Geochemical insights into a changing Arctic carbon cycle

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Circum-arctic frozen soils contain twice as much organic carbon as is currently present as greenhouse gases in the atmosphere. When permafrost thaws, the soil organic carbon within it becomes available for remobilization and introduction into inland and coastal aquatic systems. Here it can either be degraded, generating greenhouse gases, or be transported and buried in short and long-term reservoirs, attenuating greenhouse gas emissions. Geochemical techniques (e.g. isotopes, biomarkers) can be used to identify the quantity and quality of organic matter that is, upon thaw, transported from permafrost soils to streams, rivers, and ultimately the ocean. Here I will present the results of a selection of studies by me and many colleagues to provide insights into provenance, degradation potential, transport routes and ultimate fate of carbon in thawing permafrost.
Active subglacial chemical weathering processes are indicated by mineral phases from rock and sediment samples collected at a blue ice moraine at the Mt. Achernar moraine complex. Widespread subglacial weathering would have implications for East Antarctica’s impact on global climate and biogeochemical cycles. At the moraine, sediment progressively accumulates with distance from the active ice, with the oldest sediment exposed for $>500$ ka. Samples of freshly emerging fine sediment and cobbles, and fine sediment of progressively greater age, were collected. Sample aliquots were analyzed for clay and mineral content by X-ray diffraction and for salt, carbonate, oxyhydroxide, and oxide content by sequential extractions.

Salts and some carbonate species were largely absent from the rock and fresh sediment but developed in increasing abundance with age in the moraine sediment, due in part to atmospheric deposition. Oxides, oxyhydroxides, and clay minerals do not significantly increase in abundance with age in the moraine. Declining magnetic susceptibility suggests that magnetite may be oxidized with progressive surface exposure.

Substantial differences were observed between the rock and the freshly emerging sediment, suggesting that the latter cannot be merely a mixture of crushed rocks. In particular, smectite occurs in greater abundances in the emerging sediment than in any of the rock types represented in the moraine cobbles. Chlorite, kaolinite, and illite are comparably abundant in the moraine sediment and underlying sedimentary rocks. Oxides and oxyhydroxides are more abundant in the moraine sediments than in most (though not all) of the underlying rock.

We propose that subglacial formation of smectites and possibly some oxyhydroxide species best explains the observed data. Because clays, oxides, and oxyhydroxides do not appreciably accumulate under current interglacial conditions, either pre-glacial or subglacial formation is suggested. Pre-glacial soils are unlikely to be preserved in actively eroding subglacial environments and the represented rock types are not sufficiently rich in weathering products to produce the moraine sediment. Therefore, subglacial formation of weathering products is the preferred interpretation.
Relationship between Indian summer monsoon and melting Himalayan glaciers

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Melting glaciers and rainfall from the Indian summer monsoon (ISM) are the two major sources of potable water in the Indian subcontinent. However, how ISM influences the Himalayan glaciers is still uncertain, despite the fact that ISM is responsible for 80% of annual rainfall (300-400 cm yr⁻¹) over the south-facing slopes of the Himalaya. Here we have used stable-isotope (δ¹⁸O, δD) compositions of stream water to quantify the relative contributions from glacial melt, precipitation (snowmelt and rainfall), and groundwater over various stages of the monsoon’s annual cycle. Stream water samples were collected during pre-monsoon (April-June), monsoon (July-September) and post-monsoon (October-November) periods of 2014, 2015, and 2016 in the headwaters of the Ganges River. Moreover, groundwater samples were collected from all over the basin. The δ¹⁸O and δD compositions of river water show large seasonal variations. A site- and season-specific three-component isotope-mixing model was constructed using a Monte Carlo framework and matrix inversion technique. Results show that the post-monsoon season (October-November) has the highest glacier melt proportions (83±11%), as compared to pre-monsoon (53±7%), and monsoon (40±6%) periods. This is contrary to conventional wisdom that proportions of glacial runoff are highest during summer, i.e. the pre-monsoon season (April-June) when temperatures are high. This observation cannot be readily explained by temperature variability or other factors. We hypothesize that latent and sensible heat released from rainfall will act as drivers that enhance glacial melting. Energy balance calculations support this hypothesis, and our calculation reveals that rain-induced glacial melting could contribute ~8% to 30% of the total glacial runoff. It appears that Monsoon rainfall is a significant driver of Himalayan glacier melt.
Arctic soil carbon: does permafrost carbon matter for future climate feedbacks?

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Recent trends of increased global temperatures are amplified in the Arctic, where the soil contains twice as much carbon as is currently in today’s atmosphere. This enhanced Arctic warming is projected to thaw permafrost and to increase microbial activity and may release large quantities of soil carbon to the atmosphere. To examine soil carbon dynamics, we studied the in situ microbial carbon usage in mineral and organic soils from a dozen locations in Svalbard, the Canadian high Arctic and various locations in Alaska. We measured the natural abundance radiocarbon in microbial biomarkers of the viable microbial community as phospholipid fatty acids (PLFA) and the radiocarbon content of the bulk soil organic carbon. The premise of this technique is that membranes of the viable microbial community take on the isotopic value of the carbon the microbes are eating. Our results indicate that at all sites, the amount of soil carbon dramatically decreases with depth while the radiocarbon age of the soil organic carbon increases with depth. We also found that the abundance of microbes decreased exponentially with depth at all sites. This means that most of the microbes inhabited the upper 10s of centimetres of the soil profile and there were far fewer microbes at depth. Additionally, we found that regardless of the soil profile studied, the microbes preferentially used younger carbon than the soil organic carbon, which suggests that only a fraction of the soil organic carbon pool is accessible and not all permafrost carbon will be vulnerable to microbial degradation. Collectively, these results indicate the largest fluxes of carbon from microbes will be from the surface soils that contain the most and youngest carbon. Additionally, as the Arctic warmed and subsequently greens, the pool of young surface carbon will continue to increase thereby minimizing the release of remineralized deep, old carbon.
Soil biogeochemical processes under freeze-thaw cycles using a process-oriented experimental approach

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The ongoing displacement of climate zones by global warming is increasing the frequency and intensity of freeze-thaw cycles in soils at middle and high latitudes. Repeated freezing and thawing of soils changes their physical properties, geochemistry, and microbial community structure, which together affect ecosystem functioning and the biogeochemical cycling of carbon and nutrients in aquatic and terrestrial environments. A mechanistic understanding of how freezing and thawing influence soil respiration, greenhouse gas emissions, and leaching of nutrients to groundwater is necessary to predict how soil and water resources will respond to climate change. In this presentation, we present a novel approach, which combines the acquisition of integrated physical, chemical and microbial data in a newly-developed soil column system in which simulates realistic soil temperature profiles during freeze-thaw cycles. Surface and subsurface changes to gas and aqueous phase chemistry are measured to delineate the pathways and quantify soil biogeochemical processes during freeze-thaw cycles. The results indicate that the time-dependent carbon and nutrient dynamics are influenced by a combination of two key factors. Firstly, fluctuations in temperature and oxygen availability affect soil geochemical and microbial activities. Secondly, the recurrent development of a physical ice barrier prevents exchange of carbon and nutrients between the soil and atmosphere during freezing conditions; removal of this barrier during thaw conditions increases the rates of carbon and nutrients leaching and production. During freezing, oxygen levels in the unsaturated zone decreased due to restricted gas exchange with the atmosphere. As the soil thawed, oxygen penetrated deeper into the soil enhancing the aerobic mineralization of organic carbon and other nutrients. The results from this process-oriented experimental approach will help the interpretation of freeze-thaw processes in cold climate ecosystems and the prediction in models coupling soil processes to the global carbon/nutrient cycle and climate.
A Pan-Canadian study of Optical Properties of Dissolved Organic Matter in the Active Layer and Permafrost

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Permafrost soils store the greatest amount of terrestrial organic carbon on Earth [1]. Permafrost degradation associated with Arctic warming may enhance microbial decomposition of surface and deeply stored organic matter and increase the export of dissolved organic matter (DOM) to aquatic systems [2]. In this study, we focus on determining the composition of the water extractable DOM in the active layer and permafrost to better understand the permafrost carbon feedback to climate change.

We investigated 25 soil cores from the active layer and uppermost permafrost from 9 sites across the Canadian Arctic, covering sporadic to continuous permafrost regions. We analysed water extracts of these soils for dissolved organic carbon, nitrogen and inorganic nitrogen, and the composition of DOM was characterized using UV-Vis absorbance, fluorescence measurements and parallel factor analysis (PARAFAC).

The optical properties of the DOM differ between the active layer and permafrost layers and depend on permafrost nature. At all sites, the uppermost meter of permafrost is characterized by high contents of fresh and unhumified DOM while the overlying active layer is enriched in high molecular weight humic compounds. Our PARAFAC modelling shows that ~30% of the DOM in mineral permafrost samples is comprised of low molecular weight humic-like components. By contrast, protein-like components are particularly common in organic permafrost samples, accounting for up to 90% of the total fluorescence in sites located in the southern boundaries of the permafrost region.

Our findings suggest that permafrost degradation across Canada has the potential to release substantial amounts of fresh and relatively unhumified organic compounds. This pool of newly available DOM will likely be labile and may amplify the permafrost carbon feedback to climate change.

Life on Earth flourishes in the presence of sunlight and water. However, 10% of Earth’s surface is covered by ice and a growing body of evidence supports the presence of active ecosystems in subglacial environments. The lack of light energy leads to microbial metabolism and biomass being sustained through chemical energy (chemosynthesis), gained from the oxidation of inorganic substrates or detrital organic matter. Subglacial Lake Whillans (SLW), a shallow (~2 m deep) lake beneath 800 m ice cover is one of more than 400 subglacial lakes known to exist under the Antarctic ice sheet. SLW was chosen to investigate links between microbial community structure, function, and geochemistry in a deep subglacial environment. Biogeochemical parameters from the SLW water column and pore waters revealed water is primarily sourced from basal-ice melt with a minor contribution from seawater that reaches a maximum of ~6% in pore water at the bottom of the sediment core. Silicate weathering products dominate the crustal (non-seawater) component of lake- and pore-water solutes. Chemical affinity calculations performed on the aqueous chemistry data allowed the available chemical energy for potential metabolic reactions in SLW to be determined. This revealed heterotrophic metabolisms utilizing acetate and formate as electron donors yielded less energy than chemolithotrophic metabolisms when calculated in terms of energy density which supports experimental results that showed chemosynthetic activity in excess of heterotrophic activity.
Biomarker and stable isotope analysis linked to methane cycling in Lake Untersee, Antarctica

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Lake Untersee, in East Antarctica is a perenially ice-covered lake (2 – 4 m) consisting of two basins; a well mixed oxic basin ca. 160 m deep and a smaller, anoxic basin ca. 100 m separated by a sill at 50 m depth. Analysis of microbial phospholipid fatty acids (PLFA) and ether lipids (archeol and GDGT-0) and their isotopic compositions was used to constrain methane cycling and the recycling of carbon within the anoxic basin water column and sediments.

High concentrations of methane (8.5 mmol/L) were present within the bottoms waters of the anoxic basin, derived from sedimentary methanogens as shown by archaeol concentrations of 25 µg/g. Methane concentrations decreased slightly towards the anoxic/oxic interface. Methane is derived from CO2 reduction based on its isotopic composition (δ13C: -50‰; δD: -438‰ at 95m) and that of the corresponding DIC (δ13C ca. +25‰ at 95m). Methane oxidation occurred within a suboxic transition zone present at ca. 70 – 80m. Within this zone [CH4] decreased from 7.3 mmol/L at 85 m to 0.02 mmol/L by 72 m. Concurrently, δ13C-CH4 values increased, from -51‰ at 85m to -40‰ at 72m, consistent with CH4 oxidation.

PLFA concentrations varied throughout the water column, but generally increased with depth. Between 20 and 72m, values ranged from 0.2 – 3.8 µg/L (72m: 3.5 x 105 cells/L). Higher biomass was observed at the bottom of the suboxic zone: 78 and 80 m were 8.5 and 12.9 µg/L respectively (80m: 1.3 x 106 cells/L). The increase in PLFA concentrations at the bottom of the suboxic zone, combined with depleted δ13CPLFA values (δ13C-16:1: -36.8‰ at 76m) was consistent with a methanotrophic community supported by methane derived from the sediments. PLFA concentrations of 57 µg/g (5.4 x 109 cells/g) and δ13CPLFA values of ca. -20 to -25‰ within the sediments suggests an active heterotrophic population producing CO2 via organic degradation supporting the methanogenic community.

Identification of biomarkers created by the modern, viable bacterial and archaeal community is fundamental to understanding the preservation of biomarkers within palaeolacustrine environments that are relevant analogues to early Earth and Mars.
The Great Melting: the unstoppable contest between snow physics, soot, mineral dust and microbes

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The speed and extent of melting of the Greenland Ice Sheet (GrIS) and the linked surface energy- and mass balance variations are driven by changes in surface albedo. These changes are the response of the ice sheet surface to an as yet not well quantified interplay between physical, chemical and biological parameters that all increase the darkening of the GrIS surface. The drivers behind the change in albedo is derived from a combination of changes in snow and ice properties and an increased amount of light absorbing impurities (LAI). Although, traditionally LAI were assumed to be solely Aeolian delivered black carbon and mineral dust, recently bio-albedo factors have been recognized as important[1,2]. Through the Black & Bloom project we combine surface, airborne and satellite based measurements of the role of inorganic and biological particulates in the GrIS darkening. We quantify the interactions between microbes and minerals in the highly dynamic snow-ice transition zones, where snow and ice algal blooms will, in contrast to black carbon and mineral dust, more rapidly respond to the ever-increasing changes in the timing and duration of the annual melt seasons. As climate warms and melt seasons become longer, these biological-inorganic interactions will increasingly contribute to the darkening of the GrIS, yet these effects are currently not included in predictive numerical models.

Microbial CO$_2$ production at the Greenland Ice Sheet margin

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Melting of the Greenland Ice Sheet could have important implications for local and global carbon (C) cycle feedbacks [1-3]. Quantifying these feedbacks is essential for predicting future climate change, as well as understanding linkages between ice sheet decay and climate change in the geologic past. Here, we sampled supraglacial streams and subglacial discharge from the Russell Glacier in western Greenland during the 2014 and 2015 melt seasons. We synthesize geochemical (e.g., $\delta^{18}$O, $\delta^{13}$C, and $\Delta^{14}$C) and microbiological (cell counts and DNA sequencing) observations to develop a more comprehensive understanding of C cycling at ice sheet margin.

We find that concentrations of dissolved organic carbon in supraglacial streams are highly heterogenous, while concentrations of dissolved inorganic carbon (DIC) are largely uniform and derive from a spatially and temporally constant mixture of microbially-sourced C (~25%) and atmospheric C (~75%). Supraglacial inputs account for approximately 40 – 50% of subglacial DIC. The remaining DIC derives from subglacial microbial CO$_2$ production and carbonate weathering. Surveys of the microbial community in the subglacial environment primarily find anaerobic heterotrophs and C1-oxidizers (methanol and CH$_4$). Methanogenic archaea are present but not abundant. This data, combined with isotopic observations, suggest that CH$_4$ oxidation is likely a negligible input to the subglacial DIC pool. Ultimately, we find that early season snowmelt and periodic rain events deliver young, organic C to the subglacial environment. These pulses of organic C drive heterotrophic microbial respiration, with the cumulative effect being a seasonal shift in the source of basal DIC, from microbial- to carbonate- dominated. We suggest that the magnitude of microbial CO$_2$ produced by this mechanism could increase in a warming world. Upon discharge to the proglacial area, some CO$_2$ may evade to the atmosphere and act as a positive feedback to climate warming, while the remainder will impact coastal waters.

Particulate geochemistry and algal growth as factors driving melting of the Greenland Ice Sheet

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Ablation rates of the Greenland Ice Sheet (GrIS) are closely linked to the albedo of the ice sheet surface. Light absorbing impurities (LAI), including black carbon (BC), mineral dust, and microbes, lower the ice sheet albedo and increase rates of ablation. BC is the amorphous carbonaceous product of hydrocarbon-based fuel combustion. Although BC is present in low concentrations in the atmosphere over the GrIS, it can still reduce the albedo of the ice sheet surface due to its tendency to be highly absorbent of solar radiation.

The ability of BC to lower albedo is compounded by its coexistence with allochthonous mineral dust, which can increase the darkening effect of the BC through optical lensing.³ The mineral dust also provides a substrate for growth of snow and ice algae². Detailed mineralogical, microspectroscopic, elemental, and isotopic techniques were used to characterize aerosol and surface LAI samples collected during the 2016 melt season. Nutrient availability was evaluated and linked to algal growth, a relationship that will become more important as a warming climate will increase the duration of the summer algal growth season. Here we present a preliminary assessment of the complementary and combined roles that BC, mineral dust, and pigmented algae have in changing the ‘bioalbedo’ parameter³ used for modelling the darkening of the GrIS surface. These results will aid in disentangling the biogeochemical controls on the albedo of the GrIS.

Novel microbial communities in subglacial (dark) permafrost

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At Bird Brain Cave, a subglacial conduit network allows access to permafrost sediment below Bird Glacier (Fuglebreen, Svalbard, Norway). In order to understand microbial processes in the subglacial permafrost, we sequenced 16S rRNA gene tags in sediments from the cave entrance to the most distal cave passages along the water flow path. Whereas fluvial sediments are rapidly transported through the passage network, permafrost exposed in the subglacial conduit walls has been buried for several thousands of years and exposed to the cave atmosphere for less than a year. The microbial community composition of the sediments had two contrasting patterns. In fluvial sediments, the most abundant OTUs reflect an origin in the surface environment, including strains of the cosmopolitan periglacial cyanobacterium Leptolyngbya (17-21%), globally wind-distributed Polaromonas spp. (10-18%), and novel genera and species of Actinobacteria (12-20%) and Bacteroidetes (5-35%) common in soil and known for complex organic polymer degradation. In contrast, subglacial permafrost sediments had extremely high taxonomic novelty and a low abundance of the surface-derived taxa named above. They contained primarily members of novel Chloroflexi (16-31%), WS3 (0-17%) and Gemmatimonadetes (10-12%) orders and representatives of a novel Acidimicrobiales family (0-7%).

Based on the assumption that the subglacial sediments have only recently been exposed to oxygen or organic matter inputs from the surface, we hypothesized that autotrophic pyrite oxidation is likely one of the primary microbial metabolisms. This is consistent with our observation that Gallionella spp. were major populations (1-16%) in both fluvial and permafrost sediments. We retrieved little to no evidence for a methane cycle. Based on the high degree of taxonomic novelty in the dark permafrost sediments, additional inferences about metabolic processes beneath the glacier await, and will be informed by both geochemical analyses and omics approaches.
On the basis of the great information the main crigeochemical principles were formulate.


1. When ever possible on the Earth's surface low temperatures some, part of the water is in a liquid state. This can either be volumetric moisture in the form of concentrated brine, or film moisture in the intergranular space of rocks or ice. The freezing point depression of water in fact, and in another case caused by a decrease in chemical potential due to the binding of water molecules to mineral surfaces or dissolved substance. Therefore, the solute and the surface of the mineral particles are in a sense competitors. The presence of liquid water determines the possibility of chemical reactions at low temperatures in the system "water – rock". This concentration of solutions in the field of negative temperatures helps intensification chemical reaction.

2. The mobility of chemical elements at low temperatures other than positive. Thus, the mobility of sodium, calcium, zinc, cobalt in the permafrost decreases and of bismuth, tin, antimony, arsenic, waist, mercury, silver, chromium, beryllium, aluminum, iron, titanium increases. Some information on the mobility of chemical elements in seasonally-users can find all the layer of permafrost may carry data on their oreolah scattering.

3. The intensity of the processes of chemical weathering at low temperatures increases due to exothermic effects of the reactions; the temperature fluctuations inside the negative region; electrochemical phenomena; cryogenic concentration of the leaching solutions; catalytic effects in complex solvents.

4. Frozen, contains ice rocks are not impervious to concentrated solutions. The speed of gravity migration of such solutions according to our experimental data and estimates by other authors is around 15 – 20 cm per year in the absence of fracture. At about the same speed nonfreezing solutions can move up to the surface due to the capillary forces. The predominant direction of moisture movement depends on the state of the earth's surface (evaporation).

5. By freezing the aqueous solution at the water-ice occurs the jump of the electric potential, the magnitude of which depends on the composition of the solution. At some specific composition of the solution (for each system) the interfacial potential gradient disappears. This condition is called "point of zero charge". In the process of freezing dilute solutions there is a potential of freezing, which leads to the formation of extremely concentrated solutions of film as a result of redistribution of ions between liquid and solid phases (the effect of Workman – Reynolds).

6. Specifics crigeochemical systems and processes is the reason for the formation of a kind of zoning in the composition of the pore waters, and secondary minerals in cryogenic weathering crusts and the oxidation zones of ore deposits. For cryogenic oxidation zones of ore deposits characterized by the formation of minerals with water of crystallization.

7. At negative temperature (if constant) the leaching process in the "solution – rock" takes place at a constant concentration of the reagent that is provided by the process of cryogenic
The iron isotope composition of Northern Hemisphere glacial systems

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The iron stable isotope composition of subglacial streams draining the Greenland Ice Sheet (GIS) have been shown be highly variable, with dissolved load δ⁵⁶Fe [δ⁵⁶Fe, ‰ = (⁵⁶Fe/⁵⁴Fe)sample/(⁵⁶Fe/⁵⁴Fe)IRMM-14-1) x 10³] ranging from 0 to -2.1 ‰ [1]. Here we expand this data set, by systematically investigating the δ⁵⁶Fe compositions of dissolved loads, suspended sediments, and sediment leachates from glacial and proglacial environments, draining geographically and geologically diverse Northern Hemisphere glaciers. Overall, glaciers draining the Juneau Icefield (JI, Alaska), and the Columbia Icefield (CI, Canada) have fairly invariable δ⁵⁶Fe compositions with both dissolved loads and suspended sediments ~0±0.2 ‰.

We utilized leaching techniques that specifically target different Fe-pools within suspended sediments: (i) amorphous Fe (oxy)hydroxides, (ii) crystalline Fe (hydr)oxides, and (iii) residual-Fe, from the GIS, JI and CI sites. Overall, the amorphous (oxy)hydroxides, which represent the most ‘potentially bioavailable Fe’ [1] are isotopically lighter than both crystalline and residual pools by ~0.1 ‰. Nevertheless there is overlap between the extracted pools, with all leaches and residual Fe pools falling within δ⁵⁶Fe ~0±0.2 ‰.

The experiments above define ‘glacial end member’ compositions, which may not describe the δ⁵⁶Fe composition and/or flux of Fe that is delivered downstream to the oceans. Therefore we additionally present two short downstream transects of Fe and δ⁵⁶Fe from two outflows draining the south (Qoorqup Sermia) and southeast (Glacier ‘G’) margins of the GIS, with a late melt season record of δ⁵⁶Fe from the Qoorqup Sermia. Where concurrent measurements have been made, we place the glacial δ⁵⁶Fe compositions in the context of δ¹⁸O(SO₄) and δ³⁴S(SO₄) analyses and microbial metabolic function.

[1] Stevenson et al., Gold2016:abs:1718
Title of poster: Ionic content and behavior reflecting changes in an Alaskan glacial hydrological system during the summer melt season.

Hypothesis: Ion chemistry reflects timing of changes in hydrological system/subglacial environment of Wolverine Glacier.

Abstract of poster (300 words maximum):
Glacial meltwaters contribute nutrient loads that are required by downstream ecosystems to thrive. How glacial hydrological systems respond to climate change is largely unknown. In particular, the changes in water chemistry are widely unrecognized. Wolverine Glacier in the Kenai Mountains of Alaska is just one of many glaciers that drain into Prince William Sound and the Pacific Ocean. This project compares physio-chemical variables over the 2016 summer melt season; including meltwater discharge, gauge height, electrical conductivity, ion and carbon chemistry of water from glacial and non-glacial streams within the Wolverine catchment to delineate when the glacier undergoes hydrologic changes. Data thus far indicate differences in the physio-chemical signatures of glacial, tundra and mixed streams within the catchment which can be used to break up the melt season into different hydrological phases. Ions appear to exhibit different behavior during the summer season, in both concentration and presence. For example, many ions such as Calcium shrink in concentration as discharge increases between May-September, while those such as Iron follow discharge and only appear from July. Surprisingly and contrary to many glacial studies, there is no Nitrate story. Major ion concentrations are significantly different overall and exhibit good linear trends with conductivity, allowing for detailed estimates of concentration over the season. These ions will continue to be further investigated as laboratory analysis commences, in comparison to changes in the hydrological system. This project will aid in a better understanding of glacial hydrological systems, glacial ion chemistry, and how changes in both might impact downstream and oceanic ecosystems as glacial melt increases into the future.

3 keywords: hydrological systems, meltwater chemistry, physio-chemical variables
Planktonic foraminiferal Molecular study from the West Pacific: taxonomy and paleoceanographic implication

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In this study, planktonic foraminiferal specimens (Pulleniatina obliquiloculata, Neogloboquadrina dutertrei, Globigerinoides ruber and Globorotalia trunculinoides) were collected from the West Pacific Ocean and analyzed to obtain their molecular information. SSU rDNA sequences of these species are reported. Detailed comparisons of these DNA sequences with those from other regions suggest that biological isolation do not exist for these species in the West Pacific. In addition, the small intra-species differences of DNA Sequence (<1.5 %) indicate only one Gs. ruber s.s. species and one N. dutertrei species exist in the global ocean. Gr. trunculinoides DNA Sequence supports the genotype V exiting in the northwestern Pacific Ocean. The DNA sequence character of P. obliquiloculata implies only one species inside the Pacific Ocean, which confirms earlier previous speculation on this species from the molecular work in the Okinawa Trough. The molecular evidence demonstrates sufficient genetic communications of planktonic foraminifera in the ocean circulation system, which not only guarantees the accurate application of index species in the paleoceanographic study, but also provides the basis for the molecular method in reconstructing the history of ocean circulation system.
Characterization of the dissolved organic matter from arctic soils under climate change

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Expected thawing of the arctic permafrost will lead to the activation of soil biogeochemical cycles (C, N, trace elements). An increase of dissolved organic matter (OM) concentration in surface water can already be observed in North Europe and North America. To characterize the dissolved OM potentially produced by arctic ecosystems, soils from the Abisko region (Sweden) were sampled at 4 sites representative of peatland, heathland, forest and altitude meadow (from 360 to 1048m a.s.l.). Samples of the main vegetation species were also collected to characterize the soil OM sources. For all samples, organic C and N contents were measured through elemental analyzer. For each ecosystem, several soil samples were characterized through solid state $^{13}$C nuclear magnetic resonance and the proportion of 4 chemical shift regions was assessed (alkyl, O-alkyl, aromatic and carbonyl C). Soil extraction with CaCl$_2$ (0.25 mM) is running to mimic the dissolved OM pool of Abisko soil solution. Dissolved C and N will be quantified and the extracted OM will be characterized.

A high intra-ecosystem variability of soil C and N contents (from 0.6 to 49.7% and 0.04 to 4.5%, respectively) is observed and the resulting C/N ratios ranged from 23.9 to 62.7. Soil OM quality presents a high heterogeneity considering the alkyl C/O-alkyl C and the aromatic C/O-alkyl C ratios. Based on the same indicators (C, N, alkyl C, O-alkyl C and aromatic C contributions) the different vegetation species also reflect a large range of OM qualities. The alkyl C/O-alkyl C and aromatic C/O-alkyl C ratios were especially low and C/N especially high for lichen species. The characteristics of soil OM seem to be related to the altitude of the site, whereas no relationship to the soil water content could be noticed. This may be associated to different mean annual temperature leading to different decomposition rate of the OM. But the various species proportion in different ecosystems may also be responsible of variable soil OM quality. The on-going work on dissolved OM should thus allow highlighting potential changes that might be induced by the thawing of soils of different ecosystems and by possible evolution in species proportion under climate change. The impact on the dynamics of dissolved OM will be assessed and the potential consequences for associated cycles considered.
Objective

This work seeks to understand how shifting vegetation cover and permafrost thaw is altering Si exports to coastal Arctic receiving waters. We investigated the geochemical signatures of ten rivers draining a 700 km north-south gradient across northern Alaska.

Results and Discussion

Contrary to the significant negative relationship observed between average dissolved Si concentration and latitude across all sites (Fig. 1), we find no such pattern with biogenic Si behaviour. We use data on basin lithology, land cover, and river discharge, nutrient concentrations and Ge (Germanium)/Si ratios, to determine the drivers of these patterns. In turn, our results will be used to create the first predictive framework to assess how warming alters fluvial Si exports to Arctic receiving waters.
Dynamics of inorganic components in lake waters from Terra Nova Bay, Antarctica

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Water and Suspended Particulate Material (SPM) samples analysed in this work were collected in the austral summer 2011/12 from six shallow Antarctic lakes (Carezza, Edmonson Point 14 and 15a, Gondwana, Inexpressible Island 10b and Tarn Flat 20) of Terra Nova Bay (Northern Victoria Land, Antarctica). The total concentrations of a large suite of inorganic analytes were determined, in order to gain insight into the natural processes regulating species distribution, define natural background values and detect possible present or future local and/or global anthropogenic contamination. Lake water composition was found to be influenced by marine spray, lake geographical position and meltwater input. Seasonal variability was also evaluated for each analyte, and explained considering the natural transport processes involving each species. Multivariate chemometric techniques were used in order to identify groups of samples with similar characteristics and find out similarities and correlations among variables. The variability observed within the water samples is closely connected to the sea spray input; hence, it is primarily a consequence of geographical and meteorological factors, such as distance from the ocean and period of year. Higher element concentrations have been found in SPM than in water, suggesting that adsorption processes take place. SPM samples were also examined with a Scanning Electron Microscope (SEM), and many diatoms belonging to different species were detected. No evidence of a relevant metal contamination was found in the investigated area.
Pollution from the 2014/15
Bárðarbunga eruption monitored by
snow cores from Vatnajökull glacier,
Iceland

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The six month long 2014/15 Bárðarbunga volcanic
eruption released 11 Mt of SO2, 6 Mt of CO2, 0.1 Mt of HCl,
and 0.05 Mt of HF [1-2]. To study the effect of this eruption
on the winter precipitation, snow cores were collected from
the Vatnajökull glacier and the highlands northeast of the
glacier. The pH and chemical compositions of melted snow
samples indicate that these compositions have been affected
by the Bárðarbunga eruption. The pH of the bulk snow
samples ranged from 4.41 to 5.51. This is 4 times more acidic
than pure water saturated with the atmospheric CO2. The
anion concentrations (SO4, Cl, and F) were higher and the pH
was lower compared to the equivalent snow from the
unpolluted Icelandic Langjökull glacier. The chemical
evolution of the snow with depth, decreasing pH, increasing
SO4, F, Cl and metal concentrations, reflect changes in the
lava effusion and gas emission rates. They were the highest at
the early stage of the eruption. The snow scavenging potential
in close vicinity of the eruption site was minor. The snow
removed only up to 1.2% of Cl, less than 1% of F, and less
than 1‰ of S released during the entire eruption period
confirming its limited cleaning capability of the volcanic
pollutants from the air in vicinity of the eruption site. The
toxic and heavy metals concentrations did not exceed
drinking water standards given by European Commission
and the micobiological communities was similar to those found
in other parts of Arctic. This indicate that only minor
environmental impacts on the snow were caused by its
interaction with the volcanic aerosols/gases.

Using radiocarbon to fingerprint ancient sources of dissolved inorganic carbon to the Alaskan Arctic Shelf

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Ongoing warming of the Arctic Ocean is expected to release ancient carbon stored in continental shelves as subsea permafrost and methane (CH4) gas hydrates. Likewise, warming of the active layer in terrestrial environments may increase riverine delivery of terrestrial permafrost-derived organic carbon (OC) to the Arctic Ocean margins [1]. Similar to the injections of anthropogenic CO2 into seawater, the remineralization of subsea and terrestrial-OC from thawing permafrost [2] as well as the oxidation of CH4 released from gas hydrates may add additional CO2 into Arctic Ocean seawater and enhance ocean acidification [3]; yet this potential influence largely remains unquantified. To assess the influence of OC and CH4 remineralization on pH, dissolved CO2, and the dissolved inorganic carbon (DIC) pool, we present data from samples collected in August of 2015 on the Beaufort Sea Shelf, offshore of the Colville and Kuparuk Rivers. High precision pH data as well as natural radiocarbon measurements of DIC, CH4, and OC are used to evaluate the contribution of CH4-derived and OC-derived carbon to seawater CO2.

Subglacial weathering controls silicon isotope composition of Greenland Ice Sheet meltwaters


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The global silicon (Si) cycle is linked to the drawdown of atmospheric carbon dioxide through silicate weathering and biological production by siliceous algae. Consequently, more focus is being applied to quantifying Si fluxes to the ocean. Recent studies have shown that Greenland Ice Sheet (GrIS) may play a much more significant role in global Si cycles than previously thought with dissolved and labile amorphous silica fluxes greater than previous estimates. These findings have subsequently led to questions surrounding the long term impact of glaciations upon the global Si cycle. Ice sheets have not previously been considered in past ocean Si isotope budgets due to the assumption of insignificant Si fluxes.

Here, we present the isotopic composition of exported silica ($\delta^{30}$Si) from two contrasting glacial catchments of the GrIS; Leverett Glacier and Kiattuut Sermiat. The $\delta^{30}$Si composition of dissolved Si from the larger Leverett Glacier is anomalously low compared to terrestrial and glacial rivers previously measured. Additionally both catchments present a significant temporal shift in dissolved $\delta^{30}$Si in response to changing hydrological pathways. We combine these data with a hydrogeochemical dataset to investigate the role of subglacial weathering on isotopic composition. Preliminary analysis indicates contrasting weathering regimes in the catchments, which impact upon the $\delta^{30}$Si composition of labile Si exported downstream. Enhanced silicate weathering occurs within larger ice sheet systems, with extended water residence times, resulting in the lowest dissolved $\delta^{30}$Si measured in running waters.

Subglacial weathering exerts a significant influence on the $\delta^{30}$Si of meltwaters exported to oceans, which likely impacts the global Si cycle, especially during glacial cycles and meltwater pulse events. This may have a large impact on the palaeoceano-graphic interpretation of biogenic silica isotope records from oceanic sediments. We assess that chemical weathering under large ice sheets must be considered when examining global elemental cycles.
The Geochemistry of Surface Ice on the Greenland Ice sheet and its effect on the Primary Production of Microbes.

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Microbial communities have recently been shown to play key roles in the bio-albedo of the Greenland Ice Sheet (GrIS) and consequent melt rates. As such, there is significant interest in understanding how these microbial communities survive and thrive in such harsh and oligotrophic conditions. Current knowledge gaps include the effect of nutrient limitation on the primary production of surface ice microbial communities, and the impact of microbial production on dissolved organic carbon (DOC) concentrations. This study sampled a small section of the GrIS surface, approximately 35km inland from the margin, throughout the 2016 melt season. We report nutrient [phosphate, ammonium, nitrite, nitrate, total phosphorus, and total nitrogen] and DOC concentrations. Sampling focused on five main habitats representative of the supraglacial landscape, namely: surface ice with low, medium and high levels of visible particles, supraglacial stream water and cryoconite hole water. Concentrations of inorganic nutrients ranged 0.5-3ppb for PO$_4^{3-}$, 13-22ppb for NH$_4^+$, and 0.9-5.5ppb for NO$_3^-$ across the five representative habitats. In contrast, nutrients were found in higher concentrations in their respective dissolved organic phases with TP reaching 1.5-7ppb and TN reaching 8.5-250ppb. Concentrations of dissolved organic phosphorus (DOP) were found to be 2-3 times higher than inorganic fractions, while close to 99% of nitrogen was found in the dissolved organic phase (DON). DOC concentrations ranged from 80ppb to as high as 7ppm. The high relative concentrations of DON, DOP and DOC in supraglacial stream water suggest that microbial habitats facilitate retention of such nutrients within the ice surface, permitting their continual reuse and recycling. Hence, microbial processes increase the localised concentration of both nutrients and DOC in ice surface habitats on the GrIS.
Distributions of dimethyl sulfide in the Amundsen Sea water column, Antarctica, measured by membrane inlet mass spectrometer

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We investigated horizontal and vertical distributions of dimethyl sulfide (DMS) in the upper water column of the Amundsen Sea. Polynya and Pine Island Polynya during the austral summer (January–February) of 2016 using a membrane inlet mass spectrometer (MIMS) onboard the Korean icebreaker R/V Araon. The surface water concentrations of DMS varied from 1 to 400 nM. The highest DMS (up to 300 nM) were observed in sea ice–polynya transition zones and near the Getz ice shelf, where both the first local ice melting and high plankton productivity were observed. In other regions, high DMS concentration was generally accompanied by higher chlorophyll and ΔO2/Ar. The large spatial variability of DMS and primary productivity in the surface water of the Amundsen Sea seems to be attributed to melting conditions of sea ice, relative dominance of *Phaeocystis Antarctica* as a DMS producer, and timing differences between bloom and subsequent DMS productions. The depth profiles of DMS and ΔO2/Ar were consistent with the horizontal surface data, showing noticeable spatial variability. However, despite the large spatial variability, in contrast to the previous results from 2009, DMS concentrations and ΔO2/Ar in the surface water were indistinct between the two major domains: the sea ice zone and polynya region. The discrepancy may be associated with inter-annual variations of phytoplankton assemblages superimposed on differences in sea-ice conditions, blooming period, and spatial coverage along the vast surface area of the Amundsen Sea.
Title: Microbial Life in Arctic Snow and Ice

Authors: Catherine Larose, Lorrie Maccario, Laura Sanguino, Anthony Morris, Aurélien Dommergue, Timothy M. Vogel

Polar Regions are transforming and as they constitute integrators of climate variability, they provide visible signals of change. In addition, Polar Regions intrinsically participate in global cooling through a number of feedback mechanisms. The observed climate changes alter the structure and functioning of many cryosphere ecosystems and by extension ecosystems around the planet. Due to the extreme temperatures and the limited presence of liquid water, snow and ice have long been regarded simply as freezers that entrap and store microorganisms in a vegetative state, and therefore, the microbial ecology of the cryosphere has been largely overlooked. Our research on the role of microorganisms in the functioning of environmental ices highlights the links between their biotic and abiotic components. Our work focuses on observations of snow and ice in the Arctic and explores the biodiversity, the microbial population dynamics and influence of microorganisms on biogeochemical cycling, and their interactions with their physical and chemical environment. Through these studies, we have challenged the view of snow and ice as freezers and have shown that they should be considered as viable, active and important ecosystems.

Key words: Arctic, snowpack, ice, microorganisms, biogeochemical cycling
The Source and Fate of Microbes on the Greenland Ice Sheet

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Ice sheets and glaciers are important components of Earth’s hydrologic system and provide a strong feedback on the climate system. They are being disproportionately affected by global warming and are melting at an unprecedented rate. The key parameter affecting the melt rates is the rapid change in albedo of snow and ice surfaces. Although the physical and chemical components of albedo are relatively well understood, the role that biology plays in changing albedo has been neglected so far. Microbes, in particular snow and ice algae, play a crucial role in decreasing albedo [1], yet, we know very little about the dynamics of microbes or their interactions with the physical and chemical components in changing the albedo on the Greenland Ice sheet (GrIS).

Here we present results from the Black & Bloom field campaign on the GrIS during the 2016 summer melt season. Various snow, ice as well as aerosol samples were collected from 3 separated areas for analysis of the microbial diversity. The bacterial and eukaryotic (e.g., algae, fungi) community compositions were characterized by Illumina sequencing of the 16S rRNA, 18S rRNA and ITS2 genes. Aerosol and surface samples were cross-correlated to evaluate sources and fates of microbes on the GrIS. The algal community compositions of all samples were dominated by the ice algae Ancylonema nordenskiöldii with minor contributions of Chlamydomonadaceae and Trebouxiaceae taxa. In contrast, the bacterial and fungal community compositions were very similar within one habitat (snow vs. ice vs. air), but showed large differences between the habitats.

Our data thus far reveal that eukaryotes in snow and ice were seeded from the air, while bacteria and fungi in the snow were from air inputs, but surface ice showed different microbial dynamics. Combined with non-microbial particulates we aim to derive a bioalbedo parameter for the GrIS. [1] Lutz, S. et al. (2016), Nat. Commun. 7, doi:10.1038/ncomms11968.
New insights on brine dynamics and source in Don Juan Pond, Antarctica

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Don Juan Pond (DJP), located within the Antarctic Dry Valleys (ADV), is unique due to its concentrated CaCl$_2$ composition. Because of the low eutectic temperature and hygroscopicity of this brine, DJP never freezes or evaporates completely, despite arid conditions and wintertime lows near -50°C. DJP has generated ongoing interest since its discovery in 1961 because of the potential for extremophiles, as an analog site for potential aqueous flows on Mars, and due to the enduring enigma of its unique geochemistry.

Shallow and deep groundwater theories have been proposed to explain the source and dynamics of the brine in DJP. **Shallow groundwater** theories propose that salts in surface soils deliquesce and migrate into DJP. This is based on observations of deliquescence and shallow groundwater flow above DJP. **Deep groundwater** theories propose that deep groundwater regularly discharges into DJP, which is supported observations of upwelling groundwater from drill-holes. We resolve the source of salts to DJP by modeling closed-basin evaporation assuming deep/shallow groundwater inputs using a new model in the Na-K-Ca-Mg-Cl system [1].

Our model results, as well as ionic ratios in DJP, indicate that a deep groundwater source best explains the chemistry of DJP (Fig. 1). Furthermore, we find that less than a year of closed-basin evaporation is needed to form DJP, which implies a flow-through groundwater system. This system may continue towards Lake Vanda (10 km from DJP), and be responsible for its CaCl$_2$ composition. The existence of regional flow-through groundwater systems in the ADVs implies a dynamic subsurface environment and may provide clues for the formation of aqueous flows on Mars.

![Fig. 1. Left: measured (symbols) and modeled (lines) concentrations in DJP assuming deep groundwater inputs. Right: ionic ratios in DJP and ADV surface waters.](image)

Chemical composition of dissolved organic matter released from alpine permafrost soils in northeast Qinghai-Tibetan Plateau (QTP)

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The QTP permafrost accounts for 70% of global alpine permafrost. The fast permafrost degradation induced by global warming is happening not only in Arctic area, but also on QTP. The predicted permafrost loss on QTP is up to 49% by 2099. In addition, QTP is the water source area of Yangtze River and Yellow River. The thawing and mobilization of permafrost OC on QTP have significant impacts on C dynamics and inland ecosystem. However, the reports for QTP permafrost is limited. Here, we isolated colloidal-OC (COC) and SPE-DOC from different layer leachates of permafrost soils (0-200 cm deep) in QTP. The chemical composition of soils OC and COC was determined by solid state 13C NMR, and that of SPE-DOC was analyzed by FT-ICR-MS. The alkyl C proportion is substantially higher in QTP permafrost soils than Arctic permafrost soils, the latter dominated by O-alkyl C. Our leaching experiment revealed that carbohydrate, protein and lignin in soils is easily released as DOC during the thawing process. The aromatic carbon is dominant in leachate from active layer, but microbial carbon becomes dominant in permafrost layer leachate. Considering high solar radiation in QTP and steep slope from the permafrost area to river headwater, we speculate that photomineralization of the permafrost OC plays an important role in early stage of permafrost thawing, whereas biodgradation can not be neglected after its mobilization into freshwater system.
Geochemical and microbiological gradients along Arctic chronosequences

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The link between carbon cycling and weathering in recently deglaciated areas may result in important feedbacks on global warming and biogeochemical element cycles, particularly since glaciers are predicted to retreat at increasing rates in the future. In addition, recently deglaciated areas are also unique environments to study the initial and successional development stages of soil formation. Such soils are also prime targets for evaluating processes linked to the initial colonization of pioneer microorganisms, which in turn can both be influenced and impact nutrient and organic carbon bioavailability.

The processes regulating carbon and nutrient cycling in such environments are however poorly known. To close this gap, we aims to link carbon and nutrient availability with microbial community structures activity and evaluate the effects on abiotic and biotic parameters on weathering rates in Arctic soils. This study is based on samples collected in winter season along a chronosequence in the proglacial area of Longyearbreen, Svalbard.

Our results show that soils particle size, conductivity and pH decrease with soil age (e.g., pH and conductivity were 8.8 and 380 mS.cm⁻¹ in the young sites and 7.4 and 86 mS.cm⁻¹ in the older sites). The variation in chemical index of alteration (CIA), calculated using on X-ray fluorescence data, indicate an increase in weathering with decreasing size-fraction and increasing age. In additions, sequencing result show clear differences in microbial diversity between the younger and older soils along the chronosequence.
Dark material on the surface of glaciers is reducing their reflectivity and therefore contributing to increased glacier melt. This dark material typically accumulates in regions of melt on the glacier, such as in cryoconite holes. The source of this dark material has been hypothesized to be from combustion of forest fires or fossil fuels, microbes and dust. However, few studies to date used radiocarbon of bulk and specific compounds to study the composition of cryoconite material. In this study we examined the chemical composition of cryoconite material collected from three different mountain glaciers in Alaska (Matanuska, Mendenhall, and Spencer) to determine the sources of carbon to these glaciers. Additionally, we used compound specific radiocarbon analysis of the solvent extractable lipids to further investigate the carbon source(s). While the the overall amount of carbon in the cryoconite material from these glaciers was typically low (<5%), the age of the carbon in this material varied by more than ten thousand radiocarbon years across all three glaciers. The organic carbon in cryoconite material collected on Spencer and Matanuska glaciers near Anchorage, was lower in organic carbon and yet much older than today’s atmosphere. On the other hand, cryoconite carbon collected on Mendenhall glacier near Juneau, contained more organic carbon and was primarily modern carbon. If the carbon source(s) to these glaciers are the same, then these results suggest that there is a significant young carbon source to Mendenhall that is not present for Spencer and Matanuska glaciers. However, we found that the amount of solvent extractable carbon in all of these samples was low (<5% of organic carbon), which suggests that most of the carbon is mineral bound. Radiocarbon analyses of the solvent extractable lipids from these glaciers revealed young carbon, even when the bulk organic carbon was thousands of years old. Since cryoconite material is typically crustal in its composition (e.g. inorganic elemental composition) and the region near Spencer and Matanuska glaciers contains sedimentary carbon (e.g. shale), while Juneau is primarily igneous rock, we conclude that the age of the cryoconite carbon on these mountain glaciers is influenced by the local geology.