Quantification of permafrost degradation using calibrated 4D-ERT and consequent deformations in alpine bedrock.

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Slope failure from warming permafrost rockwalls is a hazard in alpine environments. For assessing the instability of permafrost-affected rockwalls, quantitative monitoring techniques are necessary to repeatedly and spatially measure permafrost distribution and link this with rock kinematics. We applied 4D laboratory-calibrated Electrical Resistivity Tomography along five parallel transect combined with mechanical deformation measurements using a tape extensometer across a permafrost-affected rock ridge in the Swiss Alps between 2006 and 2021. 1)Resistivity of saturated field samples was calibrated in a freezing chamber ranging from 20°C to−3°C. Resistivities above 13.25±1.75 kΩm indicated frozen rock. 2) A 3D inversion was applied to field data and the frozen volume was calculated by mesh filtering and integration (Scandroglio et al., 2021). All inversions confirmed a drastic degradation in the last 13 years with up to 65% less permafrost volume, well in agreement with the recorded air temperature increase. Inversion settings influenced the volumetric estimation on average by ±10%. The largest permafrost degradation was obtained without time-lapse constraints, data error estimation had strong influence on results. 1)Resistivity trends in the active layer show good correlation in time and space with kinematical changes recorded on the surface. Clear patterns could be distinguished between different slope orientations: while the summit of the ridge suffered small or no changes, the south slope showed important consistent deformations. Our applied techniques enable an accurate quantification of permafrost degradation dynamics and show that this is in strong connection with rock kinematics. Therefore, they are key tool in alpine permafrost rockwalls for detection of hazards, that are likely to be enhanced by future global warming.

Sedimentological Investigations at the Hickory Run Boulder Field, Carbon County, Pennsylvania

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Boulder (block) fields are open-work clast accumulations that occupy low-sloping surfaces. These features are thought to be the result of periglacial (cold, but nonglacial) mass-movement processes, many of which were active during the Last Glacial Maximum (~20-12 ka). There are two diverging hypotheses for the formation of boulder fields in both current and former cold regions. The periglacial interpretation emphasizes repeated cycles of mechanical weathering (e.g., freeze-thaw cycling and frost shattering) and periglacial mass movements (e.g., frost creep and gelifluction). Non-periglacial hypotheses emphasize weathering during the warmer and wetter conditions of the Neogene (~23-2.5 ma). The Hickory Run Boulder Field (HRBF), located in northeastern Pennsylvania, is the largest feature of its type in the eastern U.S.A. The research presented here uses relative weathering indices (clast dimension, fabric, and hardness) collected at the HRBF to investigate its geomorphic origins. Preliminary analyses of weathering indices show significant trends with distance downslope from local bedrock outcrops. Fabric analysis revealed the dominance of clast long-axis orientation parallel to the local slope, indicating a flow-type depositional environment. The size (120 x 550 m) and proximity (~1.5 km) of the HRBF to the Wisconsin glacial border and results of relative weathering indices support a periglacial interpretation for the formation of this striking boulder field.

Identifying Slope Instability in Mountain Permafrost Terrain: A Case Study in Colorado and Alaska

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Climate change and associated air temperature warming continues to offset equilibria in nature, including permafrost affected mountain slopes. Studies have shown an increase in the magnitude and frequency of mass movements in periglacial environments that are attributed primarily to permafrost degradation. Permafrost thaw-induced weakening of bedrock and colluvium poses a threat to human lives and critical infrastructure in periglacial environments. We aim to determine mechanisms of slope destabilization triggered by permafrost degradation and map thaw-vulnerable slopes to constrain the timing of future mass movement events.This study comprises two phases: first, we developed a GIS-based 3-D virtual model for landslide susceptibility in the San Juan Mountains (SJM). We applied a weighted-overlay method integrating six terrain variables: slope angle, slope length, aspect, lithology, vegetation, and soil drainage. This 3-D model was enhanced with a surficial-landform map constructed at a scale of 1:5,000. Our findings indicate that: 1) aspect, slope, and geology have the greatest relative influence on slope failure; 2) east and west-facing slopes are highly susceptible to landslides; 3) class 2 slopes (22.01°- 44°) are highly susceptible to landslides; and 4) talus and landslide deposits are the most widespread surficial deposits in the SJM. For the second phase of this study, we will examine how permafrost thaw may be impacting the susceptibility of mountain slopes to mass movement events in the central Alaska Range. We propose to implement the following interdisciplinary approach: 1) conduct field surveys at key road-accessible mass movements; 2) use a range of remote sensing techniques to map the location of mass movements across the study area; 3) establish a permafrost monitoring network across a suite of representative sites; and 4) integrate terrain parameters to model mountain permafrost applying the same approach used for the SJM region combined with the GIPL permafrost model.

Mountain permafrost in the Tropical Andes of Peru: the 0°C isotherm as a potential indicator

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In the tropical Andes of Peru very little is known about occurrence and extent of permafrost. Only recently more systematic studies have been initiated which focus on the high elevation sites of the mountain ranges (cordilleras) in Peru. In the framework of the first pioneering studies, and with the objective to improve the understanding of permafrost occurrence and characteristics, including occurrence of rock glaciers, we analyze here how mountain permafrost in Peru is correlated with the altitude of the O°C isotherm (ZIA). Climate change has generated an increase in air temperature and in the ZIA. These variables are associated to the state of mountain permafrost and any variation could cause changes in the presence of mountain permafrost. We focus on two different zones studies: The Cordillera Central (CC) and the Cordillera Volcanica (CV), the first located in the central zone and the second in the south zone of Peru. The study used air temperature data from 133 weather stations (2002-2016) to calculate the mean annual air temperature (MAAT), interpolated using a Multiple Linear Regression Model (MLRM) and digital elevation model (MERIT DEM). Occurrence and extent of 46 intact rock glaciers (IRG) and the global model of permafrost (Permafrost Zonation Index) were used to validate the results. The MAAT of CC has a minimum value around -0.6°C (R2 = 0.8) and a ZIA average of ~5152 m a.s.l. 56% of IRG are located above the ZIA. On the other hand, the MAAT of CV has a minimum value around of -4.4°C (R2 = 0.8) and a ZIA average of ~4861 m a.s.l. 60% of IRG are located above of the ZIA. The results show a greater variation of the ZIA in CC respect to CV, which could indicate a possible degradation of mountain permafrost in this mountain range.

Accelerated Motion Rates of Frozen Debris Slopes in the Brooks Range, Alaska, USA

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The Alaska Brooks Range supports a variety of periglacial mass movement features, including rock glaciers and frozen debris lobes (FDLs); yet few studies have focused on Brooks Range slopes and movement rates. These studies include initial investigations of rock glaciers near Atigun Pass in the 1970's and 1980's – with measured surface deformation rates of 0.03 to 0.1 cm/day – and detailed field investigations and remote sensing of FDLs beginning in 2008. Typical FDL surface movement rates from 1955 into the 1970's were 0.5 cm/day, with increasing rates of movement over the last 65 years. Here we present results of preliminary satellite-based interferometric synthetic aperture radar (InSAR) analysis for: 1) FDLs; 2) rock glaciers; and 3) a variety of slopes demonstrating evidence of movement expressed by transverse cracks or scarps. Using differential interferograms from L, C, and X-Band sensors from 2009 to 2017, we outlined areas of demonstrated movement with polygons in a GIS environment. We assigned characteristic movement rates based on measured displacement over the return period for a given satellite, and corrected the movement rates for satellite line of sight. During the years for which InSAR data were available, the average rates of surface movement for FDLs, rock glaciers, and other deforming slopes were 1.5 cm/day, 0.5 cm/day, and 0.4 cm/day, respectively. This preliminary analysis indicates that both FDLs and rock glaciers are moving faster now than in the past; and rates continue to increase, with some FDLs demonstrating velocities up to 5.8 cm/day, as determined through field measurements. These trends warrant a more comprehensive investigation, such as determining the increase in spatial extent of unstable slopes with time. Such findings will help to inform public and private agencies about ongoing changes and potential hazards related to warming and degrading permafrost slopes.

An increase of rockfall activity due to elevation dependent paraglacial and periglacial processes

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Rockfalls are important agents of erosion and a hazard in mountain regions. A compilation of rockfall erosion rates from the European Alps indicates that erosion rates increase with elevation. Previous studies have hypothesized one or more explanations for this relationship, such as an elevation-dependent increase in paraglacial processes such as debuttressing, or periglacial processes such as permafrost thaw or frost weathering. Herein we consider all of these processes in the first quantitative evaluation of the elevation-dependency on rockfall erosion rates.

Within a glaciated alpine valley in Switzerland we quantified the relationships between rockfall erosion rates to frost weathering, permafrost distribution and deglaciation. We monitored rockwall thermal regime using rock temperature loggers between 2016 and 2019 and used these data to run a thermo-mechanical frost cracking model and a permafrost distribution model. We reconstructed glacier retreat using historical images and glacial landforms. The volumes, and equivalent erosion rates, of rockfalls between 2016 and 2019 were assessed using repeat terrestrial laserscanning. Principal component analysis demonstrated that frost weathering, permafrost distribution and deglaciation all strongly influence the rockfall erosion rates measured. We found that erosion rates increase with increasing elevation, decreasing modelled mean annual rock surface temperature (MARST), and decreasing deglaciation age. Integrating the spatial distribution of MARST and deglaciation revealed that both periglacial and paraglacial rockfall-drivers increase with elevation.

The observed spatial erosion patterns at our case-study site correspond well to our compilation of regional rockwall erosion data for the European Alps. Therefore, our data suggest that a combination of paraglacial and periglacial processes drives rockfall activity and that both exert a primary control on erosion in high mountain areas. Our research contributes new understanding of alpine rockfall processes and informs efforts to mitigate rockfall hazards in a changing climate.

Development of Early Soviet Ideas About Cryoplanation Terrace Genesis

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Cryoplanation terraces (CTs) are underrepresented in the world geomorphological literature. This area of investigation appears to have been forgotten in contemporary Russian-language geomorphological and periglacial literature. The heyday of this topic was the period extending from the 1930s to the 1980s, and is associated with the names Obruchev, Boch, Krasnov, Bashenina, Sukhodrovskiy, Chaiko, and others who conducted field studies of these relief elements and incorporated them into process-oriented development theory. A primary source of early information are the papers of S.V. Obruchev, who described CTs in detail in his work in Chukotka and summarized both his own field materials and the accumulated experience of other scientists. Obruchev emphasized the division of genetic theories largely on terrace appearance. Here, we expand Obruchev's overview by treating theories developed during the 1940-1980 period.

Theories of terrace appearance can be divided into two main categories. The first and more archaic of these considers CTs as relics of past epochs associated with severe climatic regimes. Like many early 20th-century investigations, these interpretations were usually qualitative and not supported with substantial field data. This type of work attempted to explain observed phenomena largely through inference. Scientists attributed the formation of terraces to rivers, glaciers, and desert processes. The second category involved detailed field studies and is associated with Boch and Krasnov, Obruchev, and Suhodrovskiy. These studies involved ideas closer to the modern point of view typified in a 1969 monograph by the Czech geographer J. Demek, who worked closely with Soviet scientists. This viewpoint holds that terraces can be formed under contemporary climatic and geomorphic conditions, and should simply be divided into active and non-active groupings. Terminological concerns have been the subject of controversy throughout the history of cryoplanation research. The last major Russian-language study of cryoplanation landforms was a 1985 review monograph by M. Chaiko.

Early North American investigations in cryoplanated uplands

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Cryoplanation terraces (CTs) are series of large staircase-like landforms widespread in unglaciated uplands of the world's cold regions. They are especially prominent in unglaciated Beringia and are distributed zonally in uplands between the Lena and Mackenzie Rivers. Early U.S. Geological Survey and Geological Survey of Canada investigators charged with general geological and geographical surveys of Alaska and Yukon associated with the gold rush of the very early 20th century found the characteristics of these landforms to be inconsistent with the Davisian "normal cycle of erosion," then the prevalent geomorphological theory in North America. In particular, the lack of elevational accordance, the absence of alluvium on summits, and a dearth of residual soil on level upland surfaces were not consistent with criteria specified by W.M. Davis for the recognition of peneplain remnants. The publications of the early investigators such as Prindle and Moffit in Alaska reflect the confusion generated by these contradictions. After introduction and diffusion of the nivation hypothesis (erosion by late-lying snow patches) by Matthes and the periglacial concept by Lozinsky, a unified theory of CT formation was published in 1912 by Cairnes in Yukon and, apparently independently, by Prindle in Alaska in 1913. These papers outlined hypotheses of CT development consistent with current geomorphic theory, although the landforms remained controversial for many decades. In the mid-1930s Mertie employed altimetric evidence to assert the existence of a theoretical climatically determined geomorphic surface, analogous to the climatic snowline, that slopes gently from the Alaska-Yukon border to the vicinity of the Bering Sea. Russian CT literature did not have an appreciable effect on North American thought until the publications of Boch and Krasnov in the 1940s and 1950s. In the late 1960s the Czech geographer Demek surveyed the world literature, resulting in a consistent, unified view of CT development.

First evidence of rock wall permafrost in the Pyrenees (Vignemale peak, 3298 m a.s.l, 42°46'16" N / 0°08'33'' W)

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Permafrost is a relevant component of the Pyrenean high mountains, triggering a wide range of geomorphological cryogenic processes. While in the last decades, there has been an increase in frozen ground studies in the Pyrenees, there are no specific studies about rock wall permafrost, its presence, distribution, thermal regime or historical evolution. This work combines measured rock surface temperatures (from August 2013 to April 2016) along an elevation profile (four sites) on the north facing rock wall of the Vignemale peak (3298 m a.s.l, 42°46'16" N / 0°08'33'' W), and temperature modelling (CryoGRID2), in order to ascertain the presence of permafrost and to analyze its evolution since the mid-20th century. Simulations are run with various RST forcings and bedrock properties in order to account for forcing data uncertainty and varying degrees of rock fracturing. Results reveal that warm permafrost may have existed down to 2600 m a.s.l. until the early 1980s and that warm permafrost is currently found at around 2800 m a.s.l and up to 3000 m a.s.l. Cold permafrost may exist above 3100-3200 m a.s.l. Systematic investigations on rock wall permafrost must be undertaken to refine those results in the Pyrenees. The elevation shift of warm permafrost suggests the imminent degradation of permafrost in the Vignemale peak.

Ground ice content loss in different mountain permafrost environments inferred from repeated and re-processed geophysical measurements data

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Permafrost is currently warming on a global scale including not only polar but also mountain permafrost occurrences; many of these changes are operationally documented in national permafrost networks such as the Swiss permafrost monitoring network PERMOS. However, the warming trend is not uniformly distributed, as permafrost occurs in a large variety of complex landforms with different ground ice contents, surface material and therefore different thermal regimes (e.g. Etzelmüller et al. 2020).Geophysical techniques are used since a long time to spatially extend singular borehole data and add quantitative information about important permafrost properties other than temperature such as ground ice content. From the large variety of geophysical properties, especially electrical resistivity has been proven capable of accurately distinguishing between frozen and unfrozen soil due to its particular sensitivity to the presence of liquid water content. In combination with seismic P-wave velocity, quantitative estimates of ground ice and liquid water content have been presented for several permafrost environments using co-located electrical resistivity and refraction seismic tomography data (Mollaret et al. 2020). These approaches can also be applied in a monitoring context (Klahold et al. 2021, Steiner et al. 2021), however, so far only for singular and/or synthetic permafrost examples. Within a current pilot study funded by GCOS Switzerland, a focus is laid on the systematic archiving and reprocessing of historical geophysical measurements in permafrost regions with the aim to repeat these measurements and analyse them in a climate context. This contribution summarizes first results of this study showing up to 20-year long ground ice content changes in several permafrost occurrences in the Swiss Alps.

Mountain permafrost in the “Ojos del Salado” Volcano, Chile, advances and challenges

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The Andes mountain range and the Atacama Puna are ideal environment for mountain permafrost, and their associated landforms (i.e rock glaciers, protalus lobe, etc.), this landforms were mapped for this study. However, during the fieldwork it was possible to identify on pits, much more permafrost zones with ice content that does not present morphological expression. Therefore, it is imperative to have spatial distribution and behavior models in order to better understand it. The Cryosphere and Water Research Laboratory (LICA) of the University of Atacama has begun measurements that allow a better understanding of the mountain permafrost surrounding the Ojos del Salado Volcano (-27.11°S,-68.54°W). Since January 2017, the monitoring of the soil surface temperature (Sst) and at 10 centimeters depth (Dst), in altitudinal bands, at 5,000, 5,500, 6,000 and 6,500 masl, the temperature records were sampled every two hours. Additionally, studies have been carried out using geophysical surveys: ground penetrating radar (GRP), refractive seismic and electrical resistivity tomography (ERT), in the Llano de Piedras Pomez (-27.02°S,-68.69°W) near the volcano and at 5,000 masl. The results show that at 5,000 masl the average temperature for the entire period was 0.1 ° C (Dst) and -2.7 ° C (Sst), and at 5,500 masl it was -1.6 ° C (Dst) and -1.9 ° C (Sst). From the studies carried out with GPR, ERT and seismic, it appears that the permafrost layer with ice content could be more than 50 meters deep, with a potential aquifer under this layer. Considering the presence of ice in this mountain permafrost, it is an important water reserve due to its ice content, even more so in areas where it is the only water reserve. Therefore, it is essential to advance in a better understanding of the impact of mountain permafrost on the water resources available downstream.

Surface-Based Temperature Inversion Characteristics in Dissimilar Valleys, Yukon

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There is an interfingering of elevationally controlled and latitudinal permafrost in high-latitude continental mountainous regions of Yukon Canada. This is related to the occurrence of surface-based temperature inversions (SBIs) which significantly modify surface lapse rates (SLRs) annually. Therefore, it is essential in permafrost science to understand and quantify spatial and temporal variation in how SLRs are modified by SBIs annually. Particularly there is a need to review the modification of SLRs by SBIs on local valley-to-valley scales. In this research we aim to identify and quantify patterns of SBI characteristics in two proximal yet dissimilar central Yukon valleys. Investigation utilizes Elevational Transect Analysis (ETA) using sensors in valley bottoms and 100 m up slope to determine in-situ SLRs. Data from downscaled climate reanalysis products (GlobSim and ClimateNA) almost entirely missed hyper-inversions which produce SLRs that range from 0.46 °C 100 m-1 to 1.2 °C 100 m-1 annually. The magnitude of these hyper-SBIs were substantially underpredicted by recent modelling of surface air temperatures in this region as SLRs were predicted to be annually a maximum of 0.1 °C 100 m-1. Furthermore, assumptions of normal SLRs in valleys above treeline were found to breakdown in this terrain, although SLRs were more gently inverted than the treed valley. Assessment of SLR variation and microclimatic variability between the valleys yielded significant relationships of SLRs with wind speed, incoming solar radiation, and surface air temperatures. Whether these relationships between microclimate and SLRs in the two valleys are causal or covariant remains unknown. Finally, from monitoring of ground and depth temperatures at each site, permafrost is present at all locations except for the south face slope location. Presence of hyper-SBIs frequently throughout the year alongside the south facing aspect drove this recently conceptualized pattern of permafrost distribution.

Surface temperatures and their influence on the permafrost thermal regime in steep high Arctic rock walls on Svalbard

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Permafrost degradation and the effect on slope stability have been studied increasingly in recent years, especially in mountainous and sub-Arctic regions. However, the thermal regime of high-Arctic rock walls is still poorly understood and a better understanding of the occurring thermo-mechanical processes is needed.

This study presents four years of rock surface temperature measurements in steep rock walls on Svalbard, comparing coastal and non-coastal settings. For evaluation, we applied the surface energy balance model CryoGrid 3, taking into account modified radiative forcing in vertical rock walls.

Our results indicate that monthly RST in coastal cliffs are increased up to 1.5 °C compared to non-coastal rock walls, which can be traced back to higher air temperatures at the coast compared to inland locations, as well as long-wave emission by relatively warm seawater. Ice coverage on the fjord counteracts this effect. Consequently, sea ice loss might lead to higher RST in coastal cliffs during winter.

We calculated a surface energy balance of both coastal and non-coastal settings. The fluxes in summer and fall show just slight differences, while they differ significantly in winter and spring, when the water body of the fjord acts as an additional energy source for the coastal settings.

In this study, we present a unique data set of rock surface temperature measurements in steep rock walls in the high Arctic. With the surface energy balance model CryoGrid 3, we can analyze the influencing factors in coastal and non-coastal settings and the associated fluxes of the surface energy balance.

A Continental Permafrost Distribution Model for the South American Andes

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Currently, there is very limited information available on the spatial extent (horizontally and vertically) of permafrost in South America. However, as climate change has significant impacts on glaciers and associated diminishing effects on runoff during droughts, the potential role of permafrost as a substituting regulator and contributor of runoff through the thawing of potentially ice-rich ground, is controversially debated. To quantify this potential and evaluate whether permafrost degradation may even contribute to runoff, the spatial extent of permafrost in the South American Andes must be better modeled.

We introduce a new continental scale probabilistic permafrost distribution model that utilizes publicly available rock glacier inventories and parameters derived from the publicly available SRTM digital elevation model. Based on more than 14,000 rock glaciers mapped by the DGA in Chile and IANIGLA-CONICET in Argentina, a multi-parameter analysis was completed to formulate correlations between the probability for permafrost to exist and topography related parameters, such as elevation, slope angle, potential solar radiation, aspect, latitude and longitude. We run the model on more than 3.5·109 raster points using cloud computing to cover the full, >4000 km long extent of the South American Andes. The initial output was then upscaled to a raster resolution of approximately 300 m, subdivided into five probability classes (very low, low, medium, high and very high), representing different spatial probability ranges, and cleaned by applying filters within the ArcGIS package.

While the model should not be used on individual watershed scales, this new permafrost distribution model now allows users to estimate the potential extent of permafrost more accurately on a regional or national scale. For example, the model suggests that in Chile, north of 36°S, the area in which one of the five permafrost probability zones was identified covers about 5.5%. By applying the spatial probability classes used, it can subsequently be concluded that in this northern region of Chile, about 1.5 – 2.7% of the land area is underlain by permafrost.

Topographic and geologic controls on frost weathering in Alpine rockwalls

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Frost weathering is a periglacial process and a major control on rockwall erosion in alpine environments. To quantify climatic control by frost weathering on mountain erosion by frost weathering and potential effects of climate change on future erosion, topographic and geologic controls on frost cracking need to be unravelled. Therefore, we installed six temperature loggers along an elevational gradient ranging from 2500 to 3200 m in crystalline rockwalls in the Swiss Alps and 35 loggers ranging from 1600 to 3000 m in rockwalls of the North-calcareous Alps (NCA) including permafrost-affected rockwalls. We used recorded rock temperature data to run thermo-mechanical frost cracking models and compare resulting simulated frost cracking to quantified fracture patterns. Our results from the Swiss Alps show the highest frost cracking occurs in permafrost-affected north-facing rock walls, which is consistent with observed fracture and rock strength patterns (Draebing & Mayer, 2021). In contrast, the model results indicate an even higher frost cracking in all south- exposed rockwalls, which is contrary to measured rock properties and could be an effect of overestimated rock moisture availability in the model. Our data suggest that elevation and exposition of rockwalls affects rock temperature and permafrost distribution and, therefore, controls topographic frost cracking patterns is strongly depended on elevation and exposure of rockwalls, which affects temperature and permafrost distribution. As climate change potentially increases rock temperatureinfluences this dependency, frost cracking and therefore resulting rockfall will shift to higher elevations (Draebing & Mayer, 2021). To unravel topographic effects due to aspects and geology, we are currently ongoing quantifying frost weathering patterns in the NCA combined with rock moisture measurements on south- and north- exposed rockwalls in the NCA. This data We will also gain aresolve higher resolution in elevation dependency of frost cracking patterns towards permafrost- affected rockwalls in more detail.

First experiences from a high Arctic, off-grid, solar powered time-lapse ERT system

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After rock slope failures in the Karrat fjord of West Greenland led to a tsunami with catastrophic consequences for nearby settlements, there has been an increased focus on rock slope-related geohazards in Greenland. As part of these efforts, the Thawing Mountains project aims to improve our understanding of the thermal regime and permafrost distribution in rock slopes in the Vaigat area of central West Greenland. This talk presents the first experiences from a completely off-grid, solar-powered Electrical Resistivity Tomography (ERT) system installed in the summer of 2021 on a basaltic plateau and vertical rock face to collect time-lapse resistivity and IP data. The purpose of the experiment is to assess the feasibility of operating such a system under remote, high-Arctic field conditions, to obtain insight into the resistivity-temperature relationship for the basaltic rocks in the region, and to evaluate to which extent such resistivity and IP datasets are useful in the evaluation of freeze-thaw processes in the rock mass.

The field site is located on the North-East coast of Disko Island, on a plateau at approximately 1000 m elevation. The established profile has a total length of 160 m, with the first approximately 30 m installed down a vertical rock face. Electrodes are equidistantly spaced 2 m apart and consist of expansion bolts with a bentonite slurry to improve contact. The instrumentation is powered by solar panels with a total rating of 960 Wp connected to a battery bank of 550 Ah. The station measures daily profiles during summer but is scheduled to gradually reduce measurement frequency over the fall as daylight becomes scarce. Basic results and health data are transmitted from the station regularly over a cellular connection which also allows modification of collection settings. However full data download will only occur upon station visits.

20-year long permafrost evolution at the long-term monitoring site Stockhorn, Swiss Alps by combining borehole temperature, electrical and seismic monitoring data

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The Swiss Permafrost Monitoring Network (PERMOS) collects routinely the surface and subsurface temperatures, meteorological data as well as geoelectric measurements at different sites in Switzerland to observe and monitor the state and the change of the permafrost (PERMOS, 2021). The Stockhorn plateau, an east-west oriented crest located at an elevation of around 3’410 m a.s.l. in the Swiss Alps, belongs to this network. The bedrock plateau is covered by a thin debris layer (Marmy et al., 2016) and shows considerable small-scale variability with up to 1°C differences in permafrost temperatures evidenced by results from two boreholes that measure temperature since 2000 to a depth of 17m and 100m (PERMOS, 2021). In addition to standard borehole temperature monitoring, regular geoelectric and seismic surveys are performed since 2005. The particularity of this site is a continuous increase of temperatures at depth and an increase of the active layer thickness by 2m during the past 20 years. Within the uppermost 10 meters, the geoelectric data show a decrease of resistivities of more than 30% in 13 years, suggesting a substantial thawing of permafrost during this period. The advantage of the additional collocated seismic measurements is the ability to quantify ground ice content and its changes over time (Wagner et al., 2019; Mollaret et al., 2020). Coupling geoelectrical and seismic data can therefore improve the differentiation between the different phases (rock, ice, water, and air) present in mountain permafrost if suitable petrophysical relationships are used. Using this combined electrical and seismic data set we will estimate the ground ice content losses over the past 1-2 decades and discuss the potential reasons for the pronounced spatial variability over comparatively small spatial scales.

Preliminary Interpretations from a Landslide Inventory in Interior Alaska

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Landslides are geologic hazards that threaten human life, infrastructure, and property. To mitigate these threats, a landslide inventory map must first be developed. We present preliminary interpretations – as related to permafrost – of the first landslide inventory in the Fairbanks North Star Borough (FNSB) within Interior Alaska. The inventory was developed using Light Detection and Ranging (LiDAR) digital elevation models (DEMs), and validated with field checks of landslides accessible on public lands along the road system. The inventory provides a landslide spatial distribution that we can correlate to types of soil and/or bedrock, slope, aspect, and permafrost distribution. Future work will include sampling of selected landslides to determine age using radiometric dating. Without that in-depth analysis, however, we are able to determine relative age of landslides using morphology, vegetation, and cross-cutting relationships with infrastructure. Field checks indicate that most of these landslides are prehistoric (i.e., predating the first significant anthropomorphic surface changes that occurred approximately 100 years ago in Interior Alaska). Some are historic, and others exhibit on-going movement as evidenced by leaning and split trees, and fresh cracks and scarps. One currently-moving landslide has a morphology and surface features characteristic of frozen debris lobes in the Brooks Range of Alaska, suggesting that movement within the permafrost is tied to temperature and water pressure. Many of the prehistoric landslides that occurred within Quaternary loess deposits often lack clear head scarps and flanks due to excessive gullying, yet retain distinct toe deposits. We provide examples of landslides of 1) different ages and 2) mechanisms of movement, and 3) morphology as seen in LiDAR and during field checks, and explore potential triggers of the prehistoric landslides.

Characteristic Periglacial Terrain: Multi-Scale Hypsometric Analysis of Cryoplanated Uplands in Eastern Beringia

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Cryoplanation terraces (CTs) are large step-like erosional landforms conveying the impression of giant staircases. They are thought to be formed through locally intensified sediment production and transportation associated with late-lying snowbanks. CTs are ubiquitous in unglaciated Beringian uplands and are found on ridgecrests and hillsides throughout the region. They are surrounded by cryopediments, beveled lower-angle surfaces of sediment transportation dominated by periglacial fluvial and mass-movement processes. Viewed as an integrated landscape, these landforms impart a distinctive geomorphic form that can be described by the term “cryoplanated terrain.”

General geomorphometry is concerned with the geometric form of the continuous land surface and can be useful for identifying topographic “signatures.” Hypsometry, a branch of geomorphometry concerned with area-elevation relationships, has found numerous applications in several subfields of geomorphology, but has not been used extensively in published periglacial work. In this study, hypsometric analysis was applied to several unglaciated and glaciated locales in Alaska’s Yukon-Tanana Upland and Indian River Upland physiographic sections, areas of eastern Beringia in which cryoplanation landforms are extensive. At local and intermediate scales, never-glaciated areas in this region have hypsometric signatures distinctly different from those of glaciated areas. Comparison with terrain in the southwestern USA revealed substantial differences between the upland periglacial terrain of Beringia and warm-desert geomorphic landscapes, casting doubt on a published suggestion that cryoplanation landforms in high-latitude mountains are inherited from past intervals of warm and arid environmental conditions. At local and intermediate scales cryoplanated terrain exhibits a distinctive convex-upward hypsometric signature very different from the concavity of typical fluvial, desert, or glaciated terrain. We conclude that characteristic upland periglacial landscapes exist in unglaciated areas of Beringia and can be recognized through objective, quantitative methods.