to have a better insight of individual processes and in combination with selected measurements our present knowledge about high mountain permafrost formation has been increased. However, one is still far away from a realistic modelling of the real permafrost distribution on a local scale. This contribution will critically discuss several aspects of mountain permafrost distribution modelling and possible perspectives will be outlined.

Database- and GIS-based modelling of the regional permafrost distribution - Examples from the Mattertal, Swiss Alps

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key words: mountain permafrost, regional-scale distribution modelling, Mattertal

As a lithospheric phenomenon dependent on temperature, mountain permafrost is directly affected by climatic change. Natural dangers due to slope instabilities are a consequence of the degradation of permafrost in mountainous regions. In order to be able to react to these natural dangers, knowledge of the distribution of permafrost is vital. However, permafrost can only be measured selectively. Thus, models based on parameters that influence the distribution of permafrost need to be applied to the area.

For two areas (6 and 19 km²) of the Mattertal an empirical-statistical model of the permafrost distribution was developed, which takes into special account the impact, that coarse blocky surface covers have on the thermal regime in the

subsurface. The data concerning the surface are taken from aerial photography and satellite imagery and have been integrated into a database. Apart from the surface structure, the factors “potential direct solar radiation” and “air temperature” are implemented into the model. The potential direct solar radiation has been calculated for the middle of the snow-free months July to October through the r.sun module of the open-source GIS GRASS. The result represents the distribution of radiation very exactly in a spatial resolution of ten meters.

The factor map “air temperature” has been generated by data of eight mountain climate stations (altitude between 2480 m and 3345 m) of the SLF (Swiss Federal Institute for Snow and Avalanche Research). As temperatures are measured on a long-term period and organised in a database, the effects of a climatic change can be taken rather easily into account by this model in the future.

The model has been calibrated by more than 400 BTS measurements. The results of a cross-validation provide an exactitude of 63%. This is an improvement compared to the results of existent permafrost models and underlines the great impact, which the surface structure has on permafrost distribution. This study has been made possible by the EU-projects PACE and its successor project PACE21 as well as by the project “Periglacial Mattertal” of the German research foundation (DFG).

The extent of permafrost in the Swedish high mountains

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key words: permafrost, Sweden, landslides, borehole monitoring

In Sweden permafrost have received relatively little attention, possibly because such areas are generally not inhabited and containing infra-structural constructions. The primary objects of study in Sweden have been Palsas and ice-cored moraines. In addition to these scattered work on permafrost in general have been produced focussing on the physical relationship between climate and the occurrence of permafrost.

In the year 2000 one 100 m and two 15 m holes were drilled into the bedrock close to Tarfala Research Station within the EU-funded PACE programme. One 15 m hole was drilled by the station at 1130 m a.s.l. at the site of the weather station which has been during summer since 1946 and automatically all year round since 1965. At Tarfalaryggen, a smooth saddle at 1550 m a.s.l. boreholes reaching 100 m and 15 m were drilled and a weather station was erected. The permafrost depth is estimated to exceed 300 m. At Tarfala Research Station the annual mean temperature is -3.9°C and the annual precipitation is about 1000 mm.

On the southfacing slopes of the valley Kukkesvage in the Sarek region a series of debris slides/flows were triggered in 1985. The debris flows in Kukkesvage constitute only one of several observations of similar kind in high alpine areas in northern Sweden. There seem to have been an increased frequency of rapid mass wasting events during the last decades possibly a cause of thawing permafrost. Retrospective analyses on mass-wasting processes are carried out by interpreting air-photos and studies of lake sediment layers, created by known mass-movements. The latter may cover the last 1000 years and will focus on the relation between climate and geomorphic impact. Measurements on present soil temperatures and palsa distribution and changes are monitored.

Detailed modelling of permafrost is achieved through careful measurements of permafrost indicators combined with terrain data in a GIS. By measuring snow base temperatures (BTS) in a large number of locations of varying elevation, slope and aspect, and also measuring the energy balance in the area, detailed modelling of permafrost occurrence in the vicinity of the high mountain range is possible. BTS measurements have been carried out at several sites along the mountain range from Helags in the south to the Abisko area in the north. This mapping provides a first view of permafrost extent under current climatic conditions in the Swedish mountains. Scandinavian glaciers are 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. 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 to 100 m. This implies that 10 to 100% of the base of the glaciers or about 50% of the glaciated are frozen to the ground. The thermal condition is monitored at a selection of glaciers. The cold surface layer of Storglaciären thinned 10 m during the 1990s.

Normalisation of ground surface temperature measurements in mountain permafrost

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key words: permafrost, ground surface temperature, normalisation, gridded climatology

The use of miniature temperature data loggers (MTDs) for mountain permafrost mapping, monitoring and modelling has greatly increased during the last decade. MTDs pertain to the standard devices in mountain permafrost research of today and large amounts of temperature data now exist from many mountain areas. Continuous temperature recordings make it possible to determine e.g. the mean monthly and annual ground surface temperature (MMGST and MAGST) at desirable sites. However, the collected temperature records often show pronounced fluctuations and large interannual variability. Identification of MAGST and MMGST is thus not straight-forward only from a few years of measurements. A suitable strategy for normalisation must be developed to assure that these data can be reasonably handled, compared and interpreted.

The World Meteorological Organization (WMO) established a standard for a 'normal' period to ensure that calculations of climate averages (the 'normals') are calculated on a consistent period. A 30-year period is considered long enough to calculate a representative average, and to reduce the impact that one-off, very extreme events (i.e. short term climate variability) have on the average. A simple method is presented to normalise ground surface temperature data for the first determination of MAGST and MMGST in mountain permafrost areas. The study to be presented is based on experience from the past five years of monitoring and modelling programmes in the mountain regions Dovrefjell and Jotunheimen in southern Norway, where a series of ground surface temperature data and data from totally 13 boreholes exist. A recently developed 1 km gridded dataset for Norway, containing monthly air temperature and precipitation anomalies, is used in the normalisation procedure. Local meteorological observations are used as well for calibration and correction of e.g. temperature inversions and other local climate effects. This study provides information about some possibilities and limitations of normalisation of ground surface temperature data in mountain areas and possible applications to permafrost mapping, monitoring and model validation.

The hydro-thermal regimes of dry active layer

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key words: dry active layer, soil internal vaporization, atmospheric interaction, Mongolia

Global warming would shift the southern boundary of permafrost to the north, deepening active layers that control plant growth, gas fluxes, groundwater flow regimes and evaporation. Understanding the hydro-thermal regimes of the active layer is, therefore, crucial for predicting near-future terrestrial changes of the cryosphere. Although conduction is widely accepted to be dominant heat-transfer mechanism for permafrost soils, the importance of non-conductive mechanisms associated with water migration in either liquid or vapor phase, and water phase changes have been emphasized by numerous observations. This paper discusses hydro-thermal features of a dry active layer, analyzing the hydrometeorological energy budget of soil and atmosphere at a site on pasture flat plain of the northeastern Mongolia, at the southern boundary of Eurasian permafrost region, where pronounced degradation of permafrost is expected. Identification and quantification of soil heat components using two years of soil temperature and moisture data found that soil internal vaporization plays a dominant role in determining year-round heat-transfer dynamics of the active layer under semi-arid climatic conditions. This is because the dry active layers contain a large volumetric percentage of open pores that link to the atmosphere. Rapid snowmelt infiltration observed at the end of snow-rich winter drastically warmed the active layer and also supports the occurrence of such pores. They are distinctive hydro-thermal features of dry active layers. It has been widely accepted that freezing and thawing are the main contributions of non-conductive heat in the circumpolar regions where active layers are generally wet and thin. Active layers under the semi-arid climatic conditions, on the other hand, are extremely dry and sometimes reach to several meters in thickness. Freezing and thawing are of secondary importance. Soil internal vaporization uses more than 7 times more latent heat than freezing, and should be considered for modelling soil hydro-thermal dynamics of this region and future changes of permafrost distribution in both regional and global scales.

Technology of radio wave researches for 3D-geolectrical mapping of inter-well space in permafrost massiv

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key words: radiowave method, cross hole observation, borehole equipment, electric properties of frozen-thawed ground

Radio wave geoinrosopy of inter-well space (RWGI) - way of "visualization" of an internal structure of geological media in space between wells. A physic-geological basis of a method is the dependence of intensity of absorption of energy of radio waves by the rocks located on a line of distribution of a wave, from the electrical characteristics of these rocks: specific electrical resistance (ρ) and permittivity (ϵ). The rocks having lower values of (ρ) and (or) (ϵ), are characterized by higher absorption of radio waves. Using an electromagnetic field in a range of radio frequencies, special technique of measurements and data processing, with homographic image methods or wave restoration methods it is possible to detect and locate in inter-well space geological heterogeneity of relatively small sizes. Cross hole and single hole radio wave testing have a great potential in determining of electrical resistance and dielectric permittivity of permafrost formations in situ. The borehole equipment was designed and produced by "Radionda Ltd." for detailed studies and measurements of harmonic electromagnetic field intensity at fixed frequencies. The equipment includes special receiver and transmitter supplied with electric dipole antennas, which are lowered into two adjacent holes on a single logging cable each. To exclude antenna effect of the cable, the instruments in the boreholes are provided with independent source of power; they are connected to the cable through dielectric inserts with an optical channel and units of opt electrical transducers. Both receiver and transmitter have processor and ADT (automatic digital transducer), that allow carrying out two-sided exchange of information with surface: to transmit the data of measurements to the surface and to receive the control instructions. Besides measurements of the electric field at the reception point and those of current in the transmitting antenna, such a concept of the equipment structure allows performing a remote matching of the borehole antenna with transmitter and to control and stabilize of the transmitter radiation power and mode. It is worth noting that digital filtering (and special processing, if necessary) of measured signal ensures accuracy and reliability of measurements under conditions of high level of electromagnetic interference. Below are given its principal specifications:

- Operating frequencies: - 0.156; 0.312; 0.625; 1.25; 2.25; 4.5; 31.0 MHz
- Receiver sensitivity not worse than 0.1 μV
- Dynamic range - 130 dB
- Transmitter power -(10-40) W
- Diameter of the borehole instruments - 38 mm

The programs of registration provide the visual control of measured values, including parameters of radiator. The data processing is carried out with the help developed by "Radionda Ltd." the software package "ORWP-RWGI". On set of all data the electrical characteristics of the investigated blocks of the rocks, including factors electrical anisotropy are determined. 3D- geolectrical map is created by a method of wave restoration using all data, taking into account the spatial characteristics of the field. The map can be presented with a set of horizontal sections and arbitrary orientated cross-sections with isolines of effective resistance. On these sections one can see morphological features of the structure, tectonic faults, and the sites of fractured and water-saturated rocks. We discuss the examples of effective use the radio wave borehole technology in monitoring of two hydro technical objects constructed in Western Yakutia. This technology offers to localize in cross hole underground space the thawing and filtrating layers under influence of reservoirs.

Influence of snow and ground surface materials on the ground thermal regime. Examples from Sølén and Elgåhogna, Central-Eastern Norway

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key words: ground temperatures, snow, ground surface materials, digital automatic camera, Central-Eastern Norway

Snow and ground surface material cover buffer the thermal signal from the atmosphere into the ground, and cause a complicated pattern of permafrost occurrence in the permafrost transition zone. This was particularly evident in a permafrost mapping undertaken on the mountains Sølén and Elgåhogna, Central-Eastern Norway (Heggem et al., in prep). Thus, a new project governing this buffer layer was initiated in this area. Field measurements include temperature measurements in the air, winter snow cover, ground surface and the upper one meter of the ground for different material types (bedrock, till, block fields), in addition to snow depth gathered at one location using an automatic digital camera. The project is intended to give new insight into the complex climate-permafrost relationship. The field sites, Sølén (61° 55' N, 11° 31' E) and Elgåhogna (62° 09' N, 11° 57' E), Central-Eastern Norway, were instrumented summer 2004, and the first data will be gathered March 2005. The first results and preliminary interpretations from this project will be presented.

Permafrost monitoring and modelling concepts for climate change research, Qinghai-Tibet Plateau, China

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key words: permafrost modelling, monitoring, Qinghai-Tibet Plateau

Permafrost research on the Qinghai-Tibet Plateau often deals with applied aspects. Research and borehole sites are therefore concentrated along the Qinghai-Tibet Highway and Railroad, and one major research topic is permafrost degradation hazards caused by global warming. However, vast additional areas of the Plateau are underlain by permafrost. The surface temperature changes on these vast areas play also an important role for the characteristic of the monsoon circulation over South-East Asia. Intensified permafrost research is therefore urgently needed in order to get a general idea of permafrost distribution and characteristics in Qinghai-Tibet.

Permafrost has been identified as indicator for global climate change within the monitoring framework of the WMO Global Climate Observing System (GCOS). Accordingly the International Permafrost Association (IPA) developed a strategy for a Global Terrestrial Network-Permafrost (GTN-P) consistent with GCOS. A primary challenge of these global observing systems are the linkage between detailed measurements on a local scale for improved process understanding, and global coverage. The European PACE project (full title: Permafrost And Climate in Europe - climate change, mountain permafrost degradation and geotechnical hazard), a 3-year interdisciplinary and international research project, achieved an instrumented permafrost boreholes transect from Svalbard in the north to the Spanish Sierra Nevada in the south. As part of the Global Terrestrial Network on Permafrost (GTN-P), the PACE borehole strategy developed standards, which could be easily adapted to the local conditions in Tibet.

A newly developed permafrost model is presented, and would be of help for the selection of monitoring sites in close cooperation with Chinese institutions. A Qinghai-Tibet network will offer many opportunities for research in climate change monitoring and climate reconstruction. A Tibetan Active Layer Program (TALP), based on the Circumpolar Active Layer Monitoring (CALM) of the International Permafrost Association is proposed as initiative step and as addition to existing Chinese permafrost programs. A monitoring network collecting data on winter frost and permafrost is planned at the NamCo area, Tibet, reaching from 4750 up to over 6750 m a.s.l., covering a wide range of different periglacial environments.

Surface- and active layer offsets in the high arctic Svalbard landscape

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key words: Svalbard, surface offset, active layer offset, ground temperatures, permafrost

Most places in the arctic, ground is insulated by snow and vegetation, and usually the insulating effect of snow is greater. Mean annual ground surface temperature (MAGST) is therefore often observed to be higher than the mean annual air temperature (MAAT) (surface offset). Decreasing annual temperature is often seen from the top to the bottom of the active layer (active layer offset). To understand spatial variations in ground temperatures and improve the interpretation of the climate signal from temperatures measured in deep boreholes, studies on surface and active layer offsets are important.

In central Spitsbergen, in the Adventdalen area, snow cover is sparse as annual precipitation is only 200 mm and strong wind during winter cause snow to blow away from exposed areas. Also vegetation is sparse. Surface offset is therefore assumed to be smaller than what is usually observed. However, not much has been published on either surface and active layer offsets from Svalbard. Air, surface and ground temperature data from two different sites are used to present the range in mean annual offset values as well as annual variations in offsets. On the exposed bedrock hilltop Janssonhaugen, temperatures in air, active layer and permafrost are recorded in boreholes and by a meteorological station. The site has nearly no snow, vegetation or sediment cover. The active layer thickness is around 1.6 m. MAAT at 2 m during 3 years was -6.6°C to -5.7°C , whereas MAAT at 0.1 m was -6.8°C to -5.8°C , showing that temperature inversion is more a rule than an exception. MAGT at 0.2 m depth was between -6.7°C to -6.0°C . In two out of three years, MAGT at 20 cm depth is lower than MAAT at 2 m, contrary to what is usually observed. MAGT at 1.6 m depth was -6.6°C to -5.9°C showing very small active layer offset. No trend indicates decreasing or increasing temperatures within the active layer. So surface and active layer offsets are small or not existing at Janssonhaugen. In a dry river section around 15 to 20 m asl., covered with fine sediments, a snow patch accumulates from November till June. Surface and active layer temperatures are measured beneath the snow patch as well as air temperatures at 25 cm outside the snow patch. During three years MAGST was -1.5°C to -0.2°C , while MAAT varied from -7.2°C to -5.3°C , showing a surface offset of 3.9°C to 5.8°C , probably mainly controlled by snow depth. In one year MAGT at the bottom of the active layer was -2.3°C . This was 0.8°C colder than MAGST, showing the possibility of an active layer offset. The two landforms presumably represent extremes with respect to variations in surface and active layer offsets in the Svalbard landscape. Both the effect of snow cover and material on ground temperatures are illustrated and especially snow depth proves to be of importance. Also the importance of air temperature inversion should be noted, as this might lead to colder ground temperatures than air temperatures measured in 2 meters.

Assessment of ice-rich permafrost thawing and thermokarst activity on the Bykovsky Peninsula, Laptev Sea (Russia), under a global warming scenario

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key words: ice-rich permafrost, thaw settlement, coastal erosion, terrain modelling, global change

The thawing of ice-rich permafrost, subsequent to the expected warming over Arctic regions is responsible for a wide set of hazards occurring in the Arctic, ranging from the disruption of man-made structure to the rapid modification of the coastline. The spatial distribution of subsurficial ground ice has recently been investigated at circum-Arctic scales to illustrate the imminence and the amplitude of such threat in the Arctic regions. However these estimations remain rough at local scales and need to be refined with all available tools. Given the difficulty to undertake ground measurements at such scales remote sensing tools are the most efficient proxy for ground ice estimation and thawing sensitivity quantification. Our study area, the Bykovsky Peninsula, is situated southeast of the Lena Delta, close to the major settlement of Tixi. The peninsula consists mainly of very ice-rich deposits of the Ice Complex. We used a terrain classification based on Corona satellite imagery previously elaborated at the Alfred Wegener Institute (AWI) to conduct a strict estimation of ground ice contents in the corresponding classes. The ice contents were subsequently converted to a virtual thickness of pure ice (i.e. volumetric ice content = 100%) and assigned to the classes used to

describe the land surface of the Bykovsky Peninsula. The resulting layer of ground ice was incorporated in the GIS and virtually thawed leading to a settlement of the land surface. The settlement is illustrated with a digital elevation model of the surface after thawing. We applied two different scenarios. The first is based on total thaw of the ice-rich deposits without any time component. The second scenario is time-dependent and describes surface changes likely to happen under drastic warming conditions within the next centuries, including estimated thaw settlement, measured coastal erosion rates and predicted sea level rise. Coastal erosion rates were determined from field measurements and remote sensing images. The sea level rise scenario is based on a curve from the International Panel on Climate Change (IPCC).

Permafrost evolution under a seasonally varying Alpine snow cover

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key words: numerical modelling, snow cover, permafrost, climate change

The interaction between snow cover and permafrost is part of the complex system “atmosphere-snow cover-vegetation cover-permafrost”. This system is strongly affected by the interrelationship between the processes taking place in each part. The permafrost distribution in the Alps is defined by many factors as e.g. climatic factors, topographic factors and soil specific factors: thereby, the snow distribution plays a decisive role. For a better understanding of the interaction processes between snow cover and permafrost, a numerical model was developed by adding a soil module to the existing sophisticated one-dimensional mass and energy balance model SNOWPACK, which was originally developed and tested for simulations within the snow cover. The model was validated against laboratory measurements under dry conditions showing good agreement between simulated and measured temperatures. By means of a sensitivity study, the effect of different factors on ground surface temperatures and on BTS values were determined, pointing out the important role of snow insulation (snow depth and date of insulation) and air temperature: total snow depth and the duration of a thin non-insulating snow cover, respectively, show strongest effect on ground temperatures and therefore permafrost. The slope of the linear dependency between increasing mean annual air temperatures and increasing mean ground surface temperatures varies for different soil textures and different snow cover scenarios: largest gradients were determined for dry coarse blocky soil-types and shortest snow insulating periods. The effect of climate change on permafrost distribution is strongly governed by the duration of the insulating snow stage in seasonal snow cover. The role of the duration of the insulating snow cover is discussed on the basis of borehole temperatures monitored in the permafrost at the foot of an avalanche slope. The presented results show that the new soil-extended version of SNOWPACK, accurately representing seasonal snow cover, is a valuable instrument to study the interaction processes between Alpine permafrost and a seasonally varying snow cover.

Modelling and assessing global climate change impact on permafrost

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key words: permafrost, global change, climate impact, climate, modelling

The current state of the art concerning studying the problem of global climate change impact on permafrost is reviewed. This problem is clearly related to a class of problems, the solution of which stipulates the choice of strategy for sustainable development under extreme conditions. This circumstance is of great importance for overcoming the regional economical and ecological difficulties of Russia. To investigate regional aspects of climate change, two kinds of problems should be solved. On the one hand, the development of a land surface model as a key element of the climate model requires knowledge of regional peculiarities of interactions between the atmosphere and permafrost, which are most clearly pronounced in the surface energy and moisture fluxes and in the atmospheric boundary layer. On the other hand, it is necessary to assess the global climate change impact on the environment (the state of the underlying surface, natural ecosystems, water resources etc.) in permafrost regions and to estimate the potential to minimise negative consequences. In this report, some results of study of the present-day climate and climate change using the hydrodynamic model developed in the Institute for Numerical Mathematics are presented. Special attention is paid to dangerous manifestation of regional peculiarities of the climate system such as permafrost degradation. In conclusion, some possible approaches to construct regional integrated models for assessing the vulnerability of the permafrost environment due to global climate change impact are discussed.

Frozen ground response to recent climate changes in the European North

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key words: climate changes, permafrost temperature, disturbed landscapes, thaw depths, short-term permafrost

The European North is characterized by moderate changes in contemporary climate in continental areas and by slight changes in coastal areas. Changes in mean annual air temperature are of periodic nature and reveal a weak positive trend. Permafrost temperature records obtained from the Bolvansky site during the last 20 years show stability of the cryolithozone in undisturbed landscapes of the southern tundra. In upland (watershed) areas with continuous permafrost, the permafrost temperature ranges across the area from -1.6 to -2.5°C . During the entire period of observations (since 1983) variations in mean annual ground temperature at a depth of 10 m did not exceed 0.2°C , whereas mean annual air temperature varied in a wider range, that of 0.4°C . At the same time, disturbed landscapes demonstrated much larger changes in permafrost temperature. Following the removal of vegetative and soil covers from a flat hill top in 1983, the permafrost temperature at a depth of 10 m decreased by 0.2°C within the first three years, however, in the following seven years it increased rapidly by 1.0°C . This confirms the leading role of snow in winter thermal balance; no manipulations with snow thickness were applied in the discussed case. Removal of a heat-insulating layer (vegetation and peaty soil horizon) increased the amount of absorbed radiation in summertime and finally led to warming of the upper layers of permafrost. In the mid-1990s, in accordance with gradual revegetation of the disturbed site, an offset of progressing decrease in mean annual permafrost temperature was observed. In 10 years the permafrost temperature at a depth of 10 m dropped down from -1.4 to -1.9°C , in spite of a rise in mean annual air temperature registered in this period. Since 2002, however, a certain increase, up to -1.6°C , in permafrost temperatures is observed again, related to anomalously high summer temperatures. Thus, given the same period of observations, changes in permafrost temperatures in disturbed landscapes exceed those in air temperatures 2 to 2.5 times.

Thaw dynamics record from the Bolvansky CALM site suggests of the cryolithozone stability in the southern tundra. Interannual changes in the site-averaged thaw depth ranged from 104 to 119 cm during the 6 years. The thaw depths depend on heat amount during warm periods and are correlated directly with the Thaw Index (DDT). Winter temperatures do not affect thaw depths. Potential ground freezing depths in the elevated sites well exceed thaw depths at the same sites. A thawed layer gets frozen throughout its depth already by December and continues to cool during the rest of winter. Minimal temperatures at a depth of 1 to 1.5 m can be as low as -10°C . Sites with a low position of permafrost table, such as wide hollows or lake depressions underlain by closed taliks, are characterized with an unstable temperature balance. In the years with extremely cold and low-snow winters, ground freezing can reach 2 to 2.5 m. These frozen layers do not thaw out completely next summer and turn into pereletoks (short-term permafrost). In warmer years configuration of pereletoks changes and the area of taliks increases. The study is supported by the NSF-funded CALM-II project and the RFBR grant 04-05-64005.

The analysis of the active layer dynamics: comparison of CALM data with modelling results

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key words: active layer, climate change, mathematical modelling, analysis of dynamics

Russian protocols and rules of technical policy are now being improved. This stimulates the development of diagnostic methods for investigating permafrost dynamics. That means the necessity to estimate dangerous climate change and its consequences for engineering design. The amount of actual Russian permafrost data is not enough for complex analysis of permafrost evolution. The results of the International CALM-program showed the intensive response of permafrost to climate change. The CALM data provide the trend of the average active layer. The different regions are characterized by different dynamics and even opposite reaction of the active layer thickness to climate warming. We have continued to analyze the detailed data from the Yamal Peninsula (Russia) and North Slope (Alaska) CALM-sites. This means the nonlinear and variable link between permafrost and the Land-Atmosphere-Ocean system. Permafrost change can be characterized by observation of temperature dynamics, active layer dynamics, moisture and ice content

dynamics and cryogenic phenomenon change. We have tried to establish the lead factor (snow cover, vegetation cover, air temperature, amplitude of the air temperature, liquid precipitation, wind velocity, etc.) of permafrost change for each of the CALM-regions. CALM program results show that the active layer thickness value is a poor indicator for permafrost change but it is important for practical purposes. The spatial average values of the active layer thickness must characterise not only the CALM-site as whole but also the types of landscape with minimum variance of permafrost, micro-relief and vegetation characteristics. We described the influence of the local variability of active layer thickness to its spatial average value. Also we took into account the relative area of different type of landscape within CALM-grids. We plan to use the results obtained in the practice of decision making related to the regional risk estimation of permafrost degradation.

Modelling icing development at the glacier-permafrost interface

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key words: hydrology, GPR, glacier, talik, icing

Bylot Island is located in the Canadian Arctic well within the zone of widespread continuous permafrost, with about 50% of the island covered by glaciers. These glaciers modify the surface hydrology and ground thermal conditions resulting in icings forming near their termini. While small transient icings result from englacial and subglacial drainage during the winter, larger more stable icings are hypothesized to have been created by groundwater flow. This paper describes the unique conditions that resulted in the formation of one such icing and the cause of its perennial stability over the last 55 years.

Satellite and aerial photograph imagery and aerial surveys were used to study the development and extent of the icings on Bylot Island in general, while detailed ground-penetrating radar surveys and surface hydrologic measurements were employed over a ten-year period to determine the source and routing of the water forming the icing in front of Fountain Glacier. From this data, a conceptual hydrothermal model for groundwater flow through the permafrost-cored terrain beneath and around Fountain Glacier was developed. The main components of this model are groundwater flow rates, heat loss and flow stability. The influence of downstream terrain characteristics are also examined in the formation and degradation of icings in general. The catastrophic drainage of an ice-dammed lake and subsequent erosion of the side of Fountain Glacier enabled components of the model to be verified through direct observation. Finite element modelling of the thermal conditions in the proglacial permafrost and icing also support the model.

Permafrost temperature regime of northern Taiga landscapes in West Siberia

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key words: permafrost temperature, monitoring, landscape, climate changes, frost mound

The permafrost temperature regime of the West-Siberian northern taiga landscapes has been studied in the territory adjacent to the Nadym research station since 1970. Temperature boreholes of depth 10 m were established within fixed sites and along profiles both in natural and ground disturbed by a main gas pipeline. The research undertaken has allowed us to study changes of permafrost temperature in various landscapes caused by observed climatic changes and under the influence of anthropogenic factors. Maximum changes of permafrost temperature for the period of observations were marked in peat frost mounds (palsa peatlands). For the period of studies, permafrost temperature at the depth of 10 m within one of these frost mounds increased from -1.8°C to -0.7°C . The increase of permafrost temperature was caused by an increase in air temperature over the last decade. The linear trend of the air temperature increase is 0.04°C per year according to the Nadym weather station records for the period 1965 to 2003. The amplitude of annual temperature fluctuations at the depths of 9 to 10 m in peat frost mounds according to the logger measurements did not exceed 0.1°C . These measurements allowed us to study the annual course of permafrost temperature in a frost mound at different depths. In the summer to fall period at the depths of 2 to 5 m we observed a gradual increase of temperature, which reached its maximum in December. From January to February, the temperature

of the upper permafrost layers began to decrease influenced by low air temperature. The maximum winter permafrost temperature gradient was registered in March as $1.7^{\circ}\text{C m}^{-1}$. In March the influence of air temperature reached the depths 5 to 6 m, and the downturn of temperature at greater depths began only on April and finished in June. Since May, the temperature of the upper permafrost layers rose again, and the increase of temperature at depths over 5 m was only traced in July to August. Permafrost temperature has changed less (from -0.9 to -0.1°C) on flat peatlands. Minimum changes of permafrost temperature were observed on mineral frost mounds, composed of sands underlain by ice-rich silty and clayey deposits. On mineral frost mounds, increase of permafrost temperature did not exceed 0.4°C in natural conditions, and 0.5°C at the disturbed sites. The greater change of ground temperature on peat frost mounds is probably connected with minimum thickness of the snow cover (0.3 to 0.35 m), which does not prevent them from cooling in winter. On mineral frost mounds with sparse forest the snow thickness, on the contrary is much greater (0.5 to 0.7 m), its insulation effect is more noticeable and temperature fluctuations are less. The research is performed with the financial support from RFBR grant 04-05-64005.

3-dimensional investigation of ground temperatures in steep rock slopes

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key words: ground temperatures, 3D thermal monitoring, periglacial rock fall

A temperature-dependent reduction in rock-wall stability in alpine permafrost areas, that is likely induced by climate change, has recently been demonstrated both in theory and laboratory experiments. The delineation of the locations of sensitive zones that exhibit critical temperature changes (entering a range of ca. -1.5 to 0°C) and are subjected to thaw requires knowledge of the temperature distribution both at the surface and in the subsurface of rock walls. The effect of complex topography in high mountain areas leads to a strong lateral component of heat fluxes. Therefore, ground temperatures and permafrost degradation below variable topography such as ridges or spurs can only be investigated where 2- and 3-dimensional effects (geometry and variable surface temperatures) are accounted for. The Matterhorn rock fall on July 15, 2003 is an example of such a situation. The corresponding knowledge, however, still remains very limited.

In order to investigate 3-dimensional thermal responses to climate change, numerical modelling experimentation is carried out in a recently started study. To better understand natural complex situations, model simulations of typical idealized test cases are performed. In this contribution cross sections of various 3-dimensional geometries are explored to describe the distribution of ground temperatures under influence of high-mountain topography. The thermal regime inside ridges, peaks or spurs is modelled with varying topographical variables such as slope, aspect or elevation aiming at identifying zones of warm permafrost with critical temperature ranges as well the position and depth of the degrading boundaries of the permafrost body. In topographies such as East-West trending ridges these boundaries are strongly influenced by lateral heat fluxes. Areas found to be especially sensitive for permafrost degradation may be identified on maps and serve as a basis for hazard assessment of permafrost related slope instabilities.

Finite-element meshes of typical topographies are generated and forced with different surface boundary conditions. The experimentation is conducted applying a surface energy-balance model (TEBAL) to determine surface temperatures, together with a 3-dimensional ground heat-conduction scheme (FRACTure), both especially designed for use in complex topography.

Some features of cryolithozone of the European mountain countries

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key words: cryolithozone, European, mountains

In this report some features of the Cryolithozone (CZ) of the main mountain areas of the continent are analyzed, and the CZ regional variability is discussed. The report is based on published and unpublished data obtained by a number of researchers, including the author's data on the Ural and Pay-Khoy areas (Russia). Investigation of variability in distribution of altitudinal geocryological belts shows that the zonal decrease of hypsometric heights of their lower boundaries occurs in the West and Southwest of Europe two times slower than in the East. This is caused by the well-known increase of severity of geocryological conditions towards the East, due to the increasing climate continentality. For accurate comparison of geothermal observations we use the values of ground temperature at 100 m depth, which is practically untouched by the influence of climate warming in 20th century. Temperature at this depth decreases along 68° N from the Monchetundra Mountains at the Kola Peninsula to the northern border of Ural at a rate of 0.17°C per 1° of eastern longitude. Mean annual air temperature decreases between the above mentioned regions with the same intensity. Under approximately equal temperatures at the depth of annual zero amplitude CZ thickness of European mountains depends on the age of tectonic folding: in the case of equal age, CZ thicknesses are approximately equal, e.g. Alps and Caucasus. In mountains of various ages (Alps and Ural, Caucasus and Scandinavian Mountains) CZ thicknesses differ by several times. Differences in CZ thickness are also characteristic for the Paleozoic mountains of approximately the same age, reflecting differences in tectonic and magmatic activation (mountains of Western Spitsbergen, Novaya Zemlya and Pay-Khoy, Ural, correspondingly). In this case the sharp distinction between CZ thicknesses is connected with significant differences in the values of geothermic gradient, as in the cases of regions with differing age of folding.

Global warming has influenced at the CZ of all European mountains. Temperature increase at the depth of annual zero amplitude during the period of 1987-98 varied from 0.03°C⁻¹ in the Alps to 0.07°C⁻¹ in the Urals, and reached 0.01 to 0.02°C⁻¹ for the period of 1969 to 2004. As a result, in the Ural foothills the thawing of small, up to 15 to 20 m thick, cryogenic massifs occurred, and the depth and the area of closed taliks increased sufficiently. Activity of continuous CZ degradation at Pay-Khoy is significantly lower. At the same time the contemporary formation of permafrost was recorded in the beds of drained lakes. Contemporary formation of permafrost is also possible at the sites of glacier degradation.

Multi-scale permafrost mapping in mountain terrain using the TTOP ground temperature model - examples from Southern Norway

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key words: permafrost mapping, TTOP model, mean annual ground temperature, mean annual ground surface temperature, southern Norway

A TTOP model predicts the Mean Annual Ground Temperature (MAGT) at the base of the seasonal freeze/thaw layer through the use of seasonal n-factors, modifying the Degree Days Air Thawing Index (DDTair) and the Degree Days Air Freezing Index (DDFair). An additional parameter representing the conductivity ratio between unfrozen and frozen surface material (Kt/Kf) is used to model the thermal offset between the Mean Annual Ground Surface Temperature (MAGST) and the ground temperature at the top of the permafrost (TTOP). The model shows good performance in arctic low-land applications when compared with finite-element heat conduction models and borehole data (Smith and Riseborough 2002, Wright et al., 2003). The model was applied in Jotunheimen and Dovrefjell, which are two areas of complicated mountain terrain in central southern Norway. The model was implemented in a raster based Geographical Information System (GIS) which allowed a flexible multi-scale approach in model runs, parameter estimation and results evaluation. The main data source was a new one kilometer gridded dataset developed by the Norwegian Meteorological Institute and The Norwegian Water Resources and Energy Directorate (NVE). The data set consists of daily values of air temperature and snowcover in water equivalents for the period 1961 to 2005. The results from spatial

modelling are compared with data from boreholes, BTS measurements, ground surface temperature measurements and standard meteorological observations. Results are in good agreement with observational data, considering the computational simplicity of the model. Clearly, the model has obvious future potential in evaluating both past changes in ground temperatures and the impact of climate change in mountain environments. The main challenges in the future development of this model in mountain terrain can be summarized as follows:

- The redistribution of snow due to wind drift causes a highly variable snowcover. This needs to be considered in order to obtain detailed results that can be compared with borehole data.
- The variations in the shortwave radiation flux at the ground surface induced by slope and aspect have significant impact on permafrost distribution in steep terrain.
- Warm permafrost or deep seasonal frost with possible lateral heat transfer in a complex soil-water system reduces the applicability of the model at some sites.

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Simulated changes in Tibetan Plateau active-layer depth and its annual timing

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key words: active layer depth, modelling, regional warming, permafrost, Tibetan Plateau

The soil thermal regime of the Tibetan Plateau is modeled by applying a one-dimensional heat transfer model with phase change. The two main forcing parameters are surface air temperature and snow depth. Air temperature is from the ERA-40 reanalysis, and snow depth is derived from snow-water equivalents from passive microwave satellite data, in combination with climatological daily snow density. Soil bulk density as well as the concentration of fine and coarse-grained soil are from the SoilData System of the IGBP-DIS. Daily fields of soil temperature are simulated, ranging from the soil surface down to 30 m depth, with a horizontal grid cell resolution of 25 km × 25 km. Results are presented for three different soil moisture regimes. The trend analysis is based on daily fields of active-layer depth for the 22-year period January 1980 through December 2001. Positive trends for all Tibetan permafrost regions are simulated in response to positive trends in air temperature, with the strongest warming trend (+1.38 cm a⁻¹) for the Northern Tibetan Plateau. Discontinuous permafrost regions within the model domain reveal a significant warming trend of +1.23 cm a⁻¹, and sporadic permafrost regions a trend of +0.66 cm a⁻¹. Trends are virtually independent of soil moisture content. The Day of Year when the active-layer depth is reached (in general between early September and mid-October, depending on the region) is subject to strong interannual variation of up to three weeks, and mostly insignificant trends. As an application, active-layer deepening and interannual variability is presented along the tracks of the Qinghai-Tibet railroad line presently under construction through discontinuous permafrost at altitudes of more than 4000 m.

The recent warming of permafrost in Alaska

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key words: permafrost, warming, thawing, climate change, monitoring

In 1977, a project was initiated to measure the thermal regime of undisturbed permafrost in Alaska to determine the effects of climate and environmental conditions on permafrost. Permafrost observatories were established along a North-South transect of Alaska. This paper focuses on the measurements and the most recent interpretation and analyses.

The statewide warming of air temperatures that began during the winter of 1976 to 1977 produced a coincident warming of permafrost temperatures that peaked in the early 1980s and then decreased in response to slightly cooler air temperatures and thinner snow covers. Arctic sites began warming again about 1986 while sites in Interior Alaska began about 1988. Gulkana has been warming slowly since it was drilled in 1983. Snow covers increased substantially from about 1989 into the 1990s resulting in a significant warming of the permafrost at most sites. Air temperatures remained relatively warm and snow covers were generally somewhat thicker-than-normal into the late 1990s which allowed permafrost temperatures to continue to warm. The warming was greatest in the winter and spring and least in summer and fall. Temperatures at some sites leveled off or cooled slightly after the turn of the century. There are sites where permafrost is currently thawing at the top and at the bottom. At the Gulkana site, the mean basal thawing rate was about 0.04 m a^{-1} (1989 to 2002) with a value of 0.09 m a^{-1} for 2000 to 2002.

Study of the climate and cryolithozone contemporary changes in Russia

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key words: climate warming, small-scale digital map, air temperature increase, trend of air temperature changes, geocryological changes

The contemporary climate warming at the Russian North began in the middle of the 1960s. Its average rate is about 1.1°C whereas the global air temperature increase is approximately only 0.5°C . The greatest rate of annual air temperature increase was observed in the decade from 1980 to 1990. Since the middle of 1990s, the rate of climate warming has decreased sharply. In the European North, a tendency for slight air temperature downturn is noted. In some other northern regions (the Central Yakutia, Transbaikalia, etc.) the climate warming continues. Small-scale mapping based on monitoring data is one of the most effective methods of spatial analysis of present and expected climatic and geocryological changes. In 2003 to 2004 we developed a set of small-scale digital maps displaying the climate changes in the Russian North:

- a map of the main meteorological stations spatial location,
- a map of contemporary annual air temperature increase,
- a map of contemporary trend of air temperature changes.

The data from 86 meteorological stations were used. The data on the cold 1950s were the background for assessment of climate warming rate. The additional explicative information is shown on the maps. This includes the landscape zones and permafrost types (continuous, discontinuous, sporadic). The analysis of the maps shows, that the highest rate of annual air temperature rise (up to 2°C) is marked in the Central and Southern Yakutia and in Transbaikalia. Significant warming is observed at the Pur-Nadym watershed (upland), Eastern part of the Tas-Yenisei watershed in the Western Siberia. Low rates of annual air temperature increase is typical for the Arctic plains and lowlands of the European North and extreme Northeast of Russia (no more 0.5 to 0.7°C a^{-1}). The maximum temperature trend is observed in the Southern part of Siberia (on the average $0.08^\circ\text{C a}^{-1}$), the minimum (0.01 to $0.02^\circ\text{C a}^{-1}$) - in the European North and Northeast. The contemporary climate warming caused the changes in the cryosphere. To assess these changes we collected all available data on existing geocryological sites. A map of spatial location of these sites and appropriated database should be a basis for creation of the map of permafrost temperature changes. The 20 to 30 years geocryological regime observation revealed that the frozen ground temperature is a sensitive indicator of climatic changes. The period of well-indicated climate warming (1975 to 1995) is characterized by significant increase of ground temperature in many regions. In the north of Western Siberia the rate was from 0.9 to 1.2°C per annum in continuous permafrost, 0.9 to 1.4°C per annum in discontinuous permafrost and to 0.2 to 0.8°C per annum in sporadic permafrost. But since 1996, a slight downturn of ground temperature is noted here. Despite the greatest climate warming in the Central Yakutia, the geocryological features are very stable here. This is caused by gradual decrease of snow cover thickness over the last 15 to 20 years. In various climatic zones of the Russian North and even within the limits of local sites, the opposite tendency in changes of climate warming and seasonal thawing depth can be found. It shows that the active layer is not a sensitive indicator of global climate changes. Hence, it is possible to speak about thermal homeostasis of the cryolithozone under the contemporary condition, and with climatic changes since 1996, modern processes of thermal permafrost degradation have begun to fade. This study is supported by the RFBR grant 04-05-64005.

An assessment of deep ground temperature spatial distributions in permafrost regions of Russia

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key words: climate change impact, ground temperature, annual evolution, modelling

During the last decade the problem of permafrost response to climate warming has received much attention. The attention was focused mostly on the change of active layer depth in permafrost regions. The monitoring data often show a warming of the underlying layers and the rate of this warming is rather noticeable. It is evident that this effect needs more detailed investigation.

This presentation will demonstrate the patterns of ground temperature profiles in the permafrost regions of Russia. Climate-induced permafrost disturbances are simulated by means of simple ground heat transfer model. The thermal coefficients in heat transfer equation are prescribed. The annual evolution of ground temperature vertical distributions is evaluated at the nodes of a regular 1-degree grid under the current climate conditions and under the climate change forcing. This forcing is extracted from GCM output data. Several GCMs are used and the data of GCM ensemble are used also. The influence of vegetation features on the ground temperature annual evolution is investigated. Current climate longitudinal and latitudinal change in ground temperature profiles shows a connection between the climate and the thickness of the warm layer with positive temperatures underlying the low boundary of active layer. The absence or presence of the layer with positive temperatures between the freezing layer in winter and underlying permafrost marks the boundaries of discontinuous permafrost zone. The coarse resolution of GCMs prevents a realistic description of soil characteristics but we can find the modal ground characteristics on the base of several numerical experiments with various types of vegetation. The downscaling of surface climate characteristics is performed by means of multi-level boundary layer model. Annual evolution change of the permafrost temperature due to the climate warming is analyzed. The comparison with temperature measurements in boreholes is presented. The large scale retreat of permafrost based on various criteria of discontinuous permafrost position is demonstrated.

Analysis of the thermokarst's early stage with deterministic and probabilistic methods

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key words: thermokarst, mathematical modelling, climate change, shallow pond, probabilistic analysis

A mathematical model has been developed for thermokarst's early stage when shallow depressions filled with water are formed as a result of the ground ice melting. The model makes it possible to evaluate the role of the basic factors of "external heat exchange" in the thermokarst development. The most important factor is the large difference between the rates of ice formation and destruction. Over the permafrost territory, despite severe long winters, an ice cover of lakes and ponds decays very quickly. In the Central Yakutia this short period usually occupies only 4 to 5% from the total thaw impulse (sum of positive degreehours). In the summer the bottom temperature rises under the action of penetrating short-wave radiation. The water layer serves as the peculiar insulation reducing thermal losses to the atmosphere. Due to this for most of the warm season the temperature at the shallow pond bottom proves to be warmer than on the surface of not flooded ground. Crucial thickness of the water layer (at which the thermokarst process becomes irreversible) depends strongly on the snow thermal resistance and much less - on the sediments lithology. In the case of a warming climate critical depth decreases. If in the Central Yakutia the average annual air temperature increases by 1.5°C, then the crucial depth will decrease 8 to 10 cm only. At first sight it suggests that climate changes influence the thermokarst development insignificantly. However all parameters determining the thermokarst intensity, have a sharply defined stochastic character. So, all prognostic estimations should be built on the basis of the probabilistic analysis using determined description of the major elements of its quantitative model.

According to one of the most widespread scenarios of the climate change the air temperature in the Central Yakutia will be warmer by 1.5°C by 2025. Presumably the thermokarst activity corresponds to depressions large enough and with the depth greater than critical. On the basis of the relief analysis it has been established that the depth of such

depressions obeys the normal distribution law with the average of distribution 0.1 m and dispersion 0.01 m². It means that in the case of warming the thermokarst probability increases rather essentially - from 0.274 up to 0.579. It may be also suggested that the probability of thermokarst occurrence corresponds to frequency of an event at which the active layer thickness exceeds the depth of ground ice bedding. Within the limits of an examined landscape the ground ice depth is in average equal to 2.1 m and annual variations of the active layer thickness are characterized by the normal distribution law with average value 1.95 m and standard deviation 0.1 m. Then the probability of thermokarst development is equal to 0.067. As a result of warming the seasonal thaw depth will increase up to 2.03 m, and the probability of thermokarst development will increase up to 0.242, i.e. 3.61 times. More full schemes are also possible taking into account the stochastic character of such parameters as the snow thermal resistance, thermal characteristics of the soils, the depth of ground ice bedding etc. Perhaps, for the prognosis of such complex systems' behavior it is not reasonable to involve physical and mathematical model of the process since there are too many influencing factors. In similar cases the probabilistic analysis of geological and geographical factors can prove to be more effective, for example, comparison of the data on the thermokarst development during epochs with different climatic conditions. Probably, the Monte Carlo method can be successfully applied here.

Topographic effects on shallow ground temperatures - Measurements at the PACE-Permafrost monitoring site Stockhorn Plateau, Matter Valley, Swiss Alps

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key words: high mountain permafrost, shallow ground temperatures, PACE

The complex topography in high mountain environments causes a wide variability in solar radiation and snow cover characteristics. Therefore, the pronounced relief can be considered to be one of the main factors controlling the near surface ground thermal regime. The quantitative knowledge of the complex and spatially variable ground heat transfer processes induced by differences in topography and snow cover characteristics is still fragmentary. In order to contribute to their quantification, shallow ground temperature regimes within the upper part of the active layer are recorded at Stockhorn plateau (3410 m a.s.l.). The study site is located in the southern Swiss Alps in the Matter Valley, where the continental local climate is characterized by high solar radiation and low precipitation. Since August 2004 ground temperature data are recorded at twelve vertical profiles, instrumented with 5-channel-data-loggers. Ground temperatures are registered hourly in five different sensor-depths (5, 15, 25, 50, 100 cm). Additional data are provided by six UTL-Loggers, which were arranged in a N-S transect of 50 meters length, measuring ground surface temperatures in an hourly interval since September 2002. The test area incorporates a permafrost-monitoring-site, consisting of two boreholes (100 and 30 m), which have been drilled in July 2000 within the framework of the EU-project "Permafrost and Climate in Europe" (PACE). In June 2002 a meteorological station was installed close to the deep borehole providing data on air temperature, snow cover height, relative humidity, wind direction, wind speed, short-wave and long-wave radiation. Despite their short distance of about 30 meters only, the temperature profiles of the two boreholes show considerable differences. This confirms the high variability of near surface ground temperatures due to complex topography. Therefore, accurate knowledge of the local distribution of ground temperatures is needed to better understand the effects of the pronounced relief in high mountain environments.

Permafrost monitoring in Tibetan Plateau based on the GAME-Tibet and CAMP-Tibet

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key words: soil water-temperature distribution, soil thawing-freezing processes, seasonal transition, Northern part of Qinghai-Xizang (Tibetan) Plateau

The soil energy-water distribution and freezing-thawing processes varied at different sites in the northern part of the Qinghai-Xizang (Tibetan) Plateau. The temporal and spatial variations of the soil moisture content were more complex

than those of temperature. At the observation site, the soil moisture content increases with depth in certain layers but decreases in other layers. The freezing/thawing processes and the temperature distribution were strongly influenced by soil moisture content. During the summer monsoon period, the soil moisture contents at a depth of 10 cm for all sites were relatively high but differed spatially. In general, the shallow layers started to freeze in October and thaw in April at all sites, with a freezing period of about 6 months. However, the onset of freezing/thawing varied at different sites. The results suggest that the freezing process may prevent the soil moisture from evaporating. Although there is low precipitation in winter (freezing period), the soil moisture content is high when the soil begins to thaw. The abrupt increase/decrease of net atmospheric heating synchronized with the thawing/freezing of soil indicates that these processes may strongly influence the seasonal transition on the Qinghai-Xizang (Tibetan) Plateau.

Active layer monitoring in Livingston and Deception Islands (South Shetlands, Antarctic) - Methodology and results

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key words: active layer, permafrost, antarctic, monitoring, heat flux

Livingston and Deception Islands are located in the South Shetlands archipelago near the northern tip of the Antarctic Peninsula, at respectively 62° 39' S, 60° 21' W and 62° 43' S, 60° 57' W. Climate at sea level is cold oceanic with frequent summer rainfall in the low areas and moderate annual temperature range, reflecting a strong influence of the circum-Antarctic low-pressure system. Data from Arctowski Station in King George Island show a mean annual air temperature of ca. -2°C at sea level with mean-monthly values above 0°C from December to March. Precipitation ranges from 470 to 700 mm, with summer means of roughly 100 mm. The average relative humidity is between 80 and 90%, figures that are typical of oceanic climates (King and Turner, 1997).

Monitoring of active layer temperatures in Livingston Island started in 1992 in a 0.6 m borehole located at 25 m a.s.l. (Ramos, 1998). In 1999 a similar borehole located at 275 m a.s.l. in quartzitic diamicton with fine matrix and high ice content was monitored. However, these were mainly short-term and discontinuous field experiments. In 2000 two new shallow boreholes were drilled in Hurd Peninsula in order to allow continuous temperature monitoring (Ramos and Vieira, 2003). One is located in quartzite bedrock at Incinerador Point (35 m a.s.l.) and is 2.4 m deep. The other is drilled in quartzitic diamicton with fine matrix and high ice content, at Reina Sofia hill (275 m a.s.l.) and is 1.1 m deep. The later reaches the permafrost table, which is present at ca. 0.75 m depth. Air temperatures are measured simultaneously at 3 sites (35, 165 and 275 m a.s.l.). In Deception Island ground temperatures were measured in a shallow borehole (0.6 m depth) during the winters of 1999 and 2000 (55 m a.s.l.). Since the island is an active volcano, the borehole was located outside the area with anomalous geothermal heat flux, in fine-grained pyroclastic deposits with high ice content. These measurements are comparable to the first experiments conducted in Livingston Island. The study of Incinerador Point borehole winter temperatures from 2000 to 2004 allowed calculating the energy fluxes between the ground surface and the air, as well as the rate of ground cooling. The calculations using thermodynamic arguments are possible, because the ground is bedrock with insignificant water content. The procedure allows to assess the effects of air climate in the ground and to evaluate the main thermal parameters related with aggradation or degradation of permafrost in that locality.

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Meteorological characteristics of snow pit in Gorski kotar region (Croatia)

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key words: snow pit, climate change, acid rain

This paper introduces the first meteorological measurements in a snow pit near the village Slavica in Gorski kotar region in the western mountainous part of Croatia. This research was initiated by Croatian Meteorological Society and Meteorological and Hydrological Service. The aim was to find out the main meteorological characteristics of the location and to compare them with climate characteristics of the whole region. Measurements in the snow pit and surrounding area were conducted in the period from 22nd to 28th August 2004. The main idea was to find out the connection between meteorological conditions in the pit and the climate conditions of the area in which snow pits could be found. The assumption was that meteorological conditions in snow pits could be indicators of climate changes.

Temperature and relative humidity were measured inside and in the vicinity of the snow pit. Two samples of snow from different depths of snow accumulation on the bottom of the pit (depth approx 40 m) were collected for analyses. In the period of measurements it was raining and the precipitation amount was also measured. The highest temperature outside the snow pit was 16.9°C, and the lowest was 7.6°C. The highest relative humidity was 95%, and the lowest was 62%. The amount of rain was 44 L m⁻² and the pH was 6.30. Soil temperatures measured at 5 cm depth were from 12.1°C to 14.6°C, and those at 10 cm depth from 12.0°C to 13.6°C. On the bottom of the snow pit temperature was 2.9°C and relative humidity was 94.6%. Snow sample taken from the bottom of the snow pit from 0.5 m depth had pH value 5.56, and the one from 1.0 m depth had pH 6.44. Changes of temperature and relative humidity in the vicinity of the pit showed typical variations for season, but the values inside the snow pit were constant. Chemical analyses of the snow samples and rain showed that there were not acid rains at monitoring location what is surprising as we know that region is under the influence of long range pollution. Further investigations of snow pits should be conducted to test the general meaning of the obtained results.

Influence of snow cover characteristics on permafrost temperatures

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key words: snow, ground temperatures, TTOP, climate, modelling

This paper examines the relationship between the seasonal pattern of snow cover and permafrost ground temperature. The effect of variations in snow density, timing of the initiation of snow cover with respect to the freezing season, and the seasonal pattern of snow accumulation is examined using geothermal simulation, with variations constrained by climate station snow cover data. The effect of inter-annual variability of snow cover is also examined. Results suggest that the thermal effect of snow cover can be expressed in terms of snow thermal resistance, and that the initiation and accumulation rate of snow cover modify its effect on ground surface temperature, resulting in mean annual ground temperature variations of several degrees. The net thermal effect of a variable snow cover was found to be equivalent to the thermal effect of the long-term average (normal) snow cover, as long as the key mean snow cover properties were characterized correctly.

Permafrost in Alaska: A millennium of history and possible future changes

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key words: permafrost temperature, permafrost degradation, Little Ice Age

Permafrost has received much attention recently because surface temperatures are rising in most permafrost areas of the earth, bringing permafrost to the edge of widespread thawing and degradation. The thawing of permafrost that already occurs at the southern limits of the permafrost zone can generate dramatic changes in ecosystems and

in infrastructure performance. All observed and predicted changes in permafrost stress the necessity to monitor its dynamics (particularly its temperature) for timely assessment and predictions of the possible negative impacts of permafrost degradation on ecosystems and infrastructure.

Analysis of the long-term records of the near-surface permafrost temperature dynamics, obtained from different parts of the permafrost zone in Alaska, shows a significant warming trend during the last 30 years. This recent warming brought soil temperatures in Alaska to a surprisingly high level, about 1 to 3°C warmer than long-term averages. Within some areas the permafrost temperatures now are very close to 0°C and at some sites a long-term permafrost degradation has already started. Analysis of measured active layer and permafrost temperatures coupled with numerical thermal modelling (permafrost temperature reanalysis) shows that most of the recently thawing or thawed permafrost was formed during the Little Ice Age. Older Alaskan permafrost that has been continuously in existence since the last Late Pleistocene glaciation is still generally stable. However, presently, at some southern locations, such as Interior Alaska, this permafrost is just several tens of degrees off from the beginning of thawing. If recent trends continue, it will take several Centuries to Millennia for permafrost in the most of the present discontinuous permafrost zone to disappear completely in the areas where it is now actively warming and thawing. However, negative consequences of this degradation will be pronounced from the very beginning because the highest ice content in permafrost usually is found in the upper few tens of meters. Future projections of changes in permafrost temperature and integrity strongly depend on a specific scenario of the future climate changes and on quality of the permafrost models used for these projections. Several different scenarios of permafrost changes in Alaska during this century will be presented.

Monitoring High-Altitude Permafrost with GPR

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key words: Qinghai-Tibet, permafrost, GPR, seasonal ice

A large fraction of the Qinghai-Tibet plateau belongs to the high-altitude permafrost region. Due to its low latitude, it is characterized by high insolation and correspondingly high mean ground temperatures between -4 and 0°C. This region is thus particularly vulnerable to global change. As the source region of all major rivers in China and a potential source of dust, changes in extent and quality of permafrost may be expected to have major environmental impacts. The same is true for infrastructures like the transplateau highway and railroad. We explored the use of ground-penetrating radar (GPR) for the rapid monitoring of the permafrost table and of seasonal ice at various sites along a transect that extends from north of Kunlun pass to south of Tanggula pass. Working mostly with a 250 MHz antenna and running transects between 20 and 400 m length, we demonstrated the rapid detection of various forms of ground ice and verified the results at a few locations. The method is sensitive enough to reveal rather subtle relations between features of the ground surface and of the underlying permafrost. At the same time is robust and quick enough for monitoring very long transects.

Land-surface/soil processes in the HIRHAM4 regional climate model of the Arctic

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key words: numerical regional climate modeling, arctic permafrost modeling, arctic land surface schemes

HIRHAM4 has been run over 15 years (1979 to 1993) for the pan-Arctic domain whereby two different soil schemes (ECHAM4, Roeckner et al., 1996, LSM, Bonan et al., 1996) have been coupled to the atmosphere. The performance of both model versions has been evaluated by comparing different atmospheric variables (air temperature, precipitation) and selected soil variables (ground temperature profile, snow depth and season) with observations from different Russian, Alaskan and Canadian sites. The simulated spatial permafrost distribution agrees well with the NSIDC climatology. For the ground temperature, the model shows realistic temperature damping profile as well as interannual variability. For the seasonal cycle of the ground temperature, we recognize a good agreement from April to October,

but a cold bias in winter. However, this bias is less pronounced in the western Russia than in the far East Siberia. To try to explain this bias, some sensitivity studies have been done concerning the impact of PBL exchange flux, snow depth, density and albedo, soil thermal heat conductivity.

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The use climate models for alpine permafrost modelling - possibilities and limitations

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key words: alpine permafrost, RCM, modelling, climate change

High mountain environments in general and the mountain cryosphere in particular are affected seriously by climatic changes. The hazard potential of slope instabilities, such as rock falls or debris flows, are strongly related to changes in the thermal regime of high mountain areas. Therefore, the locating of potentially sensitive areas for the future is an urgent need, especially in the densely populated mountain areas of the European Alps.

The most seminal tools for modelling climate scenarios are General Circulation Models (GCMs), which have currently a spatial resolution of about 200 km. For local studies, higher resolution is required and thus dynamical downscaling techniques are used to run Regional Climate Models (RCMs) that achieve a spatial resolution of about 20 to 50 km. The coupling of alpine permafrost models with RCMs offers new and promising perspectives for the assessment of future changes in the spatial occurrence and temporal development of alpine permafrost temperatures in high mountain areas. However, there are several technical limitations for a direct coupling of the models due to the differences in model and data concepts applied in the two science disciplines. Furthermore, both the output of climate models and permafrost models has quite a large range of uncertainties.

In this contribution, we will present an overview of the data and models available so far, of the possibilities and limitations of coupling approaches and of the future needs for the cooperation between atmospheric and cryospheric science. In addition, a case study will be shown about the coupling of an RCM with two permafrost models for the area of Corvatsch-Furtschellas (Upper Engadin, Switzerland).

Permafrost verification on maritime Antarctica using ground penetrating radar

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key words: maritime Antarctica, ground penetrating radar, sedimentary permafrost, glacier forefields

Detecting sedimentary permafrost has been the challenge on Livingston Island, South Shetland Islands, maritime Antarctica, where ground penetrating radar (GPR) was used for profiling the transition from unfrozen to frozen sub-ground. At Hurd Peninsula in vicinity to the Bulgarian (St. Kliment) and Spanish (Juan Carlos) bases the studied ice-free island margin is mainly build up of raised beaches and glacier forefields consisting of morainic deposits and debris infilled depressions, rock glaciers, debris cones, and gelifluction lobes. Generally permafrost occurrence can be encountered 50 m above sea level. Single-offset and multi-offset radar records have been acquired using center frequencies of 50, 100 and 200 MHz. Records from the various surfaces are presented and discussed along with the applicability of the GPR method.

Assessment of the Circumpolar Active Layer Monitoring (CALM) network as a validation tool for spatial permafrost models

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key words: active layer, modelling, observational networks, permafrost monitoring

The Circumpolar Active Layer Monitoring (CALM) program is a network of sites at which data about active-layer thickness (ALT) and dynamics are collected. CALM was established in the early 1990s to observe and detect the long-term response of the active layer and near-surface permafrost to changes in climate. The CALM network currently includes 125 active sites in both hemispheres that report ALT and auxiliary information on an annual basis. CALM data have proven useful for assessing spatial and temporal regularities in thaw depth at local and regional scales. Here, we examine the applicability of CALM data to validation of spatial permafrost models. At present, such models are frequently evaluated either by one-dimensional tests of their performance or validated at sets of point locations. Validation procedures rarely correspond to the resolution at which models are applied. The high spatial variability of permafrost parameters requires careful selection of validation points. To address this problem, we assessed the representativeness of the CALM observational network by its ability to characterize generalized conditions prescribed by spatial permafrost models. The observed spatial patterns and temporal trends were analyzed in conjunction with spatial fields of surface, subsurface, and climatic characteristics used to drive permafrost models operating at broad (e.g., regional or circumpolar) geographical scales. To achieve correspondence between the scale of observations and the modelling resolution required, we developed a hierarchical approach to model validation. The scheme adopted includes empirical data from point locations and observational plots provided by the CALM network, regional characterization of permafrost conditions, and continental- and circumpolar-scale models. The developed approach was applied to compare observed patterns of permafrost parameters with results from the National Snow and Ice Data Center permafrost model for North-Central Alaska.

Thermal monitoring of three deep permafrost (PACE) boreholes in Svalbard and Scandinavia

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key words: permafrost, long-term thermal monitoring, deep boreholes, PACE

Three deep boreholes in permafrost were drilled in Svalbard and Scandinavia and form part of the latitudinal transect of mountain permafrost boreholes through the mountains of Europe. These boreholes were established under the European PACE (Permafrost and Climate in Europe) project. The northernmost borehole in the transect, at Janssonhaugen (depth 102 m), western Svalbard (78° 10' N, 16° 28' E, 270 m a.s.l.) was drilled in May 1998. In Scandinavia, boreholes were drilled at Tarfalaryggen (depth 100 m), northern Sweden (67° 55' N, 18° 38' E, 1550 m a.s.l.) in March 2000 and at Juvvasshøe (depth 129 m), southern Norway (61° 40' N, 08° 22' E, 1894 m a.s.l.) in August 1999.

Thermal data collected over a period of nearly 7 years are presented. These data provide the first opportunity for temporal trends to be analysed, adding a critical new dimension to current knowledge of permafrost conditions in Svalbard and Scandinavia. Results show that the permafrost has warmed considerably at all three sites, with greatest warming in Svalbard. The present regional trend seems to be an accelerated warming during the last few years.

The main purpose of the monitoring of thermal data at these three boreholes is to collect a long time series of data through tens of years for climatic research. The Norwegian Meteorological Institute is responsible for the data from the Janssonhaugen and Juvvasshøe boreholes and the Tarfala Research Station (Stockholm University) is responsible for the data from the Tarfalaryggen borehole. The national databases are linked to the GTN-P database. Other existing boreholes in Norway are also incorporated in the same national database. New boreholes will certainly be added in the future.

Spatial and temporal variability of active-layer thickness in North-Central Alaska: Results from CALM's first decade

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key words: active layer, permafrost monitoring, spatial modelling, Alaska

The uppermost layer of seasonal thawing above permafrost (the active layer) is an important regulator of energy and mass fluxes between the surface and the atmosphere in the polar regions. The Circumpolar Active Layer Monitoring (CALM) program was established in the early 1990s to observe and detect the long-term response of the active layer and near-surface permafrost to changes in climate. In Alaska systematic, periodic, spatially-oriented active layer observations have been conducted under CALM since 1995. Here we describe methodology and provide results of active-layer and ground temperature monitoring in north-central Alaska. Data from long-term field investigations were used to examine spatial and temporal regularities in the active layer and ground surface temperature for several landscape types, and to evaluate the sensitivity of landscape-specific ground thermal regimes to variability and changes in the atmospheric climate. Analysis of active-layer observations at representative locations demonstrates large differences in the magnitude and spatial pattern of active-layer thickness between several landcover units, reflecting the influence of vegetation, substrate, moisture conditions, and terrain. To address the question of ground heave and subsidence, and their influence on active layer estimates obtained by mechanical probing, we developed and applied a methodology using Differential Global Positioning Systems (DGPS) technology. Statistical representations of the spatial and temporal variability of seasonal freezing and thawing and ground-surface temperature for each generalized landscape type characteristic of the continuous permafrost zone in northern Alaska were developed. The results can be used for detailed characterization of active-layer thickness at small geographical scales, to evaluate spatial permafrost models, and to bridge the critical gap between models of climate-permafrost interaction and localized thaw depth measurements.

Permafrost temperature monitoring in eastern ridge of Mt. Jungfrau

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key words: mountain permafrost, temperature, monitoring, warming, rock wall

Progress of the thaw in the mountain permafrost has the correlation with the stability of steep slopes and rock faces. In the aspect of natural hazards, the monitoring of the response of the permafrost to the climate change therefore has the importance in high mountains.

For the alpine permafrost, due to the large effect of topography, the ground surface temperature has the wide range of local variability. Consequently, the distribution of the mountain permafrost should be estimated by the empirical rules or modellings. Yet there are difficulties of the verification for these estimations, because in situ measurements of ground surface temperature are rarely available, which is the essential parameter for the thermal state of permafrost. It is therefore important to perform the actual measurement not only for the verification of the permafrost model, but also for the grasp of the current state of permafrost by the real data. Since 1995, temperature and deformation have been measured on the East ridge of Mt. Jungfrau. Two boreholes of twenty meters depth are drilled outwards from the inner tunnel, on both of north and south sides of the ridge. Eight thermistors and six-point extensometers are installed for each borehole. The advantage of this measuring site is: (1) having deep borehole in the rock wall of high mountains, (2) measuring the temperature and deformation in the same location, and (3) measuring both of north- and south-wall of the same ridge. 10-years observation shows that the trend of rock wall temperature not necessarily follows that of the air temperature, possible reason of which is the variation of the other factors, such as snow deposit or water content. On the other hand, the entire rock wall temperature does not show a strong trend of warming for the last 5 years. It is natural that annual mean temperature does not depend on seasonal variation, but should show some trends when the long-term temperature variation exists. The data imply that air temperature may be not the most important controlling factor of long-term rock wall temperature. On the south wall, the temperature at 8 meters depth is close

to freezing point (i.e. above zero in deeper part), therefore the thickness of the permafrost is estimated less than 10 meters. Generally, permafrost has the long, decade-scale response time to the climate, but such shallow permafrost should be sensible to the climate variation. It can be thawed in relatively short period under the present climate trend. Careful monitoring is needed. Using temperature data, simple modelling in 1-D and 2-D are performed, in which heat transfer in the mountain is calculated. The results are, however, dependent on the boundary conditions on rock wall surface, and this parameter can vary locally.

Micrometeorological controls on the temperature regimes of the active layer during the summer in Livingston and Deception Islands, Antarctica

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key words: active layer, micrometeorology, antarctic, ground temperature, permafrost

Livingston and Deception islands are located in the South Shetlands near the northern tip of the Antarctic Peninsula, at respectively 62° 39' S, 60° 21' W and 62° 43' S, 60° 57' W. Climate at sea level is cold oceanic with frequent summer rainfall in the low areas and moderate annual temperature range, reflecting a strong influence of the Circum-Antarctic low-pressure system. Data from Arctowski station in King George island show a mean annual air temperature of ca. -2°C at sea level with mean-monthly values above 0°C from December to March. Precipitation ranges from 470 to 700 mm, with summer means of roughly 100 mm. the average relative humidity is between 80 and 90%, figures that are typical of oceanic climates (King and Turner, 1997).

During the summer campaigns of 1999 to 2000 and 2000 to 2001 (December to February) ground temperatures were measured at 30-min intervals at two sites: Reina Sofia Hill (Livingston Island, flysch metasediments, 275 m a.s.l.) and JB Hill (Deception Island, volcanic debris, 55 m a.s.l.). In the former, temperatures were measured down to 40 cm depth and in the later down to 100 cm. Automatic meteorological stations were installed at both sites, providing measurements of incoming and outgoing short- and long-wave radiation, incoming diffuse short-wave radiation, wind speed and direction, air temperature and relative humidity. The instrumentation was cleaned from riming and dust nearly every day in order to provide best results. The poster shows the results of the micrometeorological monitoring and of the ground temperature regimes, providing a characterization and comparison of the summer conditions in the two islands. Special emphasis is given in the characterization and analysis of the radiation balance, since the summer radiation is well recognized as an important factor controlling permafrost distribution and characteristics. The data is studied in a daily time-frame in order to classify types of daily regimes and to better identify the controlling factors.

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Comparison between the PERMOS sites Murtèl and Schilthorn: Similarities and differences of the temperature regime

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key words: permafrost monitoring, thermal regime, permafrost temperature series, alpine permafrost

The PERmafrost MONitoring project in Switzerland (PERMOS) complements the long-tradition of Swiss glacier monitoring and is in operation since 2000. It is based on three approaches to determine (1) thermal state: borehole temperature and active layer thickness, (2) permafrost distribution pattern around the lower boundary using single-channel temperature loggers all year around and BTS-measurements in winter, and (3) to ensure that aerial photographs

are taken regularly, for subsequent photogrammetrical processing, to monitor surface changes and deformation of creeping permafrost. The programme comprises more than 10 already existing boreholes, BTS-areas and about two aerial flights per year. The measurements are undertaken by the eight institutes that set up the various sites. One goal of PERMOS is to provide a base of measurements for better understanding interrelationships and ongoing processes in order to adapt and improve permafrost models.

The longest time series of repeated permafrost temperatures at depths are available from the borehole in the Murtèl rock glacier (Upper Engadine) in 1987. In contrast, the 14m drilling into the limestone schist bedrock at Schilthorn, located at the northern border of the Bernese Alps, was established for long-term monitoring only in 1998 within the EU-project "Permafrost and Climate in Europe (PACE)".

During the last years weather conditions were quite extreme: in winter 2001/2002 only little snow fell in the Swiss Alps and summer 2003 was characterised by extremely high air temperatures lasting for several weeks. Although there are some obvious differences between the two sites (e.g. surface characteristics, regional climate, mean annual permafrost temperature, permafrost thickness, active layer thickness, geomorphology, ice content), some similarities can be observed as well. In this paper, we particularly focus on the thermal regimes at the two sites and their reaction to the various extreme weather conditions. The temperature variations at about 11 m depth show an almost parallel behaviour at the two sites. In contrast, the active layer thickness is completely different: At Murtèl, it varies only within a few centimetres to decimetres, while at Schilthorn, it doubled from 4 to 5 m in one year to 9 m in the hot summer 2003. The two sites are also compared in terms of the active layer index introduced by Arenson, adding up the thickness of the active layer during one year.

Character of permafrost in Qilian mountain

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key words: Qilian Mountains, permafrost, character

The Qilian Mountains lie on the northeast edge of Qinghai-Tibetan Plateau. Permafrost widely distributed in this area. Little work on permafrost has been done in formerly times. In the 1970s, permafrost research that for the buildings of a coal mine at Reshui and Jiangcang, Muli in this region was carried out for three years. In 2004, a drilling investigation that served for several roads in Qinghai province of China was carried out. Based on information from the drilling investigation, this paper describes the character of permafrost in this area. In contrasting with the result of earlier investigation, we concluded that a general rule could be developed about frost soil distribution in mountainous area of Qilian, and the changing of permafrost status in 20 years.

Permafrost monitoring and soil thawing/freezing processes in Tibetan Plateau based on the GAME-Tibet and CEOP/CAMP-Tibet

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key words: permafrost monitoring, thawing-freezing processes, Tibetan Plateau, GAME-Tibet, CEOP/CAMP-Tibet

The Asian monsoon system is one of the most important components of the energy and water cycle in the global climate system. The GEWEX Asian Monsoon Experiment (GAME) is one of the major projects of the Global Energy and Water Cycle Experiment (GEWEX). Because the Qinghai-Xizang (Tibetan) Plateau is the ridge of the world, the energy and water cycles on the Qinghai-Xizang (Tibetan) Plateau play an important role in the Asian monsoon system. As a part of GAME, the GAME-Tibet project aimed to examine the energy and water cycles on the Qinghai-Xizang (Tibetan) Plateau and their effects on the Asian monsoon since 1996. After GAME-Tibet, CEOP/CAMP-Tibet continues to carry out the field work. Here, the observation of soil moisture and temperature and the preliminary results were introduced. The soil energy-water distribution and freezing-thawing processes varied at different sites in the northern part of the Qinghai-Xizang (Tibetan) Plateau. The temporal and spatial variations of the soil moisture

content were more complex than those of temperature. At the observation site, the soil moisture content increases with depth in certain layers but decreases in other layers. The freezing/thawing processes and the temperature distribution were strongly influenced by soil moisture content. During the summer monsoon period, the soil moisture contents at a depth of 10 cm for all sites were relatively high but differed spatially. In general, the shallow layers started to freeze in October and thaw in April at all sites, with a freezing period of about 6 months. However, the onset of freezing/thawing varied at different sites. The 7 years observation results also showed that the temperature is increasing in the context of the global warming.

Estimates of the means and trends of active layer thickness in the Arctic

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key words: active layer, permafrost, thawing index, edaphic factor

Seasonal freezing and thawing processes of soils have a great impact on surface energy balance, hydrological cycle, carbon exchange, and serious natural hazard at high latitudes. In this study, we will investigate spatial and temporal variability of active layer thickness from 1950 through 2000 over the permafrost regions north of 50° N. Active layer thickness will be estimated by a simplified Stefan solution using the “edaphic factor” and the annual thawing index of air temperature. The “edaphic factor” was determined using ground-based active layer thickness from 31 stations from 1950s through 1990 in the Russian Arctic, 103 CALM stations since the early 1990s, and six stations over the Tibetan Plateau from 1996 through 2002. Data of the “edaphic factor” from ground-based measurements are used to validate and calibrate the calculated values of the “edaphic factor” from model outputs. The validated and calibrated values are used to estimate active layer thickness over the study area with resolution of about 0.5° latitude by 0.5° longitude. Annual thawing index were calculated from gridded monthly mean air temperature. After comparing with annual thawing index obtained using daily air temperature, errors of annual thawing index obtained from mean monthly air temperature are relatively very small in the Arctic and Subarctic. We will present climatology, standard deviation, and trends of the “edaphic factor”, annual thawing index, and active layer thickness in the Arctic using all available data. Active layer thickness obtained from this study will also be compared with ground-based measurements and modelling outputs.

The thermal properties of active layer in different eco-regions on the Tibetan Plateau

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key words: Tibetan Plateau, permafrost, active layer, thermal properties, eco-regions

Based on the analysis of monitoring data on the active layer dynamics along Qinghai-Tibet Highway during the past several years, the changing processes and characteristics of temperatures and water content in the active layer in four different regions on the Tibetan Plateau were discussed. It could be concluded that the thawing processes lasted a much longer period of time than the freezing processes of the active layer, and the duration of the thawing-freezing processes has a good relationship with the thickness and moisture content of active layer, and the permafrost temperature. Very good linear regression relationship existed between the mean annual temperature and the annual amplitude of mean daily temperature (AAMDT) at the bottom of active layer. The lower the mean annual temperature, the greater the AAMDT changed, and the more stable the permafrost was. Based on such relationships, it could be concluded that the degradation processes of vegetation on the Tibetan Plateau would be from bog meadow, meadow, prairie to steppe accompanied with the degradation of permafrost. The amount of water thawed from ground ice in the active layer during the thawing stage was calculated based on the observed data. It indicated that the amount of water thawed from ground ice among different eco-regions was similar, and was about 0.3 to 0.4 m³ in the active layer under one square meter of ground surface. The latent heat should be around 110 MJ m². Such an amount of heat would lessen the changing amplitude of the annual ground temperature.

Integrated surface and ground 3D permafrost model

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key words: permafrost model, finite element method, integrated heat and water process, climate change, impact assessment

One of the most pressing environmental challenges is that of global warming. There is a strong consensus among scientists that climate change is already occurring. The UN Intergovernmental Panel on Climate Change (IPCC) estimates that the average global surface temperature is likely to increase between 1.4 and 5.8°C by 2100 as a result of various greenhouse gas emission scenarios. These changes in global average temperatures can have a dramatic impact on our climate and our environment.

According to the projections of Canadian Global Circulation Model (CGCM), temperature rise in the North will be more than that of other places due to climate change. Since about 50% Canadian landmass is underlain by permafrost, and its significant portion has average temperature above -2°C, the projected temperature increase will cause considerable terrain disturbance in the Canadian north, damaging northern infrastructures. In recent years, several infrastructure disruptions of this kind have occurred in northern communities and caused public concern. An improved understanding of the vulnerability of northern infrastructure to permafrost degradation and the potential costs, under different climate change scenarios, is needed for informed adaptation decision-making at the regional and local levels. This understanding is also required as part of larger efforts to inform the upcoming post-Kyoto debate. For better understanding permafrost response to climate change, and its impacts on house/building infrastructures, a fully integrated heat and water 3-Dimensional permafrost model has been developed to simulate permafrost dynamics underneath and outside of foundation systems under various climate change scenarios. The permafrost model is a physical process-model, and characterizes two closely linked components - the ground surface component and underground component. These two components are integrated by water flux and heat flux. The surface component models energy and water balances above ground surface. The energy balance process includes temperature, and short and long wave radiation. The water balance process includes snow layers, precipitation, infiltration, and evaporation. For the modelling target, the surface model considers several surface conditions such as bare soil, paved and unpaved surface (for example, drive way and parking lot). In particular, the component modifies solar radiation by modelling house/building's location, dimensions, and orientation as part of the energy balance process. The ground component is a ground physical process model that uses Finite Element Method for geothermal and hydrological transfers. It simulates both heat and water transfer processes in an integrated manner. The coupling of the heat and water processes is done through two key elements of the two processes: temperature and unfrozen water content.

The developed model has been validated by two data sets, one in a natural condition, and the other close to a building. The validation results show that the model results match reasonably well with the measured borehole data. The model is therefore available for simulating long-term permafrost dynamics with downscaled GCM climate change scenario data. The simulation results can then be used for assessing the costs to infrastructure due to permafrost degradation.

Chapter 9

Session 8 - Coastal and Offshore Permafrost

Session Conveners: Volker Rachold, Misha Grigoriev

in association with: IPA WG on Coastal and Offshore Permafrost, IPA-IASC project Arctic Coastal Dynamics (ACD)

Coastal processes and their influence upon the discharge characteristics from the Strokdammene plain, West Spitsbergen, Svalbard

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key words: coastal processes, permafrost, active layer, climate change, sea-ice variations

Variations and changes in the coastal sea-ice conditions along the west coast of Svalbard have during the last three decades changed and affected conditions also ashore. In this poster the effect upon the drainage and discharge characteristics of small drainage basins are discussed. During 1972 to 2000 a 50 km² large investigation area on the west coast of Spitsbergen, Svalbard has been studied primarily focusing on periglacial forms and processes. The area is situated on the outer part of Isfjorden, south of Kapp Linne' (78° 04' N, 13° 38' E) and has a dense and characteristic drainage pattern and it is extremely rich in small lakes and ponds. The geomorphological and hydrographical character of the drainage pattern is described in relation to the active periglacial processes and the presence of permafrost. The bedrock morphology, which basically is forming a cuesta landscape, the presence of permafrost and the frequent development of high storm ridges which block river outlets along the coast give the hydrographic pattern and the surface water discharge a peculiar and characteristic pattern. The study covers the period 1972 to 2002.

In this poster special focus is given to the anomalous discharge pattern of the Fyrsjöen Lake via the Fyrsjöen brook. The drainage of the lake is some years blocked by ice-cemented storm ridges delaying the spring and snowmelt peak flow several weeks and thus raising the lake level dramatically. Vast areas are flooded, which is affecting snow melt, vegetation and breeding birds of the area. The Lake is then, after several weeks of thermokarst processes in the ice-cemented ridge, dramatically tapped during one or two days with heavy flow, after which the discharge pattern returns to normal. This process, which is especially well developed and visible for the Fyrsjöen Lake, is not unique but rather common along the west coast of Spitsbergen. These special hydrographic and discharge conditions have an influence on the active layer, the permafrost, the surface morphology, the vegetation and the bird colonies of the area.

This type of events has dramatically increased during the last three decades following the large scale sea-ice variations. The distribution of sea ice shows a clear tendency towards delayed and shorter winter periods with sea-ice long the west coast of Svalbard. This is affecting the coastal processes and ultimately also other near coastal periglacial processes.

An estimate of the flux of organic carbon from permafrost soils along the Yukon Coastal Plain, Canada

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key words: coastal permafrost, erosion, organic carbon, climate change

Organic carbon is added to the world's oceans through a variety of pathways, including coastal erosion. Although the flux of this carbon from much of the world's coasts is relatively well quantified, questions still remain about how much is contributed to the Arctic Ocean from high latitude soils. An understanding of this process is especially important because of the vulnerability of Arctic coasts to climate change. Degrading permafrost and higher wave energy will likely release increased amounts of soil organic carbon (SOC) to the oceans, which has implications for the global cycling of carbon.

The Yukon Coastal Plain along Canada's Beaufort Sea represents potentially one of the most sensitive coastal climate systems because of its ice-rich permafrost and extensive wetlands in backshore areas. This area is also of interest because of the narrowness of the continental shelf and the increased possibility of organic carbon therefore being transported to the deep ocean. This research provides an estimate of the present day flux of organic carbon from permafrost soils along the Yukon Coastal Plain. Using a morphological method calibrated by field data, relative percentages of sediment and ground ice are calculated for the different geomorphic and geologic settings along the coast. Published values for soil carbon are then used to calculate the organic carbon contents of the various stratigraphic units. Using data on the height of coastal bluffs, we make a volumetric assessment of SOC. Finally, coastal erosion rates over the last half century enable us to generate an estimate of current fluxes of organic carbon. This study expands upon previous work by extrapolating site specific data to the entire coastal plain. The potential increases to the flux of SOC caused by climate change-induced thawing of permafrost and increased wave erosion along the Beaufort Sea coast is discussed.

Coastal dynamic of New Siberian Island according to comparison of remote sensing results obtained at different times

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key words: coastal dynamics, remote sensing, change detection

Studies of dynamic of extended shorelines allowing to investigate consistent patterns of coastal processing depending on various factors, are of great interest now. Using remote sensing data we can receive mean long-term rates of coastal retreat. For this purpose, we compared aerial photos of 1951 to 52 and modern scanner space images ETM+Landsat7 (2002) of coastal zone of the Novaia Sibir' island (Novosibirskie islands). Also we used a data of 1955 and 1976 geological surveying and authors personal matter. We worked with "TIMAN" software elaborated within the laboratory of remote sensing (faculty of soil sciences, MSU), applying modern algorithms of thematic image processing. A block of data space normalization of "TIMAN" program allows to perform a geometric transformation and topographic adjustment of bitmap and vector cartographic data and results of remote sensing. Thereby, we use an algorithm of oversampling which allows to maintain brightness features of image.

415 km of shoreline are surveyed. Geological pattern consists of cretaceous, paleogene-neogene and quaternary frozen grounds. Pre-quaternary deposits consist mostly of ice-depleted clays and poorly bonded sands, and quaternary deposits are mostly clays and silts, and rarer sandy loams. Their ice-content is rather high due to segregative ice. Within the late Pleistocene deposits, ice-wedges are widespread, and massive ground ice up to 30 m of thickness is common over the northern coastal area. A coastal cliff recession realizes due to thermal abrasion and thermal erosion. Full-scale observations are rare. According to Sisco (1970), coastal retreat rate at the southern part of the island was 3 to 4 m a⁻¹. According to V.E.Tumskoy coastal retreat rate at the northern part was 3 to 5 m a⁻¹ for 2002 to 2003 season. A

large time-span between surveys allowed us to receive mean long-term values averaging a temporal discontinuity of coastal dynamic.

Results of comparison of alternative images showed that maximum mean values of thermal abrasion are common for the southeastern (Pestsoviy cape - Nadiozhnaya river mouth) and eastern (Mutnaya river mouth - Pestsoviy cape) coastal areas - 4 to 5 m a⁻¹. Maximum values were measured at the Griaznaya river mouth - 10 m a⁻¹. At the southwestern part of the island with similar geological and geomorphologic conditions the mean rate of recession comprised 0.5 m a⁻¹. This is related with different dynamic of coastal streams and sea ice regime within the different parts of island water-zone. At the northern coastal zone, maximum retreat rate is common for the shores adjacent to river mouths and comprises 2 to 7 m a⁻¹. Outside the mouth zones, within the areas of sandy ice-depleted deposits prevalence, retreat rate is 0 to 1 m a⁻¹, and of clay icy deposits - 1 to 2 m a⁻¹. For the latter a variability is characteristic, due to development of massive ground ice. Therefore, an assemblage of factors discussed above shows a complex pattern of differentiation of recession rates within the Novaia Sibir' shoreline.

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New results of long-term dynamics of the gas hydrate stability zone and permafrost condition in rifts on the Eastern Siberia Arctic Shelf

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key words: offshore permafrost, gas hydrate stability zone, long-term evolution

On the Arctic shelf both offshore relic permafrost and a gas hydrate stability zone - GHSZ exist. There are considerable differences in geothermal heat flow values (qgt) and properties in rocks and sediments in undisturbed blocks of the lithosphere and fault zones in these structures comparable to those in continental rifts. These resulted in variations in the thickness of permafrost and the GHSZ during long-term evolution within these structures.

For the investigation of permafrost and GHSZ evolution in rift structures a two-dimensional mathematical model has been elaborated. A paleogeographic scenario adapted for the modelling was created for the last 400 000 years. For the last Holocene transgression a new improved variant of scenario and model for the last transgression has been made. Both, scenario and model consider the evolution of lake thermokarst and thermal abrasion during different transgression stages that appreciably accelerated the submergence of the shelf. Sea-level fluctuation for positive and negative new-tectonic structures has been considered. These variations indicate anticipatory flooding of the negative structures resulting in the formation of thermokarst lakes within these structures in the stage of the shelf emergence. Another peculiarity of transgression was the thermal abrasion of peninsulas and islands on the surfaces of positive structures in the finale stage of transgression, when the modern sea level was established and negative structures were flooded. These differences in shelf flooding for negative and positive tectonic structures resulted in differences in permafrost and GHSZ thickness dissimilarities and in their dynamics at the time of the transgression.

Model runs of both permafrost and GHSZ thickness evolution for rifts of different sizes, and different values of qgt, which are situated on the shelf in a different geographical position have been carried out. The results show that the permafrost and GHSZ thickness vary more essentially in fault zones, than in the consolidated blocks with the lowered values of qgt. Variations of the thickness of permafrost and the GHSZ depend on fault zones and single faults sizes and qgt values, as well as their geographical position on the shelf. Possibilities and conditions of the occurrence of open taliks and "breaks" in the GHSZ through which emission of greenhouse gases from relic sub-permafrost layers can be realized have been estimated. The calculation results also show differences in permafrost thickness dynamics in positive and in negative tectonic structures at the time of the Holocene transgression. The permafrost thickness is more reduced in negative tectonic structures than in positive ones and as a result open taliks may form under fault zones in these structures at the present time. Simultaneously the GHSZ may continue to exist in these open taliks and block the emission of gases.

Offshore permafrost distribution and dynamics in the near-shore zone of the Laptev Sea

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key words: offshore permafrost, coastal erosion, Siberia, permafrost drilling, ice Complex

The extremely dynamic transformation of ice-rich permafrost coastal systems is one of the main characteristics of the environment in the Laptev Sea region. Environmental changes of the Arctic coastal-shelf zone, including transformations of coasts, onshore and offshore permafrost, are very rapid and widespread natural processes. There are only several publications devoted to sub-sea permafrost and its dynamics and distribution in the near-shore zone of the Laptev Sea. Due to the lack of factual data, such as drilling and geophysical information, the main parameters of sub-sea permafrost are known insufficiently. There were only a few drilling transects within the Laptev Sea shoreface. Usually, within the Laptev Sea shallow shelf at thermal abrasion coasts the sub-sea permafrost table is found by drilling at a depth of 5 to 60 m. Sometimes new formations of sub-sea permafrost were found on shallows within bottom accumulative deposits, generally within shallow bays and at deltas. Our previous studies of coastal permafrost degradation at Ice Complex coasts showed that the subsea permafrost table slowly submerges from the shoreline to greater water depth. The inclination of the table depends on many factors, but mainly on coastal retreat rates, bathymetric and lithologic features, water temperature and salinity.

Based on the review and analyses of newly obtained data, as well as other published and unpublished information concerning shoreface composition, permafrost features, lithology, morphology and hydrodynamics, this study presents an evaluation of the main parameters of subsea permafrost within the shallow shelf zone of the Laptev Sea. All available drilling data concerning the position of the subsea permafrost table within the studied area were processed and analyzed. The main conclusions are:

- Sub-sea relict permafrost can be found within most parts of the Laptev Sea shore-face. Especially wide-spread distribution and shallow occurrence can be observed along coastal segments with sufficiently active coastal erosion;
- New formations of sub-sea permafrost occur within the shallows surrounding delta areas and shallow accumulative bays with water depths of less than 2.5 m;
- The average sub-sea permafrost table inclination in the near-shore zone at the key sites of the Laptev Sea is about 0.011 (0.002 to 0.038);
- One of the main controls of the subsea permafrost table inclination at eroded coastal segments is the coastal retreat rate;
- The peculiarities of the evolution of the upper layers of subsea permafrost depend on a number of factors, i.e. near-bottom water temperature and salinity, coastal retreat rate (or rate of accumulation/accretion), bathymetric features and shoreface inclination, general coastal morphology and shoreline configuration, coastal and shoreface sediment composition, ice content of the deposits submerged below sea level, near-shore hydrodynamics and sea ice regime etc.

Volumetric balance of ice complex deposits at Bykovsky Peninsula in NE Siberia, using field data, remote sensing and digital elevation models

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key words: ice-rich permafrost, thermokarst, erosion, volume modelling, North Siberia

The ice-supersaturated deposits of the Ice Complex have been investigated in detail at the Bykovsky Peninsula, NE Siberia, since several years. The Ice Complex is widespread in the Laptev Sea Coastal lowlands of northern Siberia. The deposits accumulated during the Late Pleistocene on vast and gently inclined plains consisting mainly of ice-wedge polygonal tundra on the subaerial Laptev Sea shelf. Beyond the absolute ice content of up to 60%, a large

amount of organic carbon is stored in the frozen sediments mainly in form of plant remnants, peat inclusions and peat layers. The up to several 10 meter thick deposits are very vulnerable to widespread thermokarst, thermo-erosion and coastal erosion, occurring in the region since the Holocene warming and the fast postglacial sea level transgression. These erosive processes lead to the release of large amounts of organic carbon to the sea or the atmosphere or to its re-deposition in newly formed deposits. Within the scope of balancing sediment budgets of Arctic shores, data of the hinterland needs to be incorporated in much more detail especially for this type of coasts. Our approach aims on the volumetric quantification of the Ice Complex deposits in a spatially distinct area, the Bykovsky Peninsula. Remote sensing investigations and field work have been successfully conducted in the study area, and additional field data acquired from various literature sources is incorporated into the model approach. By handling various data sources within a GIS environment, including a high-resolution digital elevation model, the Ice Complex volume was calculated. Finally, the amount of sediment, ice and organic carbon, which could be mobilised and released from the Ice Complex deposits, is estimated.

The main results on the permafrost studies on the Laptev sea Shelf (10 years of Russian-German cooperation)

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key words: coastal and offshore permafrost, gas hydrates, Late Pleistocene transgression, Laptev Sea region

Terrestrial and offshore permafrost in the Laptev Sea region have been studied during the last decade within the framework of the Russian-German programmes "Laptev Sea System", "System Laptev Sea 2000", and "The Dynamics of Permafrost in the Laptev Sea". As a result, new facts and ideas about the current state of coastal and offshore permafrost and its evolution have appeared and several previously unknown phenomena have been discovered.

1. It was established that relic offshore permafrost spreads from the modern coast to the edge of the continental slope. The relic permafrost has virtually continuous distribution to the -50 to -60 m isobaths and most likely discontinuous distribution further on to the outer edge of the shelf (at greater water depths).
2. Relic permafrost exist in "ice bearing" and in "ice bonded" condition. For the distribution of ice bearing and ice bonded permafrost a map has been elaborated.
3. The thawing of relic offshore permafrost proceeds mostly from the bottom under impact of the geothermal heat flux. Variation in q_{gt} values causes essential heterogeneity of permafrost thawing and especially high q_{gt} values lead to the formation of open subsea endogenic taliks only in the periphery of the shelf.
4. Closed subsea taliks which were observed by drilling and geophysical methods are the result of flooding of lake taliks and "thermokarst lagoon" taliks by sea water with negative temperature.
5. A new scenario for the Last Postglacial transgression was created. It has been shown, that accumulation of ice rich syncryogenic sediments of Ice Complex took place on the exposed shelf and lowlands during the Late Pleistocene. Ice complex began to degradate forming thermokarst lakes on the exposed shelf approximately 13 to 14 thousand years ago. The transgressing sea transformed these lakes into "thermokarst lagoons" and as a result with an increase of the sinuosity of a the coastline, coastal thermal abrasion also increased and leading to a higher speed of transgression. Islands formed by Ice Complex were destroyed, and changed to shallow sub sea areas with frozen sea floor and were then affected by "bottom thermal abrasion".
6. A zone of gas hydrates stability (GHSZ) exists on the shelf. The permafrost layer and GHSZ prevent the emission of greenhouse gases.
7. For the studies carried out, e a methodic approach was developed and applied during the investigations.

It consists of: collecting and analyzing all data related to the shelf, seaside and lowlands environment; reconstructing paleogeographic events and compiling paleogeographic scenarios; creating geologic-tectonic and geothermal models of the shelf; establishing mathematical models of permafrost and GHSZ thickness evolution, and of programs of their computer realization; and finally of permafrost modelling, analyzing of the received results and their comparison with the natural data.

Future studies will concentrate on two basic problems:

1. Long-term dynamics of permafrost and the GHSZ on the Arctic shelf with special emphasis on rift zones, the formation of anticlinal “traps”, and the conditions of gases and their hydrates.
2. The understanding of the conditions and natural processes on the Arctic shelf and lowlands where subaerial and submarine conditions periodically change are of the great scientific interest (“Problem of Arctic sea and land interaction”).

The assessment and analysis of geocryological aspects in geocology studies

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key words: Quaternary sediments, Pechora Sea, geoacoustic survey, cryogenic deposits, geocology studies

Since the beginning of development of oil and gas fields, the Arctic shelf of Russia is coming into particular importance as object of national economy. In this context the environmental investigations of the shelf are evidently urgent that is emphasized by peculiar fragility of the Arctic environment. A combined procedure of geocology studies and approved for different geological objects involves hydro- and geoacoustic survey. The survey provides data on: the detailed sequence of recent Holocene and Quaternary sediments at high resolution, the seafloor micro- and mesorelief, the surface nature, technogenic objects drowned at seafloor.

The Science-Production Association Sevmorgeologia has carried out comprehensive geocological studies in the Pechora Sea (scale 1:1000000) seeking to assess a human impact. Field works performed onboard RV Geolog Fersman involved geoacoustic, hydrophysical, hydrological, lithological-mineralogical, ecogeochemical, microbiological and hydrobiological studies. The works using onboard profilograph (OP) M-140 (5.6 kHz) proved its high efficiency in reflecting thin-layer sequences and different geological features of sedimentary and depositional strata down to a depth of 80 m at resolution of up to 20 to 30 cm. Echograms distinctly show deformed texture of the sedimentary cover suggesting the current destruction of cryogenic deposits beneath the recent postglacial sediments. The intensity of this process widely varies in different parts of the Pechora Sea. Moreover, revealed were sites suggesting endogenic inflow of a matter, including hydrocarbon gases being the result of jet degassing through zones of subvertical destruction. The analysis of seismoacoustic profiling within a Rusanovsky Oil and Gas Field in the Kara Sea demonstrates the presence of numerous zones showing abnormal pattern of seismic record. They are confined to the zones of subvertical destruction in cap rocks of oil and gas pools (Melnikov and Spesivtsev, 1995).

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Permafrost monitoring on shelf

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key words: permafrost, monitoring, a structure cryolithozone, technogenic activity

In process of activation of development of sea deposits (building materials, hydrocarbons, placer metals etc.) increasing number of the local and regional factors influencing a structure cryolithozone. The scale of influence technogenic activity, at different stages and stages of development of these deposits, on sea ecosystem causes necessity of acceptance of the appropriate managing decisions providing rational using of mineral resources. The estimation of change cryolithozone, being important component ecosystem is necessary for acceptance of such decisions. It may be carried out only on the basis of the data of monitoring.

For realization of monitoring by authors the special information and methodical-technical system realized on a shelf of the western and central Arctic seas of Russia - “SPRUT-eco” is created. The system is constructed by a modular principle and allows to estimate:

1. Change of parameters and characteristics cryolithozone

2. Scales technogenic thermo abrasion
3. Change of a hydro-geochemical mode cryolithozone
4. Change of benthonic temperature and morphology of a bottom under influence technogenic factors
5. Lithodynamic and engineering - geological processes connected with technogenic changes of cryolithozone.

The basic subsystems of this system are:

- Databank;
- The measuring block;
- The block of processing and preliminary interpretation of the data;
- The block of final interpretation and visualization of the data.

Resulting materials are under construction on the basis of standard GIS. The system is realized by authors at realization search, prospecting and production works, designing, construction and operation of oil pipelines on east arctic shelf of Russia.

Regularities of permafrost formation on the Pechora Sea coast

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key words: arctic coast, permafrost formation, cryopegs, permafrost structure

The permafrost structure on the Arctic coast depends on the occurrence of different-state (frozen, cooled) rocks, which in turn depends on the rock composition, ice content, and temperature and is related to the conditions of permafrost formation in the Late Quaternary. The model of the present-day permafrost structure is based on the complex recent engineering geocryological studies performed in different areas of the Pechora Sea coast: in the Varandei district, on the Khaipudyr Bay coast, and in the Korotaikha River mouth. An analysis of obtained data indicates that the coast cryogenic structure is nonuniform. All geomorphological structures, beginning with the first sea terrace, are composed of the non-salinized permafrost to a depth of not less than 50 to 100 m. The lower structures (high and low laida, beaches, river deltas) are constructed more complexly. They include mainly discontinuous permafrost with an average annual temperature of -0.5 to -2.0°C. Permafrost islands with a thickness of not more than 5 to 10 m are underlain by highly salinized cooled grounds with brines (cryopegs). According to data of drilling and resistivity survey, the second (from the surface) frozen horizon occurs below 15 to 25 m. The occurrence of this horizon is related to a decreased salinity of silty clay at these depths in the lida socle. The bottom of the second frozen horizon is traced at depths of 25 to 40 m and submerges toward the first sea terrace. The conditions of cryolithic zone formation and dynamics on the Pechora Sea coast in the Late Quaternary are reconstructed based on an analysis of the specific features of the permafrost occurrence, salinity, and temperature.

Preliminary results of near shore temperature measurements in boreholes in the Laptev Sea during COAST I expedition

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key words: subsea, coast, permafrost, borehole, temperature

Sub-sea permafrost is a common feature found on continental shelves in high latitudes. It formed during last glacio-eustatic sealevel lowstand, when the shelf was exposed to extremely low air temperatures. Hence vast areas of the siberia have not been significantly covered by snow and ice in Weichselian time, permafrost could develop with thickness of several hundred meters. When submerged by relatively warm seawater at the beginning of Holocene, thermal regime changes and stability of the permafrost is questionable.

Degradation of sub-sea permafrost - so called relic permafrost or submarine permafrost - due to transgression of sea water has been a persisting process on the Laptev-Sea shelf, Siberia for the last 15000 years. Especially coastal areas are subject to most rapid changes in thermal environment and hold the key to further understanding of degradation or preservation of subsea permafrost. In spring 2005 during COAST I expedition of the Russian-German Cooperation "System Laptev-Sea" temperature-measurements in shallow marine borholes have been conducted at Mamontovy Klyk to determine the ongoing processes in terrestrial-marine transition zone. First results and interpretations will be presented.

Pilot study of cryogenic structure and coastal dynamics at the western shores of Taimyr Peninsula

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key words: cryogenic structure, frozen sediments, coastal dynamics, massive ground ice

At the August 2004 we performed the pilot geocryological investigations of the Yenisey Gulf coasts. For these works the "Preven" boat was used. During the trip from the city of Dudinka to Cape Shaitanskiy at the western coast of Taimyr Peninsula we studied coastal exposures, estimated the intensity of coastal processes, and searched for the most prospective key locations for detailed investigations in the future.

The most interesting sections of the sediments of various age and origin were observed at Krasniy Yar, Sopohnaya Karga, and Cape Shaitanskiy. The geocryological study of natural exposures was accompanied by sampling of frozen sediments in order to assess ice content, grain size, organic carbon content, salinity, chemical, mineralogical, and isotope composition. The various types of ground ice (ice wedges, tabular massive ice) were studied. The body of folded tabular ground ice with inclusions of clay was examined in the big thermocirque (section SK-3, 0.5 km to the north from the Sopohnaya Karga meteorological station). The visible thickness of ice is 10 to 12 m. The ice body is overlaid by tabular sediments (loams with large vertical ice shliers), formed in thaw lake basin; the thickness of sediments is 8 to 10 m. At the upper part of the section the syngenetically frozen horizon of loams with ice wedges and buried peat layer was observed. At the thermoerosional coast of Yenisey Gulf (section SK-5, 4.5 km to the north from the Sopohnaya Karga meteorological station) the epigenetically frozen marine clays with reticulate cryostructure were studied. These sediments with epigenetic ice wedges are overlaid by syngenetically frozen continental loams and sandy-loams with syngenetic ice wedges. Preliminary results of field investigation show that the cryogenic structure of coastal sediments in study area is very complicated. The future field works at the selected sites will be connected with more detailed study of permafrost structure and composition, which will help to solve the problems of age and origin of sediments with massive ground ice. The other direction of future investigations is the study of coastal dynamics and destructive cryogenic processes. This work was supported by INTAS grant no. 01-2329.

Simulation of taliks evolution on the Laptev Sea shelf during the Last Transgression

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key words: simulation, permafrost, taliks, evolution

During the Late Pleistocene territory of the Laptev Sea shelf was drained. A long existence of subaerial conditions with low temperatures of air has led to deep freezing of deposits of the shelf. The significant part of the exposed shelf has been subjected by accumulation of lacustrine-alluvial deposits with ice wedges and very high ice content. As a result this territory has been covered by thick syncryogenic subaerial deposits of the Ice Complex (IC). During the last Holocene transgression ice-rich permafrost deposits were subjected by the lake thermokarst and thermal erosion. Using high resolution seismo-acoustic PARASOUND data obtained in the course of Russian-German cruises in 1998, we made the map of paleo-thermokarst depression on the permafrost top on the eastern part of the Laptev Shelf.

Studying of subsea taliks formation and evolution in the past and their modern conditions became a subject of the present research.

Calculations were carried out for environmental condition of modern isobaths -20, -25, -40, -45 meters and latitudes in meridian direction from 73° N to 76° N. To assess the evolution of subsea taliks thickness we used a 2-D computer-based model. This model takes into account: (1) the physic-thermal properties of deposits and their moisture content; (2) the 10 meters thickness of IC and its the volumetric iciness 80%; (3) permafrost-temperature zonality according to latitudinal position of model area on the shelf; (4) the thermo-abrasion expansion of thermokarst lakes during its development; (5) accumulation of taber deposits on a thawing IC surface; (6) different geothermal heat flow (qgt) values for the lower boundary conditions in the rift structures are equal to 100 mW m² and 50 mW m² in consolidate blocks of lithosphere; (7) changing of thermal conditions of the bottom deposits due to the evolution of thermokarst lakes depth; (8) time of lake taliks transformation into subsea one (9) salting of the fresh lake deposits and changing of their freezing-thawing temperature. For the last Holocene transgression new improved variants of scenario created by A. Gavrilov have been used. The calculation results show that the taliks thicknesses vary more essentially in rift structures than in consolidated blocks of lithosphere with lowered values of qgt. It was established that taliks thickness depends on their geographical position on the shelf, and qgt values as well as on the time of lake taliks submerging by seawater with negative temperature. Our results suggest an existence of closed taliks. Open taliks were formed only in rift structures due to high value of qgt.

Supply of organic matter and its peculiarities of frozen Quaternary deposits on the Laptev Sea coast

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key words: permafrost, organic matter, Quaternary deposits, Laptev Sea region, thermokarst processes

It is well known, that frozen quaternary deposits, occurs on the coast of Arctic Ocean are the huge reservoir of the organic matter. Due to permafrost thawing buried carbon is involved in modern biogeochemical cycle. The main goal of current research was to determine the common supply of TOC in a upper horizons of permafrost on the Laptev Sea coast and estimate peculiarities of organic matter in a different permafrost-genetic types of frozen quaternary deposits. In the investigated region following types of Quaternary deposits occurs. Late Pleistocene syncryogenic lake-alluvial deposits (Ice Complex). The deposits are presented by ice reach silty loam. During accumulation these deposits pass 2 stages:

- burring in an active layer. At this stage occurs partial decay of organic matter by the microbial community in aerobic conditions du to soil formation processes.
- transition in a permanent frozen state. The duration of a stage corresponds to age of deposits. At this stage there is an attenuation of processes of transformation OM down to their complete termination. TOC of these deposits are 2 to 2.3%.

Using the method of fluorescent analyze was determined, that OM in these deposits is poore transformed. It is necessary to note, that at decrease of sedimentation rates the horizons of buried soils can be formed. TOC=3.78%, OM is a little bit more transformed then in Ice complex.

Late Pleistocene - Holocene lake deposits of thermokarst depressions. The formation of this complex of deposits is connected with thermokarst processes. This layer can be divided into 2 horizons:

- taberal deposits, i.e. thawed and resedimentated deposits of IC. In this deposits during thousand years at transition them in a thawed condition the processes of decomposition of OM in anaerobe conditions took place, that resulted in formation of greenhouse gases. TOC=1.3 to 1.4%,
- syncryogenic lake-boggy deposits. Were formed in conditions of shallow lake or a bog. Are characterized by a high amount of buried OM (mainly at the expense of buried peat). TOC=2.57%.

Besides the above described deposits occurred in all territory of region of researches, in its east part on some sites are advanced Middle Pleistocene deposits.

Middle Pleistocene deposits of kuchuguy suite. The genesis of these deposits till now is debatable. The deposits are presented silty loam and are characterized by practically complete absence of a sandy fraction particles. Cryogenic structure mainly massive, ice content - about 30%. Deposits, presumably, epicryogenic. TOC=1 to 1.3%. Middle Pleistocene deposits of lake-alluvial genesis These deposits has features of syncryogenic formation and on the features are similar to the Late Pleistocene deposits of an Ice Complex. TOC=2%. It was determined that supply of TOC in 1 m² of territory consist from 200 to 400 kg, depending on the type of landscape and associated complex of quaternary deposits.

Peculiarities of dynamics of Barents Sea coasts formed by deposits with low ice content

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key words: Arctic, coastal, dynamics

According to common opinion, evolution of sea coasts formed by frozen deposits belongs to the thermoerosion (thermoabrasion) type. At the same time, monitoring of coastal dynamics in different regions of Russian Arctic shows that this is not a case. Coastal bluffs formed by frozen deposits with low ice content do not manifest thaw slumping, permafrost creep, gully thermoerosion, and thermokarst. In fact, features peculiar to the coasts formed by unfrozen deposits mostly characterize dynamics of the coasts mentioned above. Coasts formed by deposits with low ice content have significant extent in the south-eastern part of Barents Sea, namely the so-called Pechora Sea. These are primarily the coasts of large accumulative coastal landforms generated during the Holocene, such as barriers and spits. Large Holocene accumulative forms occupy about one third of mainland coastline of the Pechora Sea. These forms are mainly formed by sands and characterized by specific transversal profile. The absolute marks of barriers and some spits can achieve 10 to 15 m due to the dune superstructures. Low ice content of the sand deposits is favorable for development of active aeolian processes. The well-drained dune belt of the Holocene accumulative forms composed of sand beds with low ice content are quite convenient as a possible place for settlements, oil terminals, and storehouses. This place is more stable from the engineering-geological point of view than the surrounding swampy tundra lowland. This also shows that the investigation of coastal dynamics in the region is of high importance. High declination of sea slope related to the dune belt (fore dune) is convenient for the forming of shore with transversal erosion profile. At present, some of those coasts have erosion bluff, while the others represent typical full-profile beaches. Coastal thermoerosion effects are insignificant for evolution of both types of coasts. Periodicity of extreme storm surges and the total wave energy activity in the coastal zone during active dynamic period are the main factors, which determine dynamic of coasts with low ice content. We performed correlation analysis of the results of stationary monitoring of coastal dynamics and hydrometeorological data from 1981 to 2002. Varandei Island formed by sandy deposits with low ice contents considered as a key site. The obtained results permit us to conclude that: (1) for the coasts formed by deposits with low ice content (Varandei area), there is an evident dependence between the wave energy magnitude at the external border of the coastal zone and the coastal retreat rate; (2) at the same time, a trustworthy correlation between the coastal erosion rate and the average temperature of the dynamically active period was not observed. Present work was supported by INTAS grant no. 03-55-2506.

Coastal erosion of the permafrost sediments with low bulk ice content

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key words: permafrost, coastal erosion, East-Siberian Sea shore, ice content, stochastic model

The upper pleistocene permafrost deposits of ice complex are underlayered by the permafrost sediments with low ice content at the East Siberian Sea shore. The sediments with low ice content have extra limited radiocarbon dates. They were formed during the Zyryan cold epoch (Ovander et al., 1987). These layers were formed as the syngenetic

permafrost sediments under the dry and cold climatic conditions. The sea coasts with the stable profile are typical for the shore sited with such permafrost sediments. No active thermal abrasion cliffs with the wave niches were described at such sites.

An additional run-off of the erosion products takes place at the slope foot of the inlet of Khroma river relatively the sea shore. The coastal cliffs have about 35 m in high here. The Zyrian cold epoch permafrost sediments were studied at this site. These sediment is a silt with a bulk volumetric ice content less than 30% including the ice of the syngenetic wedges. It contains no ice and has the massive cryogenic structure in the polygons between the ice wedges. To estimate a role of ice thawing in the formation of the shore profile, the thaw subsidence was calculated for the thaw basin 45 m in depth (5 m lower relatively sea bottom at the offshore band). The used level is corresponded to the bottom of the thaw basin of the subsea permafrost at the site. According to the result of calculations, the level of the surface can be lowered from 35 to 28 m after the thawing only. The formation of the stable shore profiles can be explained by a small thaw subsidence during the permafrost erosion at the sites with low ice content deposits. This work is supported by INTAS, project 2329.

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A Geographical Information System to visualize and analyze circum-arctic coastal dynamics

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key words: Geo Information Systems, coastal erosion, circum-Arctic, ice-rich permafrost

The coastal zone is the interface through which land-ocean exchanges in the Arctic are mediated and it is the region of most high-latitude human activities. The coastal margin hosts a complex interaction of marine, terrestrial and atmospheric processes that are extremely vulnerable to predicted environmental changes and anthropogenic stressors. These coasts are typically permafrost-dominated and suffer from rapid erosion with serious implications for ecosystems and communities. Changes in the coastal zone will not only affect regional biological and human systems, but are also likely to influence the global system through the degradation of coastal and offshore permafrost, which can lead to the release of greenhouse gases (GHG).

Arctic Coastal Dynamics (ACD) is a multi-disciplinary, multi-national program of the International Arctic Science Committee (IASC) and the International Permafrost Association (IPA) and a regional project of IGBP-LOICZ (International Geosphere-Biosphere Program - Land-Ocean Interactions in the Coastal Zone). The overall objective of ACD is to improve our understanding of circum-Arctic coastal dynamics as a function of environmental forcing, coastal geology and permafrost and morphodynamic behavior. A major focus has been on the development of a circum-Arctic coastal classification in GIS (Geographical Information System) format to visualize and analyze the current status of the Arctic coastal region and its sensitivity to environmental changes.

This presentation provides an overview of the ACD coastal GIS. The entire circum-Arctic coastline has been segmented into homogenous elements and each element has been classified according to a coastal classification template, which includes information on morphology, composition and erosion rate. Numerous local expert groups of the ACD project were involved in the segmentation and classification procedure. Subsets of available data for various parameters, summarized under the term "environmental forcing", such as winds, waves, currents, sea-level, water and air temperatures, sea ice, etc., have been extracted and formatted for inclusion in the circum-Arctic GIS.

Offshore permafrost in the South Kara sea: seismic evidence and drilling data

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key words: offshore permafrost, high resolution seismic survey, permafrost table, shallow drilling

The results of seismic studies in the shallow waters of the SW Kara Sea at the Shpindler, Kharsavey and Mare-Sale sites made by VNIIOkeangeologia in 2000 showed the presence of a seismic interface which can be interpreted as submarine permafrost table (PT). The proposed permafrost exhibits a continuous distribution and strongly dissected top surface overlain by unfrozen sediments. PT is typically located at a depth of 4 to 6 m and 5 to 10 m below the sea floor at the Shpindler and Mare-Sale sites, respectively. At some places PT submerges down to 21 to 30 m below the sea floor. This conclusion corresponds with shallow drilling data obtained during last decades by AMIGE (Murmansk, Russia) in the south of the Kara Sea (Melnikov and Spesivtsev, 1995; Rokos, et al., 2001). Thus, at the Kharsavey key site the drilling profile situated at the distance of 7 km northward of VNIIOkeangeologia seismic polygon shows, that the cryogenic sediments are wide spreaded at the south Kara Sea shoals. The permafrost table has a hummocky topography at water depth of 0 to 10 m and occurs at the depth of 10 to 50 m below sea floor. The steep submerging of the PT (down to 50 m below sea floor) these authors correspond to the distribution of sands in the bottom sediments. Hence the drilling data gave us the evidence of occurrence of PF in the same subbottom depth in the same condition.

3D modeling of the permafrost table suggests the presence of relict buried thermodenudational depressions (up to 2 km across) at a minimal sea depth of 40 to 45 m at the Shpindler and Mare-Sale sites. The depressions may be considered as paragenetic to thermocirques found in cliffs at the Shpindler site. A zone of northwest to southeast dislocations controls the locations of onshore and offshore structures. At the Kharsavey site permafrost table has an elongated depression lying along the modern shoreline. The maxima depression depth is 20 m below seafloor. At present, relict thermocirques (Shpindler and Mare-Sale) and elongated depression (Kharsavey) are completely filled in with sediments and not exposed in modern bottom topography.

1. High-resolution seismic survey in near-shore shallow waters in the southwestern Kara Sea detected a reflector that could be interpreted as the permafrost table. In addition, the regional distribution of the submarine cryolithozone was confirmed by shallow drilling data.
2. The permafrost table lies 4 to 6 m below the sea floor at the Shpindler and Kharsavey sites and 3 to 10 m at the Mare-Sale site. Several depressions with depth of 10 to 20 m in the permafrost table (up to 2 km across) were observed. The large thermodenudation depressions incorporate a group of thermocirques that were destroyed in the submarine position. Thawed sediments fill in all depressions.
3. The depressions may be considered as paragenetic to onshore thermocirques found in cliffs at the Shpindler site. These relict thermocirques were submerged by the sea and subsequently covered by sediments.
4. The data obtained shows that the high-resolution seismic may be considered as an effective method for mapping the submarine permafrost in the shallow water.

However these investigations require further study in order to monitor the ongoing processes, both in onshore and offshore conditions. This study was supported by the INTAS (grant no. 2329).

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Seismic facies as a key to insight into the distribution and characteristic of the offshore permafrost (new data from the Laptev Sea)

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key words: offshore permafrost, high resolution seismic survey, permafrost table

The Laptev Sea shallow water area represents the key site where submarine permafrost has been predicted by geological onshore investigation and subsequently found by both the seismic and drilling methods (Rachor, 1997). This area is a key location for understanding permafrost evolution processes (incl. its rate and variability) under different climatic conditions. However, the main parameters of offshore permafrost are known insufficiently. During last decade mathematical modeling on the Laptev Sea permafrost evolution was conducted by the team headed by N.Romanovsky.

The High Resolution Seismic data were obtained in 2005 during the “LAPEX-2004/Transdrift - X” expedition (r/v “Yakov Smirnitskiy”). The investigations were focused on the seismic research that might give the base for the selection of the places for further shallow drilling. Multi-channel low frequency (≈ 100 to 400 Hz) seismic acoustic profiling was accompanied by high frequency (5 kHz) profiling. Side scan profiling was carried out simultaneously. Total 1200 km of the seismic lines were obtained during expedition.

The interpretation of the HRS data shows the following features of the seismic images:

1. The strong lowermost reflector with uneven topography have been identified as permafrost table (PT). The unequal seismic signal penetration beneath the PT in the different part of polygon led us to assumption that there are different types of permafrost (in terms of ice content, lithology, generation etc). Generally, the PT has hummocky topography, characterized by flat top banks, surrounded by basins with very steep flanks. Banks has lateral size of 200 to 2000 m and distribute at the depth of 40 to 50 m below sea level. All PT banks are slightly inclined to WNW. At the SE part of studied area the PT arises up to the sea floor and locates at the depth of -24 m below the modern sea level.
2. Within the grid area 7 separated basins filled by sediment were found. These basins are surrounded by banks of PT. The basins have a width of 800 to 1000 m, length of 1000 to 2000 m and depth up to 12 m. They are elongated at the NE and NNW direction. The basins have very steep flanks. The NW flanks are mostly steeper. Basins completely filled by stratified sediment, which should be interpret as lacustrine sediments. It made possible to suggest that here could have existed a few isolated (lakes) or partly isolated (lagoons) basins with quiet hydrodynamic regime. The lacustrine sediment, are overlayed by upper seismic unit, consist of marine sediments. There are a lot of buried ploughmarks spread within the upper subsequence.
3. A lot of gas seeps were found in the studied area. No any regularity in the gas seeps distribution have been found.
4. The most remarkable phenomena obtained during interpretation of the HRS data is transparent zones at the western flank of basins. They have an acoustic transparent seismic pattern and sharp vertical or negative angle boundary, cutting the normal sedimentation strata. These zones are located at the W-SW flank of the basins only. The top of these zones is flat and locates at the same depth level as a top of the nearby PT banks. All of these features led us to assumption that the origin of these zones can be explained in terms of postsedimentary refreezing of the sediments.

But several questions still remain: Why refreezing zone distribute only near the W-SW flanks of the basins? When this refreezing took place? How does high frequency seismic energy penetrate the permafrost zone and reflect from the subjacent strata?

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Imaging submarine permafrost in the Laptev Sea with high-resolution multi-channel seismic data

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key words: Laptev Sea, high-resolution Seismic, thermokarst, transgression

Beneath the Laptev Sea, a thick permafrost layer has developed during the last glacials when the now flooded shelf was exposed and not glaciated. The permafrost may still exist today in a submarine environment after the last transgression, since the low seawater temperatures prevented melting. Even if the existence of the submarine permafrost is proven by drilling at several locations, the distribution of the permafrost and its possible degradation in different areas is still unknown. Therefore, high-resolution multi-channel seismic data as well as sediment echosounder and sidescan data were collected during Expedition Transdrift X. This expedition was carried out in September 2004 in a Russian-German cooperation between the GEOMAR (Kiel, Germany), the VNIIO (St. Petersburg, Russia) and the University of Bremen (Germany). As seismic source, a Mini GI Gun was used; the seismic signals were received with a new 48-channel streamer especially designed for shallow water conditions. The main goal of the expedition was to image the distribution and character of the top of the permafrost as well as to analyze and interpret seismic facies in the working area. Finally, the results will be used to determine optimum locations for a drilling campaign planned for summer 2005.

On the poster, we will present seismic data showing the different seismic facies types and structural features found in the Laptev Sea as neotectonic faults and deep structures interpreted as former terrestrial surfaces. A main target of the survey was an acoustically hard interface, which in shape and scale seems to mimic the thermokarst landscapes of the Siberian coastlands today including ice-complexes and filled thermokarst lakes. The strong reflection of the interface indicates the presence of frozen sediments. A dense grid of seismic and acoustic data was collected crossing this prominent reflector to get a 3-D image of its distribution and shape. Processing and mapping should verify the hypothesis, that this reflector may represent the top of old permafrost developed before the last transgression.

Fresh water and terrestrial carbon fluxes in the East Siberian region: land-shelf system

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key words: East Siberian Sea, coastal zone, carbon fluxes, freshwater discharge, hydrochemical measurements

The East Siberian Sea (ESS) is the widest and shallowest continental shelf in the World Ocean, yet it is the least explored. The wide shelf acts as an important region for production and processing of organic matter before it is transported into the Arctic Ocean, influenced greatly by the high ice extent, thus having a high potential for global change impacts with warming in the Arctic. Specifically the shallow shelf of the East-Siberian Sea is an important region for processing carbon, with the largest gradients in freshwater and nutrients observed for the entire Arctic Ocean. The ESS is influenced by water exchange from the eastern Laptev Sea (local shelf waters diluted mostly by the Lena discharge) and Pacific-waters from the Chukchi Sea. Pacific water inflow occurs through the Bering Strait crossing the Chukchi shelf and entering the Arctic Basin through Barrow and Herald Canyons.

The coastal zone in this area plays a significant role in the freshwater budget; the carbon transport, accumulation, transformation and seaward export of particulate and dissolved materials to offshore shelf/slopes regions. Warming causes thawing of the permafrost, which underlies a substantial fraction of the Arctic that could accelerate river discharge and carbon losses from soils. Siberian freshwater discharge to the Arctic Ocean is expected to increase with increasing temperatures, potentially resulting in greater riverine export of old terrigenous organic carbon to the ocean. Increasing river heating discharge would effect coastal permafrost and its degradation. Although, the

role of the coastal zone of the EES in transport and fate of freshwater and terrestrial organic carbon has not been discussed sufficiently, because a lack of a reliable oceanographic data; only bottle hydrographic technique has been used there. Note that intensive multi-agency Soviet oceanographic ESS studies were cancelled in the 1980s. That time temperature was observed using reversed thermometers mounted on the Nansen bottles, and none the data sets obtained by conductivity-temperature-depth (CTD) profiler. Hydrochemical measurements especially nutrients were mostly with low quality with using of different techniques which is impossible to recognize in present.

In the present study we report hydrological and hydrochemical data obtained in Russian Trans-Arctic cruise 2000 onboard Nikolay Kolomeytsev, the 1st and 2nd Russia-USA cruises in the East-Siberian and Laptev seas onboard Ivan Kireev (2003, 2004) and describe the surface sediment “mean” sample taken from the upper 0 to 5 cm layer) distribution of the organic carbon ($\delta^{13}\text{C}_{\text{org}}$) and nitrogen ($\delta^{15}\text{N}_{\text{org}}$) isotope ratios. Using the historical and cruise water data we divide the East-Siberian Sea for the two specific areas: the Western area that is influenced strongly by the Lena River input; and the Eastern area that is under direct influence of the Pacific-derived water. We used also the the $\delta^{13}\text{C}_{\text{org}}$ and ($\delta^{15}\text{N}_{\text{org}}$ stable isotopes to find sediment geochemical boundary (or “geochemical FZ”) between Pacific “marine-derived sediments” and “terrestrial derived sediments” which can be considered as a long-term (in scale of 102 years) position of westward extension of the Pacific water. Dynamics of the carbonate system and carbon dioxide flux between air and water are also discussed in detail. New data obtained along the Lena river during flooding time (2003) and in the adjacent part of the Laptev Sea integrated with other offshore data demonstrate that coastal erosion plays a major role in offshore transport of terrestrial particulate material, biogeochemistry and sedimentation. These are among the first reliable hydrological and geochemical data reported for the East-Siberian Sea from the Dmitry Laptev Strait to the Long Strait, and they reveal novel insights about interaction between Pacific water and local shelf water.

Cryogenic structure and chemical composition of Quaternary sediments with tabular ground ice in the Sarre-Sale area, Western Yamal

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key words: cryogenic structure, massive ground ice, Quaternary sediments, sedimentational salts

The type of cryogenic structure of Quaternary sediments depends mostly on their composition and cryogenic origin. At the study area the typical cryostructures of syngenetically frozen sandy-loams and loams are close-layered, ataxitic and reticulate. The main cryostructure in epigenetically frozen sands is massive, in clays - reticulate, massive and lens-layered. At the accumulative coasts (laida) the contemporary syncryogenic alluvial-marine ice-rich sandy-loams with growing ice wedges were studied; gravimetric moisture content (W) of sediments reaches 150%. Geological section of coastal cliffs with the height up to 30 m can be divided into two main strata. The thickness of the upper stratum of continental sands and sandy-loams (III2-IV) varies from 1 to 2 m to 25 m. This stratum consists of syngenetically frozen ice-rich sediments (W=30 to 120%) with ice wedges, underlain by epicryogenic ice-poor deposits. The lower stratum of folded marine and shallow-marine saline deposits (mIII1), which visible thickness can reach 20 m, is formed by epicryogenic loams and clays with layers of sands (W=20 to 90%). The tabular ground ice with visible thickness up to 3 m was met in these sediments. The ice bodies are folded and stratified; they contain inclusions of clay or sand.

Sampling of frozen sediments, tabular ground ice and inclusions was carried out. The salinity of the lower stratum increases with depth from 0.20 to 0.90%. The ionic composition of sediments is similar to that of seawater. Tabular ground ice is fresh and considerably differs by its chemical composition from overlying and underlying sediments. Also the mineralogy and grain size of sands was investigated in details. The analysis based on the distribution of heavy minerals and quartz within various grain size fractions was fulfilled by A.V.Surkov (Moscow Geological-Survey University). The results of analysis shows that sedimentation of sands overlying the tabular ice body occurred in shallow marine conditions at the depths 10 to 15 m. Sedimentation of underlying sands was connected with output of material from river delta. Sediments of the lower stratum were deposited at the period of sea regression without interruptions in sedimentation; at that period the role of alluvial processes sufficiently increased. The tabular ground ice formation may be connected with the freezing of water-bearing sands with desalinated water, which occurred at the boundary clay-sand under shallow-marine or continental conditions. During the freezing the part of dissolved sedimentational salts migrated to the underlying horizons causing the increase of their salinity.

Coastal dynamics of the western sector of Russian Arctic in the context of climate changes

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key words: coastal dynamics, geocryology, climate, sea hydrodynamics

Last years the great attention has been paid to investigations of coastal dynamics in the Arctic regions. These studies are coordinated by the Arctic Coastal Dynamics (ACD) program, supported by International Arctic Science Committee (IASC) and International Permafrost Association (IPA). Its overall objective is to improve our understanding of circum-arctic coastal dynamics as a function of environmental forcing, coastal geology, geocryology, and morphology (Brown et al., 1999, Rachold, et al., 2003).

This report presents the results of investigations in the western sector of Russian Arctic. The data concerning the climate of territories were collected. These data include air temperature, velocities and directions of the wind, Arctic Oscillation (AO) index, which can be considered as complex index of changes in atmospheric circulation. The data on the hydrodynamic parameters of the Kara Sea were also collected, such as daily wave height at the period 1989 to 2004, direction of their approach to the coast, duration of ice-free season, temperature and salinity of the seawater. The geologic and geocryologic structure of the coast was studied. The annual monitoring of the coastal dynamics has been conducted since 1978. Analysis of the data shows that general trends of changes in climate, marine hydrodynamics, and coastal dynamics exist. Western sector of Russian Arctic is the region where the increase of temperature does not exceed 0.70°C for the last 50 years. At the same time, at several areas (Novaya Zemlya archipelago, Kanin peninsula, etc.) the growth of temperature was not observed. The temporal variations of the average annual and summer temperatures have oscillating character and occur synchronously in the whole region. The similar synchronous variations are observed in the dynamics of Arctic Oscillation index and duration of ice-free period. It is known that in the Northern Atlantic the increase of the wave height caused by the change of AO index is observed (Kushnir et al., 1997). Therefore we may expect strong correlation between AO index and coastal retreat rate. Really, the temporal variations of coastal retreat rates in the Marre-Sale area (Western Yamal) and AO index are very similar, and the correlation coefficient reaches 0.63. These data allow us to make an important conclusion concerning the synchronism of climatic variations and temporal changes of coastal dynamics. On the basis of established correlation between AO index and coastal retreat rate the stochastic method of the coastal dynamics forecast for the western sector of Russian Arctic was developed. The calculations show that the next 20 years will be characterized by relatively temperate coastal retreat rates. This work was supported by INTAS grant no. 01-2329.

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Measuring coastal cliff erosion by means of terrestrial photogrammetry in the Kongsfjorden area, Svalbard

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key words: coastal erosion, Svalbard, Arctic Coastal Dynamics, terrestrial photogrammetry

Four sites for measuring coastal cliff erosion in the Kongsfjorden area on Svalbard (79° N, 12° E) were established in the period August 2nd to 8th 2002. The sites were measured again in August 2nd to 9th 2004. Comparison and calculation of changes in surface morphology are done. The sites were chosen to compromise different kinds of material and exposure. Both cliffs consisting of rock and deposits were chosen. The changes are generally small in this two year period. More details will be given in the presentation at the workshop. At each of the sites fixed points

were established and surveyed with GPS and traditional surveying equipment in 2002. Photos were taken at distances ranging from 7 to 15 meters from the cliff walls with a Hasselblad camera. The camera positions were also measured by surveying from the fixed points. At each site photographs were taken from 2 to 3 different camera positions to get three-dimensional coverage of the cliffs. The same procedure of surveying and photographing was repeated in 2004. The photos are scanned and digital terrestrial photogrammetry is applied to construct digital terrain models of the cliffs. The erosion rate is simply the difference between these two sets of terrain models. Due to the short distance between camera and cliff, the accuracy is in the millimetre to centimetre range and small enough to enable measurement of the low erosion rates.

Chapter 10

Session 9 - Permafrost Engineering, Land Use Planning, Hazard and Risk Assessment in the Context of Global Change

Session Conveners: Michael Davis, Andreas Käab, Martin Gude

in association with: IPA WG Permafrost Engineering, IPA WG on Glaciers and Permafrost Hazard in High Mountains, IGU Commission on Cold Regions Environment

The Zermatt railway and funicular companies as construction pioneers in mountain permafrost of the Swiss Alps

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key words: permafrost degradation, natural hazards, climate change

Permafrost at Zermatt reaches from sporadic permafrost areas at about 2600 m up to the (often unglaciated) continuous permafrost zone above 3400 m. This large vertical extent is an effect of the surrounding high mountain ranges that reach over 4000 m a.s.l., resulting in a dry and sunny climate and a high glacier equilibrium line. These excellent natural conditions have favoured the touristic development of Zermatt into a summer and winter resort with more than 1.800000 overnight stays per year. The necessary infrastructure includes subsurface water pipes (for drinking water, artificial snowing of ski-runs), sewage, communication and electricity lines, often located in permafrost regions. Several hotels, restaurants and mountain huts are also built on permafrost. The Gornergrat Bahn leading from Zermatt to Gornergrat (3000 m a.s.l.) went into operation on August 20, 1898. It was the first electric cogwheel-railway in Switzerland. Due to the climatic conditions, permafrost has developed naturally in the railway dam of the uppermost part. The first ski season in Zermatt was as early as 1927/28. The Zermatt Bergbahnen constructed a large number of funiculars since, e.g. to Stockhorn (3407 m), Hohtälli (3286 m), Rote Nase (3250 m), Furggsattel (3351 m), and to Kleinmatterhorn (3820 m) leading well into the zone of continuous permafrost. The construction of these mountain top stations always demanded special precautions in order to cope with permafrost. During the last years, most of the mountain traffic installations were upgraded to modern standards, with station buildings of railways, funiculars and ski lifts, and other structures such as masts, tunnels, elevators, shelters for vehicles, and workshops. The Matterhorn Gotthard Bahn (fusion of Brig-Visp-Zermatt-Bahn and Furka Oberalp-Bahn in 2003) leads from the Rhone valley through the deeply entrenched Matter valley to Zermatt. It is in some sections a cogwheel railway. Along its track, natural hazards range from avalanches to mudflows and rockfalls. Some of these hazards may be connected with permafrost degradation due to climatic warming and a rise of the lower permafrost limit in the steep upper slopes of the valley. The railway track from Visp to Zermatt leads through 16 tunnels and galleries, and over 9 bridges, many of them have been built as protection devices against the mentioned natural hazards, ensuring safety for the traffic.

The poster gives an inventory of the existing structures on probable and proven permafrost sites and describes some problems encountered. Today, the responsible authorities and engineering geologists have become increasingly interested in the distribution and characteristics of permafrost. Its degradation due to climatic change may increasingly develop into a serious threat, also at many other tourist resorts of the Alps, especially when the facilities are not properly maintained. Therefore, relevant knowledge must be improved by scientists and passed on to the managers of these installations and to local authorities, where it is always well received.

Influences of urban settlement structures in Yakutsk on thawing depths of the active layer - First results from urban ecology studies in the capital of the Republic Sakha (Yakutia)

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key words: active layer, Yakutsk, urban ecology, thawing depths

Yakutsk in the Russian Far East is with its area of about 135 km² and a population of about 200.000 inhabitants one of the largest cities built on continuous permafrost world wide. Climatically the region is characterised by a mean annual temperature of ca. -10°C, mean monthly temperatures in winter of <-40°C (abs. minima <-60°C), and mean monthly temperatures in summer of barely 20°C (abs. maxima 38°C). By different allochthonous and autochthonous immissions the city and its rural surroundings are partly heavily stressed. Permafrost, which inactivates the buffer system of soil/deeper ground effectively, is a very important geocological factor.

Field works in Yakutsk took place in summers 2003 and 2004 and integrated the registration and mapping of urban/landscape ecological structures of the region, estimation of urban/landscape ecological processes and their spatial connections and the determination of urban/landscape spatial units (geo-ecotopes). By mapping the surface conditions (buildings, vegetation, land use, surface sealing, etc.) the recent state of the urban environment is described. These investigations serve for the production of a three-dimensional landscape model that takes into account the compartments lower atmosphere, buildings/vegetation/landuse, topography/surface waters, soil/active layer and permafrost/taliki. First results of the research project are presented and will discuss the distribution of geo-ecotopes that will be included in the GIS-based modelling that is planned for 2005. Final results will include future scenarios of the environmental state of the urban area of Yakutsk for the years 2010, 2020 and 2050. Thereby not only the prognosted climatic changes for Eastern Siberia shall be considered but also and especially the future development of the settlement (inclusive development of population, construction, economy, and traffic as well as the administrative control of municipal supply and sewage/waste management).

Problems related with slope orientation along Qinghai-Tibetan lines and their formation mechanism

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key words: Yin-Yang Slopes, lengthways cracks, diurnal variety of solar radiation, Qinghai-Tibetan lines

Qinghai-Tibetan lines (including highway and railway) mainly extends from the north to the south. Long-term ground temperature observation shows that the east slope temperature has been higher than the west slope temperature. This phenomenon is called Yin-Yang Slopes. For Qinghai-Tibetan lines located in permafrost regions, Yin-Yang Slopes will bring big damages to the roadbed. In the sunny slope and sunny shoulder, a lot of long broad cracks occur along these two lines. Under some conditions, the sunny shoulder will probably sink abruptly. These are very dangerous to the running vehicle. This thesis was focused on the reasons that Yin-Yang Slopes developed in the east and west slopes from the point of solar radiation. Then it pointed out that the regularity of solar radiation diurnal variety leads to Yin-Yang Slopes phenomenon. Finally, the authors gave some suggestions to eliminate Yin-Yang Slopes phenomenon.

Experimental study on the heat transfer difference of air bricks

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key words: permafrost, air bricks, thermal conductivity

Protecting permafrost is one of the two principles which are adopted in the course of engineering construction in the permafrost area. Variety kinds of engineering practice shows that adjusting convection can effectively protect permafrost. Compared with solid construction material, air brick's void ratio is much higher. Therefore, its interior convection effect will be much stronger. On the basis of this common sense, authors did a lot of experiments on the thermal conductance difference of vertical air bricks with different thickness. Test results showed: (1) for one system with the same temperature of the cold end, it was cooled more quickly when the cold end was located on the top than on the bottom; (2) when the temperature regime of system came to stabilization, the temperature of warm end was lower for the cold end located on the top than on the bottom. At the same time, the former temperature grads were less than the latter. Finally, approximate calculation indicated that there exists much difference between two kinds of vertical thermal conduct mode. Thermal conductivity was far bigger for the cold end located on the top than on the bottom.

Engineering geocryological zoning and territory protection from hazardous cryogenic processes

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key words: cryogenic hazards, engineering geocryological zoning, cryogenic processes, prognostic calculations

Construction mastering of the territory is accompanied by the disturbance of natural conditions which can cause the rise and activity of hazardous cryogenic processes leading to the deformation of engineering structures and irreversible changes of nature ecological systems. In this connection the questions of the engineering objects stability and minimum technogenic interference in natural media should be settled on the basis of engineering geocryological zonation of the territory according to the prevailing cryogenic processes. Zonation of the territory according to the data of forecast calculations of the interaction between structures and permafrost allows to develop the measures on engineering protection of the territory and structures from potentially hazardous cryogenic processes. The method of zonation involves a consecutive execution of the following tasks:

1. natural complexes typification;
2. engineering geocryological zonation;
3. forecast calculation for the cryogenic processes development in various engineering-geocryological areas during construction and operation of engineering structures;
4. determination of the permissibility of technogenic effect on the geological media;
5. development of the recommendations on the nature protection measures and engineering protection of the territory.

The given method was used in compiling the map of geocryological zonation according to the prevailing cryogenic processes of the gas-condensate field in the Yamal peninsula (scale: 1:25000). The main parameters of permafrost (composition, iciness, temperature, seasonal thawing depth) defining the activation and development of the most hazardous cryogenic processes were taken into consideration in zonation.

The recommended complexes of the measures on the engineering protection of objects and territories from hazardous cryogenic processes were defined on the basis of the forecast calculations according to the estimation of the permissibility of technogenic effect and with regard to functional peculiarities of engineering structure under design, for each specified taxon, characterized by the definite complex of the prevailing processes. The following types of the most characteristic engineering structures were considered: industrial and residential buildings with ventilated cellars, site fills, embankments of linear structures, elevated over ground pipelines on piles (or viaduct), underground pipelines.

Centrifuge modelling of soil-structure interaction resulting from solifluction mass movements

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key words: physical modelling, permafrost engineering, active layer, soil-structure interaction, climate change

Because of the processes associated with solifluction, when a structure - such as a cable car pylon or a retaining wall - is located on or in a slope subject to an annual cycle of freezing and thawing there will be an interaction between it and the soil forming the slope. This interaction will result in additional loading of the structure or its foundation system that, depending on the nature of the structure (or structural elements), might lead to unacceptable deformations or, in the extreme, total failure. This process is exacerbated in the context of global climate change because thickening of the active layer, caused by a rise in mean annual air temperature, will result in increased mass movements. It is important, therefore, that the mechanisms associated with the interaction of freezing and thawing slopes with structures are understood.

In this paper we will present the results of an experimental study conducted to investigate soil-structure interaction mechanisms resulting when two types of structural element, a retaining wall and a single pile, are located in a slope subject to solifluction mass movements. The experiments were conducted using the technique of geotechnical centrifuge modelling. Models, constructed at a scale of 1:20, consisted of a 12° slope with an active layer depth of 100 mm (2.0 m at prototype scale). In tests to investigate solifluction interaction with a retaining wall the slope was retained by a 100 mm (2.0 m) high cantilever wall. When a model pile was included in the slope, this represented a 0.5 m diameter pile embedded in the ground beneath the active layer. Techniques were developed to freeze the models during centrifuge operation, this permitted for the first time the soil-structure interaction resulting from both freezing and thawing phases to be correctly modelled. The model slopes were instrumented with miniature pore pressure transducers, thermocouples and deformation markers. Structural deformations were monitored using strain gauges and Linear Variable Differential Transformers (LVDTs). The instrumentation permitted quantification of the soil-structure interaction mechanisms, which allowed structural response during the freezing and thawing phases to be resolved separately. The results indicated that, for the geometries investigated, loading resulting from soil-structure interaction during freezing can dominate the displacement response of both retaining walls and single piles during the annual cycle of freezing and thawing. The significance of these results for the design of structures located in the active layer is discussed.

Permafrost degradation and slope instability in mountain areas: case studies from the Italian Alps

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key words: permafrost, climate change, landslide, slope instability, Alps

The physical stability of permafrost terrain is highly sensitive to thermal disturbance, especially when the ice content is relatively high. The thermal changes within permafrost are:

1. thickening of the active layer with thaw settlement in supersaturated materials (immediate response);
2. disturbance of temperature distribution at depth (intermediate response);
3. basal melting of permafrost ice with thaw settlement in supersaturated materials (final response, lasting even thousands of years).

The first is a seasonal phenomenon that results in high pore water pressures (Harris et al., 2001) and is associated with mass movements such as skin flows, debris flows or detachment failures. The second is more difficult to analyze because its possible effects are not directly visible. Thermal changes are responsible for changing the liquid water content within the ice in the 0°C to -3°C temperature range (Williams and Smith, 1989) but also for changing the ice strength at lower temperatures (Patterson, 1994). The effects of these changes are essentially two: first, the reduction

of ice “adhesion” to the rock and hence a consequent decrease of the total rock strength; second, a release of water that can increase water pressure (Davies et al., 2001). The final response of permafrost to thermal change, i.e., basal melting, can provide potential slide surfaces, inducing large landslides, especially in supersaturated deposits. The occurrence of permafrost in the Alps seems to be the most important triggering factor of debris flows, as shown by the results of a multivariate analysis that compared morphological factors and absence-presence of permafrost. Considering also that the majority of debris flows happened in the early summer, when thawing is starting, generally in correspondence with rainstorms, we think that the permafrost table acts as an impermeable barrier increasing pore water pressure and decreasing the shear strength of soils. The huge Val Pola (1987) and Thurnweiser rockslides (2004), whose accumulation masses included ice-cemented blocks, could be explained as the result of strength reduction along preexisting potential sliding surfaces, induced by permafrost temperatures approaching 0°C (Davies et al., 2001). Taking into account that permafrost temperature in the Alps is generally higher than -2°C, it appears clear that the effects of global warming could lead to a larger number of landslides in the future.

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The environmental and GIS approach in studying of subsurface cryolithozone in Russian North

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key words: GIS, geosystem, mapping, environment, cryolithozone

The main attribute of geoeological conditions of Northern regions in Russia is the dynamics of natural and technogenic geosystems. The dynamics are controlled by interaction of the geological environment with external spheres (an atmosphere, hydrosphere, biosphere), and also with human activity. To assess this interaction digital maps with corresponding databases are created. The territories with large economic complexes present them self as original “key sites” described by appropriate maps. The maps as spatial graphical models are obliged to give background on current natural and technogenous conditions, and also to be a basis for the forecast of geocryological parameters changes within geosystems. The idea of geosystem classification and typification serves as basis for these realizations in mapping and forecast. The map type is determined by their special-purpose designation, tasks of mapping and spatial extent of studied territories.

The largest models - **the models of a global or continental level** - present most general data on spatial allocation of natural and technogenous characteristics (e.g. circumpolar landscape and geocryological maps, maps of the Russian cryolithozone, etc.). **Models of a regional level** usually describe the areas of important economic regions or wards and as against global give more exact and detailed spatial allocation of displayed parameters. The number of displayed parameters is also enlarged. **Local graphical models** are made for areas of economic structures and complexes, reserved territories, wards. The structure of the displayed information, a list of examined parameter and a set of corresponding maps are determined by local natural and technogenic conditions, and also by engineering or scientific tasks. We developed a hierarchical complex of cartographical models of natural and technogenic geosystems of Russian North, coordinating graphic and information blocks of global, regional and local levels. Various level generalization of natural and technogenic data is stated using these blocks. In turn the geosystem maps are the basis for derivatives: landscape, geocryological, ecological, environmental, monitoring and over maps of different purpose and scale. The manners (methods) of statistical, spatial, substantial and temporal processing are offered for correct generalization of in-situ and laboratory data. In case of new data files income the designed methods allows to complete a set of monitoring maps on quick changing components.

The GIS-technique provides a mutual exchange and updating of the graphic and thematic information blocks. A number of global, regional and local level maps by use of GeoDraw/GeoGraph and ArcInfo/ArcView software is

made. For northern part Russian cryolithozone it is made the geosystem map displaying taxons ranging from landscape types up to landscape zones; for Timan-Pechora and Western Siberia oil-gas-provinces the atlas of environmental and geocryological maps is made. The scale is 1:2500000...1:4000000. For areas of the important economic structures in cryolithozone (oil-gas fields in the Western Siberia, the Norilsk economic region, areas of ore deposits in mountain ranges) natural and technogenic geosystem maps are drawn up. The synthetic, the single component, the monitoring, the geocryological and the environmental derivative maps are made corresponding to graphic scale 1:25000...1:200000. This research was supported by several grants of RFFI (RFBR), INTAS and Tyumen Gubernia.

Application investigation of awning to roadway engineering on Qinghai-Tibet Plateau

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key words: awning, permafrost, permafrost table, roadway engineering

With the rising of the global air temperature and the thawing of the permafrost on Qinghai-Tibet Plateau (QTP), the conditions of engineering, especially roadway, were from bad to worse. Some techniques were put forward, the awning was one of they, which can protect the permafrost against thaw. Based on the models test data indoors, combined the numerical calculations, and the air temperature and permafrost temperature data of the test roadbed in Fenghuoshan, the protect effects of the awning on the permafrost table along the constructing the road and railway in permafrost regions are compared. The superiority and feasibility of the awning were confirmed. The awning can resist the solar radiation to land surface in effect, it can descend the ground surface temperature 8 to 15 °C, and the maximum value is 24 °C difference, lift the permafrost table with big rang, the awning was very important to the roadway safety and unblocked. Of course, under special conditions, if there is a lot of solar radiation in a year, it is necessary to use the awning.

Heaving as one of the most destructive process for the pipelines in cryolithozone on the example of Urengoy gas and oil deposit

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key words: heavy, destructive processes, pipeline, West Siberia

The paper devotes to analysis influence permafrost conditions on engineering construction. Field investigations of several gas mains were carried out in Noviy Urengoy oil and gas field (Western Siberia) in different geosystems during spring-and-summer periods of 2003/2004. The deposit site is located in cryolithozone. Permafrost is very sensitive to anthropogenic influence and to global and regional climate fluctuations, which lead to change of operation conditions.

There are multiple sites of natural landscapes destructed or totally destroyed during building and exploiting of the pipelines. This leads to occurrence of new cryogenic processes and transformation of already existing processes. Field investigations revealed that permafrost is mostly sensitive to climate fluctuations in anthropogenic-modified sites. Temperature increase leads to the active layer depth increase. This corresponds to the development of such processes as thermokarst, thermoerosion, solifluction and heaving. The most dangerous process is the heaving, that reaches up to several meters in humid landscapes. The heaving of piles leads to pipe deformations and the emergency situations to occur. Gas mains as linear extended systems cross various landscapes. In investigation area there are exist 5 basic groups of natural complexes connected to various geomorphic levels. In various landscapes evolution of cryogenic processes proceed in different ways. The old drainage fifth sea plain is the most inert system for the exterior impact. The most flooded and covered with peat fourth lacustrine-alluvial plain common with river complex are mostly subjected to various influences both anthropogenic and natural. On the given territory was studied influence of frost jacking on the pile support. In various landscapes the heaving forces differ. This needed to prevent the frost jacking in different types of environment. Also have been calculated the minimum optimal depth of foundation. For example, the minimum depth of foundation is 170 to 1200 cm depending on natural conditions. Frost heave as one of the main factor of decreasing in reliability of pipelines operation in criolithozone. It is possible to predict negative cryogenic processes development and so far to reduce an emergency risk.

Discret distribution of liquid phase in frozen sandy-clayey soils relying on the some their physical properties

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key words: frozen soil, unfrozen water, dielectric properties

Liquid phase in sandy-clayey soils that is usually named "water" and in frozen soils "unfrozen water" is practically always a pore solution. Moreover this liquid phase freezing in such porous inhomogeneous media is noticeably distinguished from freezing of solutions (including eutectic temperatures) all the more from free fresh water. Actually the liquid phase in frozen soils is always the boundary phase, characterized by the marked allotropy in view of its interaction with the dissimilar (in uncompensated electric charges distribution, micro relief etc.) surfaces of soil solid matrix grains. During freezing, that is various pore and segregate ice forming, pore solution allotropism increases (the similar is during drying of soils). Physically that is "unfrozen water" amounts to a set of various liquid phases with different energy states (the net of hydrogenous bonds, ion content and its mobility etc.) that lead to appearing the discrete or semi-discrete domains. This appears to be in the case and the usual notions about "unfrozen water films" and its thickness estimations are schematic and not always adequate to real situation in frozen soils.

The experimental data on dielectric, elastic properties and electroacoustic energy conversion in frozen soils show that obtained results can be correctly physically explained only if the unfrozen liquid phase domains are existed and the ion migration effects within these domains are taken into account. The our model of the medium electric polarization in response to an applied time varying electromagnetic field based on this mechanism of electric macro dipoles formation by ion migration in discrete domains of unfrozen pore solution. The known models of additive mixtures and various capillary-porous media failed when tested by experimental data, especially in the case of electromagnetic fields at low and middle frequencies are inadequate to experimental data. In the paper will be discussed the examples of corresponding experimental data on physical properties and principal features of unfrozen liquid phase changes, including liquid discretisation and spatial redistribution, in frozen sandy-clayey soils in changing of their temperatures. The model of the domain-macro dipolar polarization will be also shortly considered as the alternative to additive mixture and capillary-porous models, that is especially important for low-moist soils (including frozen ones).

Permafrost changes in buildings construction on areas of inter-ground massive ice sheet development

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key words: inter-ground massive ice sheet, Early Holocene, cold ventilated cellar, ground cooling

Inter-ground massive ice sheet is a wide spread phenomena in many regions of permafrost zone and in Norilsk area (North of Middle Siberia) as well. Here they are located at the 2nd terrace of the Norilskaya River where in lateral piedmont parts of the valley buried glacier sheet ice occurs. High ice content and occurrence of ice sheets and ice wedges are the reasons of thermokarst, thermoerosion and cryogenic landslides development on coasts of rivers and lakes.

The Valyok Valley (lacustrine-alluvial terrace of the Norilskaya River) is located in the intermountain depression limited by the Putorana Plateau offshoots from the north, east, south and south-west. To the north-west it spreads towards the Pyasino Lake. In the Late Pleistocene and Early Holocene the valley was occupied by the cold fresh-water lake and ancient permafrost melted. After the water retreat 9000 to 8000 years BP, epigenetic freezing began. The lower part of sediments of this epoch (al III34 vI - al-b IV vI) is represented by bandy clay covered by loam and loamy-sand deposits on the plain and by loamy-sand and gravel deposits in the piedmont part. The surface on many sites is composed of peat up to 2-3 m thick containing ice wedges. For epigenetically frozen sediments of the Valyok formation, high ice content (*i* up to 30 to 60% by volume) in upper layers is characteristic. In buildings

construction, dangerous ground subsidence resulted from ice-rich deposits thawing may occur. At the same time, a contrary tendency was marked.

In the central part of the valley, a large building of a suburban ski base was erected in 1977. Between the frozen ground surface and the building bottom, a special cold ventilated cellar 2.5 m high was made. In engineering prospect in 1970, before construction, ice-rich clay of lattice cryostructure ($i = 25$ to 40%) was found near the surface and at the depth of 8 to 12 m, a massive ice sheet 3.2 m thick was discovered. Temperature measurements (5 November, 1970) detected that the permafrost here is in the degrading state and lattice cryostructure formed under colder thermal conditions of Holocene age. Besides, thawing and thawed ground below the depth of 9 to 11 m was disclosed. Temperatures measured 5, November, 1970, were as follows: 1 m= ± 0.0 ; 2 m= -0.2°C ; 3 m= -0.2°C ; 4 m= -0.2°C ; 5 m= -0.1°C ; 6 m= -0.1°C ; 7 m= -0.2°C ; 8 m= -0.2°C ; 9 m= ± 0.0 ; 10 m= ± 0.0 ; 11 m= $+0.1^{\circ}\text{C}$; 12 m= ± 0.0 ; 13 m= $+0.1^{\circ}\text{C}$; 14 m= $+0.1^{\circ}\text{C}$. Natural ventilating of cold cellar resulted in gradual ground cooling and after 24 years of the building operation the clay ground is in the stable frozen state and its bearing capacity is secured. Temperatures measured 29, July, 2004, were as follows: 1 m= -0.8°C ; 2 m = -1.2°C ; 3 m = -1.3°C ; 4 m = -1.5°C ; 5 m = -1.7°C ; 6 m= -2.0°C ; 7 m= -2.1°C ; 8 m= -2.2°C ; 9 m= -2.1°C ; 10 m= -2.1°C . Thus, in the Norilsk region, ice rich deposits frozen after the Holocene thermal optimum, are often in the state of degradation but the cold ventilated cellars construction may reduce risk of permafrost thawing and dangerous thermokarst processes development.

Natural observations on landscape-geocryological conditions changes along a gas pipe line in the permafrost zone

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key words: gas pipeline, permafrost, active layer, dangerous cryogenic processes

Field investigations of permafrost change along a section of the gas pipeline "Messoyakha -Norilsk" were held in July to August, 2004. The site of research was located on the surface of Valyok lacustrine-alluvial plane (2nd fluvial terrace above flood-plane of the River Norilskaya) where the epigenetic permafrost was formed after the retreat of Late Pleistocene deep and cold lake during last 8 to 10 ka. Clayey and loamy-sand ice-rich deposits in the upper part of sediments contain massive ice sheets and polygonal ice wedges as well. Numerous lakes of this area are as the remnants of ancient lake, so and are of thermokarst origin. Along the gas pipeline, the activity of thermokarst processes is by 30% higher than under similar natural conditions outside the technogenic linear system. The relief of terrain is of hillocky and shallow depressions shape. The diameter of relict and themokarst lakes is from 10 to 20 up to 80 to 100 m. Natural landscape of the area is a typical spruce-birch-larch-shrub-low shrub-cereal-grass-moss forest tundra. In the zone of the pipeline this landscape is almost destroyed and the surface is polluted. Actually, this area is a strongly disturbed spot-medallion tussock shrub-low shrub-cereal-grass-moss tundra. In swampy hollows and near thermokarst lakes herbs changes into the sedge. The pipeline (550 mm in diameter) was built 35 years ago. It is based on a system of paired steel pipes (325 mm in diameter) installed up to 4 to 6 m deep below surface. Sometimes, Ferro-concrete or wood piles were used. About 80% investigated slopes were undergone the active solifluction because the vegetation cover was disturbed in construction. High heat conductivity of steel pipes supporting the pipeline results in the increase of the active layer thickness and frost heave activation. Besides, numerous ground subsidences from 0.2 to 0.3 up to 0.7 to 0.9 m deep filled with water appeared around most of piles that caused ice rich ground thawing. Loamy-sand ground near piles and within subsidences thawed up to 0.7 to 1.0 m by July while at the distance of 6 m apart the pipe line thermal influence the active layer depth was 0.5 to 0.8 m under the same ground conditions. The frost heave area thus became thicker and at the same time cohesion force in the frozen ground reduced because of the ground temperature increasing in the frozen zone. 160 piles were inspected and 125 were undergone frost heaving. Some of them were heaved up to 2 to 2.5 m above the initial position. Geocryological-landscape change reduced the reliability of the pipeline as a geotechnical system.

The IGU commission on cold region environments within the context of changing landuse impacts in permafrost areas

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key words: global change, cold environments, human impact, International Geographical Union

Cold region environments encountered significant changes in recent decades - a trend expected to be continued and even accelerated in the near future. This is due to changing global climates, but it is also caused by direct human impact on a regional and local basis, in particular in terms of increased pressure on nature and its resources. In many sites, both in polar areas and in high mountains, land use in many regions is already intensive and probably will even get more intensive in the future, because:

- infrastructure, construction and transportation developments are increasing as technical facilities and societal needs are increasing;
- living standards are improving;
- political pressure for resource exploration, mining and transportation is growing;
- tourist activities are increasing.

All of these land use types may effect significant changes in natural geosystems, especially in hydrology, permafrost, snow cover, soils, geomorphology, and regional and local climate (e.g. water contamination, permafrost degradation). In addition, in many regions such land use is accompanied by hazards for humans and their constructions, especially due to the sensitive landscape character in these cold environments.

These aspects of land use - among others - are investigated and discussed from a geographical perspective within the IGU commission on Cold Region Environments (CRE), with the principal aim of providing information for sustainable land use in these regions. For achieving this sustainability, beside geo-ecological features the social assessment of land use impacts and human-nature systems' vulnerability are essential. These issues are discussed in general and illustrated by several examples.

Rationalizing climate change for design of new structures on permafrost, a Canadian perspective

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key words: climate change, permafrost, engineering, landfills, foundations, roads, dams

Design of structures on permafrost soils requires a thorough understanding of the ground thermal regime at a site. The thermal stability of permafrost over the lifetime of any civil structure when used as a support medium is ultimately dependent on the climate. Engineers working in northern regions have had to adapt design procedures to recognize climatic warming trends in arctic regions that have been debated in the scientific literature for the past decade or more. The authors were contributors to a guideline entitled "Climate Change Impacts on Permafrost Engineering Design" published by Environment Canada in 1998. That document sets out a probabilistic approach to identifying the level of analyses appropriate for different classes of civil infrastructure projects. It also provides general guidance for selection of parameters characteristic of a site and potential climate change effects.

This paper describes the authors experience putting the guidelines into practice. Seven years of application have included structures on permafrost such as frozen core dams, building foundations, highways and landfill site remediation.

The system is described and examples are provided to illustrate different approaches for inclusion of climatic warming into engineering design practice. Reference is made to published data from Global Circulation Models (GCM's) and to use of trends extrapolated from historic data when it is available.

There is substantial scientific uncertainty associated with adoption of a realistic climatic warming scenario for engineering design purposes. The Canadian arctic is vast with both marine and continental climates. Most GCM based predictions are too generalized to be directly useful. Regional climatic effects are not well represented in such models. All of the data needs to be considered along with engineering judgment that includes consideration of the future consequences of adverse performance. The effective lifespan of most engineered structures is less than 50 years. The potential effects of climatic warming can usually be accommodated in the design in a realistic fashion with the exception where permafrost is close to 0°C and sensitive to any disturbance. The design becomes much more difficult for structures of a perpetual nature such as those left behind for environmental management purposes following reclamation and abandonment of past developments.

Permafrost distribution along the Huashixia-Changmahe highway on Qinghai-Tibet plateau and the inter-impact with highway

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key words: Huashixia-Changmahe highway, permafrost

Huashixia-Changmahe Highway (part of provincial highway No. 205) starts from Huashixia and end at Changmahe, Qinghai province, China. Permafrost along the highway exists widely, however, few jobs on permafrost have been done in the region that this highway passes. In 2004, a drilling investigation was carried out. By the drilling investigation information, it was found that most sections of this highway pass the continuous permafrost region. This paper introduces the character of permafrost distribution, ground temperature and the damages to the highway by permafrost along the highway. Then, based on these, reasonable suggestions are proposed to the road reconstruction.

Sensitivity of permafrost terrain to clearing of North-Taiga forests in the Yana Valley, Northern Yakutia

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key words: sensitivity, geoecological state, plowfields, cryogenic processes, ice content

Sustainable development and protection of agricultural lands in the permafrost regions require analysis of their geoecological state. This problem has been studied by many investigators, including those from the Permafrost Institute Siberian Branch, Russian Academy of Sciences. To study sensitivity of agricultural landscapes in the Yana River basin, a terrain analysis has been done on the land of the Yanksy collective farm using field studies, a review of reports of the Sakha Ministry of Agriculture and other agencies, and interpretation of large-scale aerial photographs. Based on investigations carried out in different years, three periods have been identified in the qualitative and quantitative modification of the environment: prospecting, development and intensive exploitation.

At the first stage, 10 to 15% of the total area was subject to disturbance. At the first stage, the degree of surface disturbance was quite low, and the geoecological situation can be assessed as good. Further on, impacts on the environmental components and their modification grew in magnitude with expanding human activities. At the second stage, further disturbance of the surface soil and vegetation results in increased wetness in the area. Thaw subsidence and increased depths of thaw are observed during this period which cause changes in the structure of ecosystems. Forest clearing and subsequent plowing cause a 3 to 5-fold increase in the depth of seasonal thaw (from 0.3 to 0.9 to 1.2 m) and partial melting of ice wedges to a depth of up to 0.5 m. The geoecological situation is assessed as moderate. The third stage is characterized by extensive areas affected by secondary processes, such as cracking of the ground, heaving of peat soils, and development of polygonal patterns on the disturbed drained sites. The geoecological state

is deteriorated by disruption of the ground surface ranging in severity from weak to very strong (to a depth of 0.3 to 1.5 m), as well as by formation of numerous polygonal structures, thermokarst depressions and lakes due to natural and anthropogenic factors (frequent fires, damage to the surface vegetation and soil by off-road movement of vehicles, etc.). The geocological situation at this stage is assessed as poor.

According to terrain sensitivity to anthropogenic impacts, I have made a sensitivity analysis of the Batymakh area where the plowfields were created by clearing of a sparse northern forest. The low sensitivity areas are those of ice-poor permafrost (a volumetric ice content of less than 0.2) with no wedge ice. The thickness of the active layer is 1.0 to 1.2 m. The development of adverse cryogenic, soil and other processes is not expected. In the areas of moderate sensitivity, the permafrost has a volumetric ice content of 0.2 to 0.4. The active layer is up to 0.9 m in thickness, surface deformations are 0.3 to 0.5 m in depth, the depth to the top of ice wedges is 1.5 to 1.7 m. The highly sensitive areas are characterized by a volumetric ice content of over 0.4. Adverse soil and cryogenic processes are present: thermokarst depressions 0.5 to 0.8 m in depth, soil disruption and erosion. Ice wedges occur from the 0.9 to 1.1 m depth. The Yana River valley is within the zone of risky agriculture. If possible, clearing of the land occupied by north-taiga cryosols underlain by ice wedges should be avoided. Treeless areas, particularly the steppes of low river terraces with meadow-chernozem and turf-meadow soils, are appropriate for agricultural development.

Interdependence and degradation of wetlands and permafrost in eastern Qinghai-Tibet Plateau and their environmental impacts

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key words: Eastern Qinghai-Tibet Plateau, permafrost paludification, permafrost-wetland systems, degradation, desertification, water diversion, eco-environmental rehabilitation

The Qinghai-Tibet Plateau hosts the largest expanse of permafrost and wetlands/peatlands in China and in middle latitudes. The evidence and mechanisms of the interdependence and degeneration of permafrost and wetlands in “the Sources of the Three (Yangtze, Yellow and Lancangjiang) Rivers”, and on the Zoïgé Peatlands in eastern Qinghai-Tibet Plateau have been observed, especially during the past half-century. The presence of permafrost as an aquiclude, low soil temperatures and subsequent slow metabolisms of microorganisms and proper topography are in favor of peat and organic accumulation and subsequent formation of wetlands and peatlands. The wetlands and permafrost are largely relics of Quaternary cold periods, and have been intermittently but persistently degrading since the Holocene. The water resources and ecological environments in the sources of the Yellow River have been deteriorating, resulted in drying lakes, shrinking wetlands, and degenerating grasslands, and dried river bed of the Yellow River. The recent, accelerating degradation of permafrost-wetlands systems are due to the strong impacts of a warming and drying climate, and increasing anthropogenic activities in this region during the past 50 years. The general trend of the degradation, which might continue for a long time, has caused the general deterioration of cold regions environments in eastern Plateau China, resulted in widespread desertification and salinization. The major recommendations include the enhanced multidisciplinary studies and long-term monitoring on the permafrost-wetlands ecosystems, their impacts on regional water and land resources, ecosystems, and human society, and the ecological, engineering, and administrative measures for their mitigation. Based on thorough and extensive research, logical planning and management on the basis of sustainable development should be adopted and enforced. Because of the rich biodiversity and relative higher productivity, its irreplaceable habitats for many and endangered species, and its important functions in water and soil conservation, the wetlands should and could be restored, rehabilitated or even created through some well planned and executed engineering and ecological programs. The route from the upper Tongtianhe River to the Sister Lakes as one of the optimal alternatives of the West Line of the Water Diversion Program from the Yangtze to Yellow Rivers are strongly recommended for the second and/or third term of the West Line Program due to its merits in eco-environmental rehabilitation, engineering economy and technical feasibility and sustainable development.

Regression models for analysis of ice content in frozen ground

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key words: ice content, water content of mineral layers, ice-cement, regression model

Quality of engineering - geological researches in various regions of cryolithozone is depended on by quality and detail of the account of spatial changes iciness and frozen soil water content. Ice-lense iciness (II), total frozen soil water content (W_{tot}) and water content of mineral layers in frozen ground (W_m) are used in engineering-geocryological calculations, or as classification parameters as the major characteristics of frozen ground. However frozen ground frequently is characterized by small-scale reticulate and small-scale layered cryogenic structures. In these cases direct measuring II and direct sampling of ground owing to the small size of mineral units for estimations W_m are impossible. Then W_m frequently accept equal soil water content of the lower plastic limit, and II calculate, proceeding from known W_{tot} and density of frozen ground. However in most cases W_m it is not equal to water content of the lower plastic limit, therefore such assumptions are unacceptable. The use in normative documents and, accordingly in calculations, of parameters which cannot be unequivocally determined, is inadmissible and can lead to dangerous consequences; it is especial in the context of risk assessment under global change. For loamy frozen ground with fine and frequent ice lenses (in which direct sampling from mineral layers is impossible) we had been carried out estimations I_i . I_i was calculated using photodocumentation of frozen core samples; thus II was equated to a share of the area occupied with visible ice. W_{tot} and density of a frozen ground were determined by sampling. W_m was calculated, proceeding from received values W_{tot} and I_i . It appears, that between W_m and W_{tot} exists a direct relation, it is marked both in syngenetic, and in epigenetic type of permafrost. The more samples of frozen ground contained schlieren ice, the more they contained also ice-cement. Thus in epigenetic frozen ground relation between W_m and W_{tot} closer, also can be qualitatively appreciated as close enough (correlation coefficient $r = 0.82$); in syngenetic frozen ground such relation is estimated as appreciable ($r = 0.64$). In both cases relation is proved on Student criterion with probability not less than 95%. For epigenetic frozen ground more significant influence granulometric characteristics on the contents of ice-cement and schlieren ice, than for syngenetic frozen ground has been marked. As a result of calculations by a method of the least squares linear models of regress with two independent variables are received. For epigenetic frozen ground

$$W_m = 8.7 + 0.46W_{tot} + 0.07W_l \quad (10.1)$$

for syngenetic frozen ground

$$W_m = -3.3 + 0.33W_{tot} + 0.68W_l \quad (10.2)$$

with W_l - humidity on border of fluidity. Estimations of adequacy and accuracy of models are carried out on the basis of Fisher's criterion and a standard mistake of an estimation, an average relative mistake of model and determination coefficient. It has allowed to draw a conclusion that the received model is suitable for forecasting values W_m in epigenetic frozen ground. Use of the received model for syngenetic frozen ground unfairly for the purposes of forecasting because of a high relative mistake, the model is suitable for the preliminary analysis. This study was supported by the Russian Foundation for Basic Research, grant no. 03-05-64832.

System of the engineering - geocryological monitoring as the basis of effective operation railways and highways on permafrost

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key words: railway, highway, permafrost, embankment, settlement, engineering-geocryological monitoring

Railways and highways on permafrost are under constant influence engineering - geocryological processes owing to what frequently there is a threat of traffic safety, restrictions of speed of movement of transport are entered, there is a significant growth of working costs. It is typical of all railways irrespective of term of their operation: for Transbaikalian Railway, taking place in operation one hundred years, Baikal-Amur and Amuro-Yakut trunk-railways - tens years, access roads of the Chara-China and Ulak -Alga - some years. The railway embankment on permafrost much more often is subject to deformations, than on non-permafrost regions. So, on a site of BAM from Hani to Komsomolsk-na Amur with branches in the common length of 2674 km in 2004 there were 2045 places with defects

and malfunctions of the embankment in the total extent of 780.8 km or 29.2% from operational length of a site, that almost in 4 times more than a common network parameter. Thus settlement of the embankment made 93% from all deformations. Basically they are connected to degradation of a frozen ground in its basis and their amount constantly increases. For example, on a site of BAM from Tynda up to New Urgal in the length 951 km since 2001 on 2004 extent of places with settlement of the embankment has increased with 219.9 up to 325.4 km or on 48%. Only permanent repairing of railways about which unpredictability else M.I.Sumgin wrote to 1926, movement of trains allows to provide. Similar situation and on motorways. So, the federal road "Amur" Chita-Khabarovsk is not completed yet, and on the constructed part already places require major overhaul. Without regular protection of roads, in particular on sites with rich ice permafrost it is impossible to provide their stability and designed speeds of movement. Most effectively such protection as shows experience of last 15 to 20 years, it is possible to carry out only within the framework of system engineering - geocryological monitoring of the roads, providing the regular control, the analysis, an estimation and the forecast of change permafrost conditions on a line of roads for duly detection, easing and suppression of undesirable development of cryogenic processes and the phenomena. In the report by the example of the Amuro-Yakut highway, access railway way Ulak - Alga and a federal highway "Amur" Chita-Khabarovsk scientific - methodical bases and the concrete contents of systems engineering - geocryological monitoring railways and highways are considered.

Geoinformation system of engineering geocryological mapping for construction of gas-and-oil pipelines

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key words: geocryological zoning, mapping, cartographic system, matrix schemes of zoning, GIS technology

The long-term complex engineering geocryological survey for construction in plain and mountain areas of the permafrost region allowed us to develop and implement the technique of geocryological zoning and mapping. The technique makes it possible to perform multicomponent mapping of engineering geological parameters, to successively modify constructed cartographic models, and to correlate different-scale maps and their information capacity. The cartographic system is constructed against a unified structural-geomorphological background, which corresponds to the concept of a geosystem approach and allows one to integrate different (engineering geological, geocryological, hydrogeological, seismotectonic, etc.) maps into an album. The mapping is based on the creation of multilevel computer databases and on the development of matrix schemes of zoning. The matrices are used to analyze, organize, and generalize information and form the basis for map legends. Moreover, the matrices reflect the interrelation between the main components of the natural environment to be mapped, depict the structure of thematic electronic layers of a map, and correlate with a database. The elaborated system makes it possible to map the entire body of obtained data, to easily read mapped information, and thereby to effectively apply the GIS technology. The system was used to plan different options of the Russia - China, Eastern Siberia - Far East, Western Siberia - European northern regions, and other oil-and-gas trunk pipelines.

The influence analysis of the slope seepage on embankment stabilities in permafrost regions

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key words: slope seepage, ponding, embankment stabilities, permafrost regions

The seepage phenomena of ponding on the slope of the embankment in permafrost regions were analysed in summer time by using the numerical modelling. It was obvious that because of the convection heat transfer of water from the slope after the construction of the embankment, the permafrost table under the roadbed would degraded and the concave thawed core was formed or further enlarged, thereby the thawing settlement in summer and frost heave in winter would be increased, and the stabilities of embankment would obviously be decreased.

The creep characters of frozen silt under dynamic loading with confining pressures

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key words: creep, frozen silt, dynamic loading

A series of tests were performed to study the creep behaviour of frozen silt under dynamic loading with confining pressure at various temperatures and frequencies. The paper discussed the influence of temperature, confining pressure and frequency on creep characters of frozen silt. An experienced creep equation was also developed in this paper.

Mechanisms of oil contamination transfer in freezing soils

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key words: permafrost, seasonal freezing, ecology of cryolitizone, oil pollution, migration

Recent investigations show that the processes of seasonal freezing of active-layer became the factor of redistribution of oil pollution. This study takes up the aspects of chemical and physicochemical interactions of the components of freezing soils and oil. Conditions and mechanisms of oil transfer with in freezing soils are presented. In water-saturated and oil-polluted soils the main part of oil volume is presented by non-aqueous phase liquids and is able to move with water flow and by itself. In this system water as a polar liquid appear as a wetting phase. Oil, pushed off from the surface of mineral particles, is situated in the centre of pores. Being combined with mineral particules, water possesses lower mobility in relation to oil. Two mechanisms of oil transfer can be found in the soils beginning to freeze up. The first mechanism is cryogenic expulsion of oil components from freezing to thawing zone and the second one is advective transportation with water flow from the thawing to freezing zone. Freezing porous water causes the presence of crystallized pressure in porous space of soils. As a result, part of oil-contaminant is pressed back by the freezing front in the thawed zone. According to the experimental data the cryogenic expulsion is a prevailing mechanism of oil transfer in freezing contaminated soils. The mechanism of cryogenic expulsion is effective, when oil forms a combined hydrophobic phase in porous space of soil. If the initial content is less than 1% (relation of the weight of oil to the weight of dry soil), oil is not redistributed in the freezing soil. In this case, oil is probably situated in porous space as separated inclusions and is captured by crystallizing water. Efficiency of cryogenic expulsion is defined by freezing speed and structure (properties) of hydrocarbon contaminant. Experimental data show that up to 70% of oil pollution can be expulsion from a freezing zone in favorable conditions. In fine-dispersion (clay) soils oil can be expelling by front of freezing and either be collected in frozen zone in case of intensive migration of water flow within the freezing zone. Oil transportation with water flow (advective mechanism) is locally advanced in fine soils. It is caused by hydrophobic behavior of oil. However, the presence of oil-polluted ground water beneath the zone of seasonal frost, can cause soil pollution subjected to freezing.

Geophysical monitoring of hydrotechnical objects in western Yakutia

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key words: permafrost, geophysical monitoring, storage dam, filtration

Authors present original results of long-term geophysical study on hydro technical objects of Western Yakutia analyzing problems associated with use of geophysical methods for the study of rocks and soils in permafrost area. Frozen rocks in permafrost zone are very sensitive to natural and man-caused influences. The hydro technical engineering objects which are carried up in permafrost zone like Western Yakutia, are exposed to action of a different sort of the

negative factors step-by-step resulting some of them in a labile state, down to catastrophic. Owing to these circumstances for last 5 to 8 years on a number of hydro technical objects of Western Yakutia are observed thawing-filtration processes, are found out local filtration zones posing under threat their secure exploitation. The primal problems of studies were focused to eliciting and check of a position of talik zones and places of filtering of water in a body of foundation and coastal contiguity of Sytikan dam and Vilui HPS (constructing and operating reservoirs) dams and also to an estimation of dynamics of progressing of filtration processes for a development of a complex of measures, directional on exception of losses of water from reservoir and supply of stability of a body of a dam. Due to a difficult and hardly predictable geocryological situation in this area, the geophysical methods were included into the system of local monitoring. From ground-level methods of studies in composition of operations were included high frequency electric profiling, electric profiling on a method of a natural field, georama, seismic profiling and seismic sounding. Down hole observations on dams included long-term regime temperature measurements and complex of logging studies (resistance, flow meter survey, gamma logging, neutron gamma logging, caliper measurement, radio wave cross-borehole testing). On the ground of down hole geophysical studies included methods of nuclear logging and flowmetry, the detailed geological section was studied and the binding of filtering spacing to definite lithologic horizons was established. The purpose of geophysical investigations was, first, to control the frozen rock thawing (talik) within the coastal zone of the reservoir and to assess the dynamics of the process, and second, to identify and to locate places of the most intensive thawing and filtration of water from the reservoir. On the base of detailed surface and boreholes geophysical observations the numerical model of the part of right-bank contiguity was done. The model shows temperature evolution of thawing zone as a function of air and water temperature, lithology, thermal properties of the section. Observed geophysical data compared with numerical modelling.

Field experiment study on effects of duct-ventilated railway embankment on protecting permafrost of the Qinghai-Tibet Plateau

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key words: Qinghai-Tibet railway, permafrost, ventilation embankment, ground temperature, heat flux

The Qinghai-Tibet railway is the longest high-altitude railway in the world. It crosses 632 km of permafrost, which is undergoing degradation currently and may cause engineering damages. Based on ground temperature data monitored at Beiluhe section of the railway, an experimental embankment was constructed. To study the engineering effect of a duct-ventilation embankment to protect the underlying permafrost is discussed in this paper. The analysis of ground temperature changes and heat influx shows that ventilation ducts can effectively cool the soils surrounding the ducts in the embankment, and the yearly heat collection of the ambient soils displayed as heat release. The permafrost below a common embankment and the embankment with ducts buried in a high position relatively processes warming tendency all along the length in the following three freeze/thaw cycles following embankment construction. The permafrost below the common embankment and the duct high-positioned embankment absorbs heat during the three cycles. However, the temperature of the permafrost below the embankment, in which the ducts are buried in a relatively low position, rises a little in the first freeze/thaw cycle. After that, it cools down gradually because it begins to release heat in the coming cycles. This phenomenon proves that the ventilation embankment with low-positioned ducts shows efficient temperature-controlling effects. Such embankments can actively cool the subgrade soils, and, therefore keep the roadbed thermally stable. Therefore, it is strongly recommended to apply a duct-ventilation kind of railway embankment structure in the construction and maintenance of the Qinghai-Tibet railway.

Effects of cast in place pile construction on permafrost temperature profile

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key words: cast in place pile, temperature profile, permafrost, field observation

The mechanical properties of high temperature frozen soils are extremely sensitive to variation in its temperature. Therefore, it is necessary for determining the bearing capacity and optimizing the construction process to study the effect on the permafrost temperature profile of construction of cast in place piles, which is a widely applied foundation

type in high temperature and high ice content permafrost regions along the Qinghai-Tibetan Railway. Here, the response of the permafrost temperature profile to construction of cast in place engineering piles and its recovering process are analyzed by in-situ measurements. For the specific situation monitored, it is found that the soil temperature under observation is raised 0.7°C, and the thickness of thawed cirque is less than 0.5 m, the temperature of the pile decreases to below 0°C in 60 days after reaching its maximum value of 4°C, however, it may be a long process for the soil temperature around the pile to decrease to its original value.

Gas permeability of frozen coarse fragmentary rocks

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key words: permeability, filtration, frozen, rocks, Yakutia

The paper reports the results of laboratory and field investigations of frozen rocks. The laboratory investigations were performed in a steady-state regime on samples of artificially crushed stone with a mean particle size of 4 mm over a wide range of filtration velocities covering the viscous, transitional and inertial regions at the degrees of pore saturation by ice, S , varying from 0 to near 1. It has been found that both the viscous permeability K_{μ} and the turbulent permeability K_{ρ} , in the presence of a general tendency to decrease with increasing S , have extreme values not at $S=0$, but at $S=0.1$ to 0.2 . The field investigations were carried out in the permafrost massif which consisted of dolerites of the trap formation $\gamma\beta T1$ occurring on Mesozoic sandstones (P, C). The permafrost had a temperature of -2 to -4°C , and its thickness in the study area is about 700 m. The investigations were conducted with a passive experiment method based on the study of massif reaction to pressure oscillations in a source well. The investigated layer was 60 to 80 m thick and the piezometric wells were at a distance of 100 and 200 m from the exciting well. Although the excitation pulse was low and accounted for about 1% of the absolute atmospheric pressure, the author could obtain reliable estimates of the mean values of permeability, effective porosity and piezoconductivity of frozen rocks, as well as to determine the spatial distribution patterns of cryogenic screens in the permafrost massif.

Engineering-geocryological conditions of the western part of Bolshezemelskaya tundra in area of head river Black

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key words: engineering-geocryological research, engineering-geocryological zoning, permafrost, Bolshezemelskaya tundra, complex analysis

Due to the intensive development of the Russian European North the engineering-geocryological research of territory is carried out now. During the work the engineering-geocryological zoning in large scale for sites of development of oil field were executed in western part Bolshezemelskaya tundra in area of head river Black. The engineering-geocryological zoning is made on the basis of landscape zoning. The geological-geographical factors: geomorphological level, genetic type of deposits, lithological structure of grounds, inclination of a surface, microrelief, drainage of a surface, vegetation, were used as a basis for definition the types of micro areas. The scheme of the engineering-geocryological zoning is represented in the matrix form, which allows to establish ties between landscape attributes and set of geocryological parameters: distribution of permafrost, mean annual temperatures of ground, iciness, thickness of active layer, physical-geological processes and phenomena. Territory of investigation is located in the zone of continuous permafrost. Intermittence of permafrost is caused by the presence of open and closed taliks under the rivers, brooks and temporary streams. Thickness of permafrost is 100 to 200 m. Mean annual temperatures of ground change in the limits of -0.5 to -3.5°C . From a surface up to the depth of 10 to 11 m the permafrost is composed of lacustrine-alluvial deposits (Kazantsevskaya suite, IaIII1). They consist of interstratification of sand, silty sand and clay and have epigenetic type of freezing. The sand has low ice and massive cryostructure. The silty sand and clay are icy and low icy. The cryostructure of two levels is thin- and medium-schlieren, layered-reticulate, subhorizontal or inclined, frequently broken. Glacial-marine deposits of (Rogovskaya suite, gmII2-4) are found lower, they are clay with inclusion debris of material. This also of epigenetic type of freezing. Loamy is low icy, the cryostructure is thick-schlieren, layered-reticulate, subhorizontal or inclined. The most part of the surface is overlapped sheeted

by lacustrine-swamp deposits with high iciness, with thickness up to 2 m. Thickness of active layer varies between 0.4 to 2.0 m. The minimum active layer thickness (0.4 to 0.6 m) is observed in region of peatlands, the maximum (1.5 to 2.0 m) - at the top part of slopes, consisting sand-loamy sand grounds. In the region of investigation the physical-geological processes and phenomena are widely spread: frost heave, termokarst, physical weathering, polygonal relief. Along abrupt coast of the river Chornaya, consisting mainly of loamy, the landslides, erosion and thermal erosion are observed. Thus, complex analysis of natural conditions of researched territory was executed in process of the engineering-geocryological zoning the with the purpose to establish the regularities of geocryological conditions formation.

Talik formation in the flank shore of water-storage reservoir in permafrost area

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key words: talik formation, numerical modelling, filtration

Regular water and energy supply in permafrost areas are vitally important conditions for inhabitants of the large North territories of Russia, Canada, US and Alpine areas of China. Dam and flank shore stability is the key point for safety of reservoir (power pool, water supply, tailing pit, etc.). In permafrost areas stability of many engineering structures, including hydraulic work, associated with thawing-freezing process. As a result of it we can have the loss of mechanical properties causing destructive of the unit. Emergency situation of the unit we have when seepage occurs in originated permeable talik zone adjoining to reservoir. In our work we numerically analyzed conditions causing origin and development of talik near reservoir constructed in permafrost conditions. On the base of detailed surface and boreholes geophysical observations in Western Yakutia the numerical model of the part of right-bank contiguity was done. The results of 2D heat-mass transfer modelling indicate that the development of the talik formation strongly depends on the specific thermal and hydraulic material parameters, thickness of the layer covering talik, seasonal temperature trend and the winter snow front insulating ground rocks.

Snowpack stability on mountain permafrost

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key words: snowpack stability, stability evaluation, permafrost

Analysis of recreational avalanche accident statistics indicates that 37% of accidents occur in potential mountain permafrost terrain. Accordingly, it has been proposed that the presence of sub-zero ground temperatures may favour snowpack instability. In the Swiss Alps, permafrost prevails in unglaciated shady slopes above 2400 m a.s.l. Locations on glaciers were excluded from the analysis. In order to investigate the effect of mountain permafrost on snowpack stability, 254 snow profiles with stability tests were analysed, taken in both permafrost-free and potential permafrost terrain, at different elevations and on slopes oriented N, NE and NW. The snow profiles were effected around Davos in two winters with distinct snow conditions: 2001 to 2002 (75% of long term average snow depth) and 2002 to 2003 (130%) and the forecasted avalanche danger ranged from low to high during the sampling periods. The profiles from the two types of terrain were rated into five classes of stability for comparison. The temperature at the base of the snowpack, the temperature gradient and the maximum grain size in the lowermost 50 cm were also compared. No significant difference in snowpack stability between permafrost and permafrost-free locations could be found. Basal snow temperatures were statistically significantly lower for the permafrost locations. Snowpack depth had a significant effect on the temperature at the base. With the lower basal temperatures, temperature gradients were accordingly slightly lower and thus a little less conducive to kinetic grain growth. The effect on the maximal snow grain size and on snowpack stability was minor. Overall, no indication was found that permafrost causes the development of an unstable snowpack. However, shallow snow depths favoured sub-zero ground temperatures as well as snowpack instability. Snow depth was significantly positively related to snowpack stability. In conclusion, the presence of many avalanche accidents on permafrost terrain rather reflects skiing preference - due to more enjoyable snow conditions on shady slopes - than a causation, and is therefore merely a coincidence. The analysis focused on sites with similar ground cover, surface roughness, and climate. The characteristics of the snow cover in steep, blocky permafrost terrain such as rock glaciers or rough scree slopes, where air circulation has an important role is probably different and still needs to be further investigated with respect to snowpack stability.

Monitoring the frost mound surface dynamics along a gas pipeline route Nadym-Punga, northern taiga zone of West Siberia

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key words: frost-heave mound, monitoring, climate changes, tectonic disturbance, processes

The study area is located near the town Nadym, at a margin of the Third lacustrine-fluvial plain. The plain is built of the upper Pleistocene Zyrianka deposits: sands with silty and clayey interbeds. They are locally overlaid by modern peat. Permafrost is distributed in patches with mean annual ground temperature from 0 up to -2°C linked to peatlands, and frost-heave mounds and ridges. Most widely occurring exogenic geological processes are bog formation, thermokarst, seasonal and perennial frost heave.

In 1972, the vegetative cover and, in part, peat horizon had been removed during the gas pipeline Nadym-Punga construction. To study the changes caused by anthropogenic intervention, monitoring of the surface dynamics was organized on two fixed transects 6 km apart. The first transect was established in 1977. It crossed peat-mineral and mineral frost-heave mounds. Frost-heave mounds are surrounded by wet drainage hollows with bogs. Frost-heave mound surface is poorly drained. The peat thickness at the peat-mineral mound varies from several centimeters up to 50 cm. Peat is underlain by sand extending to the depth of 5 m and containing interbeds and lenses of loam on top of clayey sequence. Except for the first 15 m transect is within the disturbed zone. Second transect was established in 1972 immediately after the gas pipeline was installed. It crossed peat-mineral frost-heave ridge. The surface is more drained compared with the first transect. Frost-heave ridges are surrounded by drainage hollows, without superficial water. The peat thickness at the frost-heave ridge is about 50 cm. Peat is underlain by sand to the depth of about 2 m, and loam beneath sand. During the pipeline construction vegetative and peat covers were removed along a 30 m wide strip. Near the first transect a 3-year old small frost-heave mound was observed. It was located on a peat bog. There is a 30-year old small frost-heave mound near the Second transect. It was located on a drainage hollow on flat-top peat mound. Both small frost-heave mounds were in undisturbed conditions. Monitoring of the surface of these newly formed frost-heave mounds was undertaken as well. At the study sites permafrost table was found at the depth of 3 to 4 m. In 2000s ground temperature was 0°C at the depth of 3 to 5 m and -0.2°C at the depth of 10 m. In 1970s at the depth of 10 m it was as low as -0.5°C . Increase of ground temperature was caused by a higher air temperature. Leveling of the first transect surface was carried out in 1980, 1984 to 1986, 1991, 1992, 1995, 1999 to 2004. Leveling of the Second transect was performed in 1974, 1986, 1991, 2001 to 2004. In modern conditions of northern taiga of West Siberia, at the sites with high-temperature permafrost, despite of the climate warming and removal of the vegetative cover frost-heave mounds continue growing at the sites surrounded by wet drainage hollows. Formation of new frost-heave mounds is observed at the undisturbed sites. In the same area, under dryer conditions there is a partial degradation of frost-heave mounds if the vegetative cover has been destroyed during the construction of a gas pipeline. Maximal subsidence on degrading frost-heave mounds occurred within the first two years after construction was over and has made more than 1 m. Following the vegetative cover restoration, subsided sites had gradually started to rise, but for 32 years since then their surface did not reach initial height. The research is performed with the financial support from RFBR grant 04-05-64005.

Map of engineering geocryological zoning in the European Northeastern regions at a scale of 1:1000000

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key words: geocryological mapping, European northeastern regions, matrix schemes of zoning, GIS technology

Engineering geocryological zoning and mapping are the main link in the complex study of geoenvironmental conditions of areas for the purpose of their development. The GIS technologies used in the system of engineering geological survey (based on multifunctional electron databases, engineering geocryological zoning, and program modules) in order to estimate and predict the main parameters of the natural environment will make it possible to intensify the studies and to make them more informative.

Since the studies are performed in stages, this is responsible for the hierarchy of zoning scales, which makes it possible to continue the studies at all survey stages. Therefore, the hierarchic system of the zoning maps and the system of matrix explication of the zoning schemes are the main link in regional engineering geocryological GIS. The maps of engineering geocryological zoning, used to construct the series of special and evaluation environmental-geocryological maps, are the main elements of the information-cartographic block of engineering geocryological GIS at all levels of the system. The map of engineering geocryological zoning in the European northeastern regions is the main map in the regional GIS album. This map reflects variegated engineering geocryological conditions in the upper 15-m horizon of the geological section. The matrix form of zoning, which is the form of analysis of presented data and the map legend, was elaborated during mapping. This made it possible to combine information about the geological-geomorphological structure of the area (geomorphological level, composition of the geological-genetic complexes of rocks at different geomorphological levels, and ice content of these rocks) with the main geocryological characteristics: permafrost occurrence and average annual temperature. Exogenous geological processes and shallow bedrock formations are also mapped. The map can be used to assess engineering geocryological conditions in the region in order to efficiently route designed main pipelines and to rationally locate other construction facilities.

Numerical simulation on the optimum grain-diameter of the open-graded embankment in Qinghai-Tibet railway

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key words: Qinghai-Tibet railway, frozen-soil, open-graded, cooling-effect, diameter

Combining the constructing railway in Qinghai-Tibet plateau, a new method was studied which protected the permafrost positively called cooling embankment -open-graded embankment. This embankment can be viewed as porous media and its thermal problem is air convection in porous media. Assuming the local thermal equilibrium between the fluid and solid, at the same time Boussinesque approximation is employed, we can get the mass, momentum and energy equations. Then the Galerkin method is used to divide these equations. The best diameter of the grain by the numerical method was studied in this paper. We found that when the diameter is 3 cm, 6 cm, 9 cm and 15 cm, the cooling effect of the 9 cm grain is the best, air convection occurred in the whole embankment and the decreasing amplitude of temperature is 1.18°C , air velocity at the bottom is 0.73 m h^{-1} . The cooling effect of 6 cm grain is better than the other two diameters, the decreasing amplitude of temperature is 1.18°C and air velocity at the bottom is 0.73 m h^{-1} . The worst cooling effect is 3 cm and 15 cm, air convection hardly occurred at the bottom. From the primary result, we suggest that the 9 cm grain is applied in engineering widely.

Deformation of embankment in permafrost regions on Qinghai - Tibetan Plateau

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key words: settlement, embankment, creep, freeze-thaw, equivalent permafrost table

Settlement of embankment in permafrost regions comes from several simultaneous processes with different mechanisms. The first is the well-known thaw settlement because of the possible down moving of the permafrost table. This has been considered to be the most dangerous to the embankment and has attracted great efforts in the previous studies. The second one is creep. Field measurements show that due to the existence of a linear construction, even without movement of permafrost table, the temperature in permafrost layers can rise remarkably which bears a considerable warm frozen layer with high creep features. At the same time, within several months of the warm seasons, creep also happens in the thawed soil layers. Thirdly, because freeze-thaw cycles in the active layer can change the soil properties, extra settlement can also happen in the first several years. These three processes are intervened, which makes any single attempt very difficult to handle. Based on the practice in the No. 214 highway and Qinghai-Tibetan railway on the Qinghai-Tibetan plateau, this study analyzes these possible settlements. In order to investigate the whole settlement comprehensively, an idea of equivalent thaw depth is proposed. This paper is prepared with support by the Max-Planck Society in Germany.

Review of influence of freeze-thaw cycles on geotechnical properties of soils

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key words: review, freeze-thaw, geotechnical properties, soil structure

It has become a common understanding that freeze-thaw cycling is a kind of weathering process which considerably changes geotechnical properties of soils due to cryogenic actions. Therefore, the influence of freeze-thaw must be taken into account when selecting soil parameters for stability and deformation analyses of slopes, embankments and cuts in cold regions. This holds in particular for permafrost regions, where newly exposed soil layers are bound to be subject to freeze-thaw cycling. The study on changes in engineering properties of soils induced by freeze-thaw is not in the same level as on the mechanical properties of frozen soils, especially the creep behaviors of frozen soils, which were reviewed by various researchers in different time. In recent years, some new findings have been published on the freeze-thaw induced change of soil properties. However, from the point of view of soil mechanics, many aspects are not yet clear.

This paper reviews the general findings of the research on the effects of freeze-thaw on soil properties based on an extensive literature study. The methods of investigation and testing techniques and influence of freeze-thaw on both physical and mechanical properties of soils are discussed. To this end, typical research results are taken from various resources. Special concern of this paper is put on destructuration and structuration of soils. For this reason, natural soils and reconstituted soils must be differentiated. The logical findings are summarized. Comments and suggestions are more given from the point of view of soil mechanics. It seems that much more efforts are still needed. This paper is prepared with the support by Max-Planck Society in Germany.

Laboratory experiments on slope stability using an inclined shear box simulating the active layer above alpine permafrost in steep scree slopes

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key words: mountain permafrost, active layer, slope stability, inclined shear box

In mountain permafrost terrain slope stability could decline in the next few decades, particularly at the surface, with active layer deepening due to global warming. Hazardous events related to slope destabilization such as landslides or debris flows can affect infrastructure and human being.

In this project it is therefore investigated how grain size of the ground, soil water content, seepage on the impermeable permafrost layer and ground temperature influence the shear strength between the active layer and the permafrost table. In order to determine the effect of each influencing factor separately, the investigations are carried out under controlled conditions in the laboratory. The theoretical basis for the investigations is provided by the infinite slope model. According to the Mohr-Coulomb failure law the shear strength is determined by the effective normal stress, which also accounts for the uplift by water in the saturated zone, the inner friction angle and the cohesion. In the case of a seepage additionally the shear stress caused by the downslope water current has to be considered. The experimental setup consists of a plate, whose inclination can be adjusted continuously, a block of frozen mineral substrate saturated with ice on the plate simulating the permafrost and granular material kept by a frame of vertical walls, which can slide downslope, representing the active layer on top. At the front and backside this frame is bounded by gratings and geo textiles keeping back the solid material but allowing the water to flow through. The experiments showed that the apparent cohesion which is due to capillary tension in the porous granular material leads to a higher shear strength in a moist substrate than in a the equivalent dry substrate. But a seepage on the simulated permafrost layer lowered the inner friction angle and therefore the shear strength significantly. With the substrate representing the active layer being completely frozen, winter conditions were simulated. But also close to 0°C the cohesion due to ice in the pore space of the granular material was very high. The perceptions gained by this laboratory study will help to improve to estimate the disposition of active layer instability in mountain permafrost regions spatially and temporally.

Principles of GIS-based engineering geocryological mapping in the regions of different geological structures

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key words: matrix analysis, geocryological zoning and mapping, cartographic system, matrix schemes of zoning, GIS technology

Development of the permafrost region should include complex studies of engineering geocryological conditions to be performed in different regions at an up-to-date level based on unified information positions, taking into account specific features of construction under these conditions. The revealed regularities in the formation of engineering geocryological conditions form the basis for estimating the natural dynamics of these conditions and the changes caused by the man-made impact on the geological environment during construction and operation of a facility.

Construction of the maps of engineering geocryological zoning based on GIS technologies resulted in an increased role of a preliminary analysis of engineering geocryological conditions, development of zoning cross-schemes, and implementation of these schemes in the form of matrix explications. The schemes of zoning based on a matrix analysis have been constructed in order to improve an analysis of engineering geocryological conditions and to develop the methods of engineering geocryological mapping. The main principles of a matrix analysis, used to perform engineering geocryological zoning and to create albums of specialized digital maps, were realized in the regions of different geological structures: northern European regions of Russia, Western Siberia, the regions around Lake Baikal, Mongolia, etc. The matrix base of the zoning scheme is not only the method of data analysis, organization, and generalization but also the main element of map legends. The matrix structure generally reflects the structure of digital map layers and, therefore, makes it possible to more effectively use the possibilities of GIS technologies to solve engineering geocryological problems.

Geocryological condition changes due to water supply on the new Urengoy water deposit

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key words: water inlet, temperature monitoring, permafrost dynamics, seismic

There is progressive decreasing of the water production due to geocryological condition changes on the New Urengoy water inlet during last 3 years. Field researches were made by Earth Cryosphere Institute researchers (supported by INTAS 01-2332) in purpose to find what caused it. We used new unique methodic of high-resolution seismic reconnaissance with the cross reflected SH-waves. Modern geocryological conditions of the key site have been investigated over 1997 to 2004. So we organized temperature monitoring for the top part of permafrost (first 50 m). On this basic we investigated detail permafrost structure, studied its spatial distribution and estimated the permafrost structure influence on the water intake.

Geocryological estimation of Urengoy gas deposit area was made according to the research data of the 1975 to 1999 years than on basis of it the set of electronic maps and unique database were created for this area. So natural and man-caused dynamic of geocryological conditions on the Urengoy gas deposit was analyzed, taking into account the influence of natural and technogenic factors over more then 25th year period.

Under the natural heating effect the permafrost main annual ground temperature (MAGT) increased (according to the different landscapes) on 0.2 to 2.1°C since 1975 to 1993. Apart of the natural increase of the MAGT, constructions and well developed infrastructures have a considerable impact upon the MAGT too. So in the nearby areas it's gap accounts 1 to 2°C. Also there is significant increase of the thickness of an active layer (seasonal thawing layer) and developing of the technogenic thawing halos. Consequently similar changes of MAGT occurred within New Urengoy water inlet. From the one hand there is general temperature increase connected with changes of the dynamic over the last 25 years which caused degradation of the ice lenses in sandy ground within New Urengoy water inlet. From the other hand surface conditions were formed such way that provoked to expansion this permafrost lenses. Here we can observe how natural heating influence was intensified owing to the technogenic influence: ground water dynamic has changed due to water pooling and due to snow redistribution after cleaning roads between water boreholes.

Frost heave damage to a road on a permafrost island

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key words: permafrost, road, frost heave

There widely exists permafrost over Qinghai-Tibetan Plateau. Many roads have to pass permafrost regions. In north-west edge of the plateau, a section of a road has been suffering from frost heave damage for many years. In 2004, a drilling investigation was carried out. It was found that the section of the road was built on a permafrost island, and the soil in active layer belongs to the frost-sensibility silt. Springs on mountain slopes supply the silt with sufficient water. Samples of the silt were taken back to conduct frost heave tests. The frost heave tests were conducted under three moisture conditions, namely sufficient water supply, at liquid limit water content without water supply, and at plastic limit water content without water supply. Test results reveal that a considerable frost heave appears for the water supply samples, and multi-layer segregated ice is observed. On the other hand, the frost heave is not obvious while keeping water content of samples below its plastic limit. Based on the results, reasonable suggestions were proposed to the road reconstruction.

Response of permafrost conditions to surface disturbance and climate change in the Norman Wells pipeline corridor, Northwest Territories, Canada

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key words: thermal regime, permafrost engineering, thaw depth, climate change, northern development

The Geological Survey of Canada has maintained a network of permafrost monitoring sites along the Norman Wells to Zama oil pipeline corridor since 1984. This program has provided the opportunity to investigate both the impact of surface disturbance and climate change on permafrost conditions in the Mackenzie Valley, Northwest Territories.

Ground temperatures, thaw depth and thaw settlement at sites on the cleared pipeline right-of-way (ROW) and in the adjacent undisturbed area have been recorded since 1984. Analysis of thermal data from the undisturbed sites indicates that there has been a general warming of permafrost at 10 to 15 m depth of about 0.03°C per year in the central Mackenzie valley where permafrost is at mean annual temperatures of about -1°C. No apparent warming trend has been observed in the southern valley where permafrost temperatures are close to 0°C. The observed warming of permafrost is coincident with a general increase in air temperatures of about 0.07°C per year since the mid 1980s. Warming at depths of 4 to 5 m on the ROW of up to 2°C over the 20 year period has also been observed in response to clearance of vegetation. This warming beneath the ROW has been accompanied by increases in thaw depth ranging from 2 m to greater than 5 m and settlement of up to 1 m. Where thin permafrost (<5 m) was initially present beneath the ROW, it has completely degraded. Greater warming has occurred in coarser mineral soils with low ice content compared to finer grained lacustrine sediments, or organic terrain, with higher ice content. The climate warming signal has largely been obscured on the ROW by the response of the ground thermal regime to the larger warming signal from the ground surface disturbance. In later years distinct interannual variability in the ground thermal regime and thaw depth has been observed at some sites on the ROW that is related to the climate variability.

Continued data collection and analysis and future enhancement of the monitoring network in the Mackenzie Valley will provide further information on baseline permafrost conditions as well as long-term change. Knowledge of current and assessment of future permafrost conditions in this region is becoming increasingly important for engineering design and environmental impact assessment associated with development, in particular the proposed MGP buried gas and natural gas liquid pipelines and extended use of the existing oil pipeline.

Multilevel database in the structure of the regional geoinformation system

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key words: geoinformation system, database, engineering-geocryological map, European North of Russia, matrix scheme

The multilevel database is an informational-attributive block of the developed regional engineering-geocryological geoinformation system. The informational content of the database is made up by the attributive facts about the territory of separate objects of the oil-and-gas complex: deposits, pipelines, platforms of the oil-terminals and other objects. First-level database represents a system of equal tables, which contain structured data. The name of the table depends on the well's number and also contains the complete characteristic of the well: depth and interval of boring, lithology, cryotexture, genesis, temperature, humidity, density, etc. The next constituent of the first-level database is the overall table, which consists of the total list of boreholes and also of the information about the geomorphologic situation, the geogenetical characteristic and the engineering-geocryological conditions of the site, where the borehole is situated. The function of the overall table - spatial lock-on of the wells to the subject of inquiry on the map of the actual material of the European North of Russia (scale 1:1500000). Second-level database represents a system of summary and compilation tables connecting the database and the matrix schemes of zoning of the informational-analytical block of the regional geoinformation system. All the information fields of the summary table contain statistically processed information on the engineering-geocryological conditions and the ground's physical properties within every of the detailed in the matrix scheme of zoning geocryological areas. An important element of the operated multilevel database is the possibility of its connection with the actual material's map by the inquiry system. The inquiry system is based on the search and selection of the information by one or several parameters. The result of selection is the list of boreholes satisfying the inquiry terms. Thus, there is a developed algorithm of both straight and reverse connection of the database with the actual material's map. On this basis the informational filling of the matrix circuits of zoning and also the accomplishment of the forecasting calculating for the compilation of the engineering-geocryological and ecology-geocryological maps are made.

Large scale survey of mountain permafrost displacement in alpine areas from satellite radar interferometry

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key words: permafrost, displacement, radar interferometry, inventory

Repeat-pass Satellite Radar Interferometry (SRI) is a powerful technique for mapping land surface deformation with mm accuracy at fine spatial resolution over large areas. Surface deformations include subsidence, landslides, tectonic and volcanic activities, and ice sheet and glacier movement. In spite of limitations due to temporal and geometric decorrelation, satellite viewing geometry and inhomogeneities in the tropospheric path delay, in recent years SRI was also successfully applied in mountainous areas to quantify the degree of activity and the order of surface velocity of rock glaciers, with the possibility to also detect very small movements of inactive and relict rock glaciers. The Service for Landslide Monitoring (SLAM) project was launched in 2003 by the European Space Agency (ESA) for the definition of a service based on the integration of Earth Observation (EO) data within the current practices of landslide mapping and monitoring in Switzerland and Italy. Regional users have been involved as partners of the project, in order to validate the provided products, to assess the quality of the services and to assure scientific aspects. The expectations of the users are connected to the possibility, by integrating EO-derived information within the current practices employed in the landslide risk management, of providing standard methodologies for landslide mapping and hazard assessment. As a part of the SLAM project, a large scale survey of mountain permafrost displacement in alpine areas was compiled from SRI. Satellite radar data from 1993 to 2000 of ESA ERS-1/2 satellites and of the Japan Aerospace Exploration Agency (JAXA) JERS-1 satellite have been processed interferometrically over an area of about 5000 km² in the Swiss cantons of Valais and Bern. Favourable conditions for radar interferometric observations were found during the snow free period between early summer and mid fall. A geomorphological interpretation of a series of interferograms was conducted to derive an inventory map of displacement on regional scale. Most of the

interferometric signals have a strong relation to creeping permafrost and in particular to active rock glaciers. It could be shown at different places (e.g. Saas Valley, Turtmann Valley, Aletsch Glacier) that the interferometric signals are congruent with existing rock glacier inventories. In addition, within known rock glacier shapes velocity differences could be differentiated. Similarly to rock glaciers, also signals related to rockslides after glacier retreat were identified on a number of interferometric pairs. Results from radar interferometry can form the base for further detailed in-situ investigations.

In situ test on cooling effectiveness of the air convection embankment with crushed rock slope protection in permafrost regions

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key words: air convection embankment; crushed rock slope protection; cooling effectiveness, permafrost engineering

During 2001 to 2003, an experimental air convection embankment (ACE) was constructed in Beiluhe, the Qinghai-Tibet Plateau, using coarse (5 to 8 cm and 40 to 50 cm), poorly graded crushed rock fill material on the slope of embankment with thick ground ice permafrost foundation, which should be called the air convection embankment with crushed rock slope protection (ACE-CRSP). The highly permeable ACE-CRSP installation was designed to test the cooling effectiveness of ACE-CRSP concept in an actual railway project. Using thermistor sensor strings, ground temperature data were collected from test sections. The results showed that the mean ground temperature under the layer of crushed rock with diameter of 40 to 50 cm was lower than that under one with diameter of 5 to 8 cm, and the fluctuating range of temperature under the former was bigger than that under the latter. It was obvious that the maximal thawing depth was raised under the layer of crushed rock with diameter of 40 to 50 cm, which was resulted from the stronger cooling effectiveness of air convection during winter-time. The amount of heat budget also showed that in supplying cold energy for foundation, the layer of crushed rock with diameter of 40 to 50 cm was larger than that with diameter of 5 to 8 cm. So, we would think that the cooling effectiveness of the crushed rock layer with diameter of 40 to 50 cm was stronger than that one with diameter of 5 to 8 cm.

Complex assessment of cryogeological and bioecological state of Tundra geosystems

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key words: risk assessment, stability of geosystems, ecological GIS-mapping, West Siberia

The key point of complex assessment of modern and future state of cryogeosystems is criteria choice including not only their resistance to mechanical and geochemical impact but their bioecological resources as well. Regional patterns of assessment criteria and GIS-mapping application are presented for two test sites situated in the subzone of southern tundra on the Yamal and Tazovsky peninsula.

1. Electronic maps series for Yar-Sale site enable to assess cryological, ecological, resource and geochemical state of geosystems. The assessment is based on multifactor correlation analysis of biota and lithological geosystems composition. Besides the principle permafrost characteristics which transformation is connected cryogenic processes activation (the annual temperature and ice content of frozen rocks, the depth of active layer, heat protecting properties of vegetation), bioecological parameters are used. They control a degree of geosystem ecological potential preservation (vegetation natural recovery, reindeer pastures capacity, soil self purification potential, etc.). Multiple regression equation is based on these criteria. It enables to calculate ecological adverse effect coefficient for each geosystem followed by classification according to sustainability to economic development impact. Series of assessment maps are compiled in the result, based on 4 to 8 parameters variations. Comparative maps analysis demonstrated that use of 8 parameters for coefficient calculation gives smaller sizes of territories most unstable in the course of economic development impact because of lower importance value of protective role of plant cover and mean annual rock temperature. But according to the principle characteristics - high ice content of permafrost, low self-recovery speed, considerable reindeer pastures resources, extremely low self-purification because of sorption geochemical barrier in the peat soil horizon, frost plain-mound bogs are the most dangerous in the integrated cryological and ecological assessment of tundra geosystems.

2. GIS for the projectable Harvuta deposit (test site “Harvuta”) includes the following maps: geomorphological, geobotanic, soils, geosystems, technogenic impacts, modern and forecast ecological state. The latter is the assessment map comprising 6 layers and two raster files - topographic map and photo-plan. Such maps contain scientific and reference information necessary for decision making support of oil-gas industrial sites location and meet all the demands of ecological engineering and nature conservation standards.

Cryogenic researches in technogenic-modified forest-tundra and tundra landscapes

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key words: permafrost, landscape, cryogenic, technogenic

Special ecological-cryogenic-landscape researches were carried out In July, 2004 in vicinities of Norilsk (the largest industrial centre of cryolithozone) on a representative site (7.5 km²), representing with flat-wavy, hole-oval surface, complicated with termocarst hollows. Natural supervision were executed with the purpose of studying a specific complex of cryogenic processes developing within ice-rich deposits of Valkovsky retinue (alIII3v1-lbIV), generated in top of Pleistocene in the closed cold reservoir surrounded with an ice cover on the Putoran plateau.

The special attention was payed to measurement depth of seasonal thawing in different landscape conditions. The territory is occupied with forest-tundra with northern taiga fragments. It was allocated 5 types of landscapes:

Type of landscapes	Depth of seasonal thawing (cm)
1. The slopes and the tops of hills occupied with forest-tundra	100-150
2. Humidified downturn in a relief, occupied with a rich willow bush	≥ 100
3. Flat-hilled turbaries with herbaceous shrub vegetation	30-40
4. Dried water-separate surfaces occupied with cereal vegetation	60-70
5. The flat-wavy surface deprived of wood vegetation	65-70

Zones of layer ice distribution on coasts of thermokarst lakes are revealed in exposures, therefore solifluction is advanced. Coasts sometimes are of terrace-like kind. The part of lakes is subject to cryogenic landslides 3 to 5 m high. Cryogenic slurries were observed on some coasts. Their average length is 2.5 m, width - 80 cm. On a rate of anthropogenous influence, infringement of natural landscapes, activation of cryogenic processes 6 ecological zones among which are available as almost absolutely not disturbed forest-tundra so completely changed, so-called the modified tundra completely deprived of wood vegetation as a result of economic activities were allocated. The ecological-cryogenic-landscape map was compiled as a results of research. Landscapes, active cryogenic processes, depth of seasonal thawing as well as influence of linear constructions and emissions of Norilsk factories on an environment are shown on this map.

Design, construction and performance of culverts in permafrost regions of Qinghai-Tibet Plateau

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key words: culvert types, structure, foundation, ground thermal regime, deformation

More than onethousand railway culverts and nearly 8 hundreds highway culverts were constructed along Qinghai-Tibet railway and Qinghai-Tibet highway in permafrost regions. The structures and schemes of four types of culvert (prefabricated box culvert, cast-in-place concrete box culvert, prefabricated concrete pipe culvert and corrugated metal pipe culvert) that are traditionally used or newly adopted in permafrost regions of Qinhai-Tibet Plateau are discussed in the paper. Prefabricated concrete block foundation, cast-in-place concrete foundation, prefabricated pile foundation and ground improvement methods, such as geocell technique, are implied in the culverts construction. Three years monitoring date of ground thermal regime and structure deformation are analyzed. On the basis of the performance analysis of the test culverts, suggestions of improvement are proposed.

Strength behavior of frozen saline fine-grained soil

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key words: frozen fine-grained soil, saline, unfrozen water, strength

Strength data for frozen saline soil are necessary in the areas of saline permafrost and soft saline unfrozen soil involving artificial freezing in highway, railway, subway and building construction. But little data available for engineering up to now in China. This paper summarizes an extensive laboratory program undertaken to study the influence of soil type, initial water content, temperature, strain rate and salinity on strength of three different frozen fine-grained soil under conditions of unconfined constant strain rate tests. The soils included silt, silty clay and clay which were taken from the sites along the Qinghai-Tibet railway in construction. The range of initial water content was 4% to 50%, and the salinity was varied from 0 to 40 parts per thousand. The range of temperature of strength test was -2 to -10°C, and the range of strain rate was 1.1×10^{-3} to $1.1 \times 10^{-6} \text{ s}^{-1}$. Results indicate that an increase in temperature and salinity causes a significant loss of strength. The salinity dependence of yield stress, peak stress, and initial modulus is represented by a simple exponential law. The strength predictive models for soils tested in terms of salinity and temperature is presented. The change of salinity behaves the strongest effect on the strength of frozen silt among the three type of soil, and then that of silty clay and clay. Comparing with NaCl, the effect of salinity of Na₂SO₄ on the strength of frozen soil is not quite obvious. The law of the effect of salinity on the strength of frozen soil can be explained by the law of the effect of salinity on the unfrozen water content of frozen soil.

Permafrost modelling in the North Ossetian Caucasus

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key words: permafrost, modelling, GIS, Caucasus, Russia

On September 20th 2002, an enormous rock/ice avalanche occurred on the northern slope of the Kasbek massif, North Ossetia, Eastern Caucasus and subsequently developed into a mudflow. Starting from the NNE wall of the peak Dzhimarai-khokh (4780 m a.s.l.) the catastrophic event travelled over a horizontal distance of 33 km, destroying parts of the valley of Genaldon-Karmadon and killing approximately 140 persons. Shortly after this incident, the North Ossetian government sought the cooperation of the Swiss Agency for Development and Cooperation (SDC) in order to assess the arisen risks and to help implement mitigation measures. The present contribution reports about a regional permafrost analysis that was initiated within this context.

Two empirical models were applied to assess the permafrost distribution in the North Ossetian Caucasus: the empirical model PERMAKART and the statistical model PERMAMAP. Both models were originally developed to estimate the permafrost distribution on a regional scale in the Swiss Alps and require a DEM (digital elevation model) as input data. Climatic conditions (general parameters, seasonal variability, precipitation values) in the Caucasus and the Alps are quite comparable. Therefore, it seems feasible to use the Alpine models to get a first order estimate of the permafrost distribution in North Ossetia. However, the models have to be adapted to account for the differences in latitude and mean annual air temperature (MAAT). Using temperature data from a meteorological station close-by, the altitude of the 0°C-isotherm in the Karmadon valley was determined at approximately 2640 m a.s.l. This agrees well with temperature measurements at Djankuat glacier in the central section of the Main Caucasus Ridge which suggest a 0°C-isotherm at about 2500 to 2660 m a.s.l. Therewith, the 0°C-isotherm in the Kasbek massif is approximately 400 m higher than in the Swiss Alps, for which the described models were calibrated. Permafrost distribution was estimated by using this Caucasian 0°C-isotherm altitude. The model verification with rock glacier inventory data and intercomparison of the two modelling results showed that the model adaptations serve well as a first order approximation of the permafrost distribution in the Kasbek massif. However, due to differences of the models themselves, each model has its advantages and disadvantages which have to be taken into account when interpreting the results.

In the course of this project, ten miniature temperature loggers were installed in the upper part of the Karmadon valley. The data of these loggers will help to better calibrate the models and will give insights into the temperature pattern of the Dzhimarai-khokh wall. This will contribute to the understanding of the very complex thermo-mechanical conditions, which most likely contributed to the enormous ice/rock avalanche.

Experimental study on thermal conductivity of railway ballast layer

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key words: permafrost, railway ballast, thermal conductivity

In this paper, the thermal conductivity of a railway ballast layer is measured by steady comparison method. The experiment was carried out at room temperature and two thermal conditions, heated from below and from above, were studied. The test results show that the thermal conductivity of the railway ballast layer is almost the same for the two thermal conditions when the temperature difference between the top and bottom of the layer is smaller. When the temperature difference of the layer is larger, however, the thermal conductivity for the thermal condition of being heated from below is greater than that for being heated from above. Moreover, under the thermal condition of being heated from below, the thermal conductivity increases with the increase of the temperature difference between the top and bottom of the layer. Thus it means that the heat transfer in the railway ballast layer is dissymmetric for the two thermal conditions. In the engineering of railway construction in cold regions, if we take advantage of this characteristic of the heat transfer in the railway ballast layer, it is hoped that the permafrost under the railway embankment be protected and reinforced.

The research on permafrost in the Tatra Mountains, new results and geotechnical aspect

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key words: Tatra Mountains, permafrost, geophysics, evolution

Due to its relief, the Alpine belt of the Tatra Mountains is a place where geotechnical hazards occur. Another one, which so far has not been taken into account during construction works, is the existence of permafrost. Since the reconstruction of the cable railway to Kasprowy Wierch is being planned, geotechnical expert research has been conducted which was to determine its safety standards. This is the first document of this kind, where the presence of permafrost and the consequences that can follow from it are discussed. Two-dimensional DC resistivity tomography, two, and three-dimensional shallow and deep electromagnetic soundings were used for the purpose of the project. The data gathered indicates that permafrost is present from the peak of Kasprowy Wierch to the altitude of about 1850 m asl. The results also support the thesis on the existence of two layers of permafrost in the Tatra Mountains: the active one, connected with the present climate, which occurs on Kasprowy Wierch at the depth of about 1.2 to 4.0 m and the one of pleistocene origin. The depth at which the latter occurs depends on altitude above sea level, and ranges from about 20 to 40 m below the ground surface. The engineering structures connected with the reconstruction of the cable railway are based on solid granitic rock so the presence of permafrost will impact on the selection of appropriate materials that are to be used.

Chapter 11

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Chapter 12

Late Contributions

Thermal history, ice loading and inversion of the southwestern Barents Sea as revealed by basin modelling

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key words: Barents Sea, basin modelling, Hammerfest Basin, thermal changes, ice loading

The southwestern Barents Sea is a frontier area for petroleum exploration on the Norwegian Margin. The juxtaposition of the North Atlantic rift system with the borderlands of the Eurasian continental shelf makes for an unusual basin evolution with oil- and gas-prone petroleum systems. The area is home to giant gas fields and one of the largest known ocean floor gas hydrate deposits in the world. Since exploration began in the early 1980s, some 60 wells and 250000 km of seismic have helped define seven distinct plays in the petroleum systems of the region. Prospective drilling has largely concentrated on the three principal plays of the Hammerfest Basin, i.e. the sandstones of the Triassic, Lower to Middle Jurassic and Upper Jurassic to Lower Cretaceous. These have yielded giant gas discoveries, very little oil and evidence of significant inversion during the Late Cenozoic. These findings are typical of peripheral North Atlantic Margin basins that have undergone exhumation during the Cenozoic. At present, there is a consensus on the three principle episodes of Cenozoic exhumation in the region as having occurred during the Paleocene, Oligo-Miocene, and Quaternary respectively, and the amount of total erosion within the Hammerfest Basin as approximating 1000 to 1500 m. However, the relative severity of each individual episode and associated impact on fluid dynamics within the basin are poorly constrained. This modelling study aims to establish the sensitivity of the south-western Barents Sea petroleum systems to thermal, ice loading and isostatic changes during the Late Cenozoic. Here we present our initial findings for the Hammerfest Basin. Using a 2D basin modelling approach (PetroMod 2D, IES, Germany) a north-south section extending from the Finnmark Platform to the Loppa High has been tied to well data from the core area of Snohvit-Albatross-Askeladd. Available vitrinite reflectance and temperature data provide the constraints for calibration of the burial and thermal histories. Calibration studies focused on the individual effects of erosion timing and magnitude, heat flow history, and timing and thickness of glacial ice coverage. While it is not possible to achieve a good calibration using heat flow variations alone, the effects of erosion and ice coverage seem to result in similar results with respect to calibration to the available data. We are currently testing, and will report, the model response to the combined effects of these three model input variables.

Thermal regimes and degradation modes of warm permafrost on the Qinghai-Tibet Plateau

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key words: QTP, warm permafrost, ground temperatures, geothermal gradients, permafrost types, degradation modes

Warm (-1°C) permafrost on the Qinghai-Tibet Plateau (QTP) is characterized by shallow depths of annual zero amplitude of ground temperatures, small thicknesses, unstable thermal and moisture regimes, and widespread areal distribution. At present, the total area of warm permafrost is about $0.5 \times 10^6 \text{ km}^2$, or about 40% of total permafrost area on the QTP. Under a warming climate, warm permafrost has been retreating in marginal areas of permafrost distribution on the QTP during the past a few decades, which is indicated by general rising in ground temperatures, deepening of the maximum thaw penetration, and thinning or disappearing of permafrost layer(s). According to the differences in the intensity and rates of permafrost degradation, and shapes of ground temperature curves and trends of changes, warm permafrost on the QTP is divided into two types: conspicuously degrading warm permafrost and relatively stable warm permafrost. The former is further divided into four stages of degradation based on the features in the changes of ground temperatures at the permafrost table and shallow depths during the past several decades: (1) initial degradation, (2) intensive degradation, (3) vertical disconnection (talik), and (4) seasonally frozen ground (SFG). The division of 4 stages illustrates the evolution process from warm permafrost to the SFG. The degradation modes of warm permafrost on the QTP are analyzed using geothermal gradients, measured heat fluxes in soils, and large quantity of ground temperature data. The downward degradation of warm permafrost generally results in thawed sandwiches/nuclei, or vertical talik that can last a few years or more, disconnecting permafrost from seasonal frost action. The upward or simultaneous 2-directional degradation of warm permafrost would generally cause the thinning or complete disappearance of warm permafrost. In the margins of warm permafrost islands, lateral degradation also exists. Although with strong differentiations in locality and permafrost types, the combinations of 3 modes of permafrost degradation would ultimately transform warm permafrost into SFG. The present distribution of warm permafrost on the QTP is a continuation of permafrost degradation under an intermittently warming climate since the Holocene and the complicated interactions of local factors and permafrost. This project was supported by CAS 100 Talents Program "Research on the Stability of Linear Engineering Foundations in Warm Permafrost Regions under a Changing Climate", Subproject "Interactions of Climate and Permafrost along the Qinghai-Tibet Railway" of the CAS Knowledge Innovation Key Program "Interactions between Qinghai-Tibet Railway and Permafrost and Their Environmental Impacts", and "Environmental Changes on the Qinghai-Tibet Plateau since the Holocene and Their Relationships with Ecosystems" (KZCX3-SW-339-3).

Activation of technogenic rock glaciers movement

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key words: technogenic rock glacier, technogenic warming, rapid movement, technogenic hazards

A problem of natural and artificial slopes stability in the permafrost zone have been aggravated during the last decade. In many regions of the permafrost zone this problem is connected with global climate warming. In industrial centres of the North, the mobility of slopes is caused by negative technogenic warming. The largest technogenic rock glacier ("Post-1" waste dump) is located on the slope of Rudnaya Mountain, in Norilsk industrial area, north of Middle Siberia. In 1948 to 1973, a process of ground masses accumulation on the slope up to 8 to 120 steep formed a ground-ice-snow mixture. The natural surface was represented by boggy tundra and forest tundra with peat patches 1.5 to 2 m thick. A cover of ice-rich sedimentary rocks was from 0.1 m (upper part of slope) up to 7 to 12 m (lower part) thick with separate massive ice sheets up to 2 to 3 m thick. Mean annual ground temperature (MAGT) was -5 to 7 °C. Total volume of the rubble slope was $65 \times 106 \text{ m}^3$, its height was 120 to 130 m and the front scarp was 1.2 km long. In 1992, unpredictable movement of 2/3 total volume began. In 1999, MAGT was -1.5 to -2 °C so the durability properties of frozen massive decreased and its mobility increased. The increasing of MAGT is connected with the tendency to the permafrost degradation caused by technogenic reasons in the Norilsk industrial region. At the same time, a tendency to the climate warming in this region during last 70 years was not revealed. Movement of the rubble-slope was similar to natural rock glacier movement, front ridges on the underlying surface were formed because of ground excavation by the moving front. Speed of movement in 1992 to 1997 was from 20 to 30 up to 800 to 1000 mm per day. The replacement of technogenic rock glacier was from 180 up to 360 m. The front destroyed roads, buildings, pipelines and other objects. The front of technogenic rock glacier crossed the river valley and formed a water reservoir. Since 2001, a stable part of rubble-slope also began to move, meanwhile in the active part cracking into the blocks and rock-falls occurred. Up to 2004, total replacement of the front was 450 m. A spring flood in 2004 washed away the frozen dam and the debris flow destroyed a railway bridge and some other constructions. Another result of technogenic warming is a formation of landslides on the surface of dams enclosing reservoirs filled with liquid toxic waste and movements of other technogenic embankments.

Severe periglacial conditions during the last ice age in eastern Germany

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key words: periglacial structures, Niederlausitz, permafrost, ice-wedge casts

Extended sedimentary sections in the open-cast mines in the Niederlausitz (eastern Germany) reveal the occurrence of many phases of periglacial distortion during the Weichselian. The periglacial structures are expressed as small- and large-amplitude involutions, ice-wedge casts, frost cracks, and eolian sands and desert pavements.

At least at three different periods periglacial conditions were considerably more severe than in the more oceanic regions of western Europe:

- In Early Glacial times (c. 72 to 123 kyr BP) surprisingly two levels of large cryoturbations appear in fine and medium sands, associated with an occasional ice-wedge cast. Such features, at least pointing to discontinuous permafrost, are very exceptional in western Europe.
- The fluvial gravels that were deposited during the later part of the Middle Pleniglacial, starting with the Hasselo Stadial at c. 40 kyr up to c. 27 kyr, contain several levels of well-developed ice-wedge casts that are associated with large involutions at their top. These obvious indications for continuous permafrost contrast strongly with the generally occurring conditions of deep seasonal frost in western Europe at that time.
- Just below the dunes of late Younger Dryas age deep (probably syngenetic) ice-wedge casts are found. Their exact age is still under debate and may extend from the end of the Pleniglacial (c. 15 kyr) to the beginning of the Younger Dryas (c.12.5 kyr). Anyway they point to continuous permafrost when permafrost was absent or discontinuous in more western Europe.

It is concluded that, at given times, continental Europe suffered at least from colder winters than the western, more maritime regions did at the same latitude.

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