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Cover: Small icebergs from Columbia Glacier blocked by a moraine at Heather Island, Alaska. August 2006 by Tom Lowell.

The View from the Moraine: the President's Message

By Tom Lowell
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Passing the Torch

The recent passing of Wally Broecker (18 February 2019) marks a time of passage. Our community lost the scientist who gave us the ocean conveyor belt, the concept of climate jumps, and ocean-atmosphere reorganizations.

The first paper Broecker as the lead author was *Lamont Natural Radiocarbon Measurements III* in 1956. Back then, before the journal *Radiocarbon* came on line, routine age estimates were considered worthy of publishing in Science. The utility of chronology deeper into the past was being recognized. Wally then measured radiocarbon and pondered what it could tell us about lake levels, nuclear tests, ocean circulation, humans, fresh-water systems, caves, buried forest beds all by 1963. He moved on to other isotopes in natural systems.

His "Climate change: are we on the brink of a pronounced global warming?" in 1975 was the first of many papers that framed a question. Questions that were novel, yet sometimes contentious but moved the thinking and perspective of the Quaternary community along. His some 400 publications have been cited nearly 30,000 times. A fitting tribute to Wally is at http://www.comerfamilyfoundation.org/articles/remembering-wally-broecker.

Who will fill his shoes?

In 1969, Link Washburn founded the Quaternary Research Center at the University of Washington (QRC). Link advocated that key problems require an interdisciplinary approach.

Problems such as patterns, causes, impacts of the ice ages that define the Earth's atmosphere, oceans, and land surface for the last 2.6 My.

The QRC began publishing *Quaternary Research* to communicate new developments. *Quaternary Research* has grown from a niche journal to one with global scope by publishing articles that have interdisciplinary interest.

The publication of more than 4000 papers includes these classics: -*Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300,000-year chronostratigraphy* - Martinson, Pisias, N.G. Hays, J.D. Imbrie, J,, Moore Jr., T.C. Shackleton, N.J. Martinson, D.G.

-*Oxygen isotope and palaeomagnetic stratigraphy of Equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a 105 year and 106 year scale* - Shackleton, N.J. Opdyke, N.D.

-*Holocene climate variability* - Mayewski, P.A. Rohling, E.E. Stager, J.C. (...), Schneider, R.R. Steig, E.J.

-*Origin and consequences of cyclic ice rafting in the Northeast Atlantic Ocean during the past 130,000 years* - Heinrich, H.

Each paper has been cited more than 1300 times.

In 1970 a new organization with Link Washburn, President, Margaret Davis, Secretary, and Robert Ruhe, treasurer called itself the AMerican QUaternary Association (AMQUA).

This outfit headed to Bozeman Montana to confab in what has become a biannual affair. We realized that each disciplinary was only seeing a piece of the elephant and communication among various workers was essential for any deeper understanding.

Much has changed in the last 50 years: the pace of science, the tools we use, the reporting system. The Quaternary has become, for better or worse, associated with "Climate Change". It may be few outside our field appreciate the difference. Every week some report based, on remote sensors of some kind, declare "this is the most extreme event yet". At least that is the way the newspapers write it up.

As students of deeper time we place things in a longer time scale and sometimes ask if this really was a record or simply the extreme captured by modern techniques. What more is there needed to understand the structure of the Quaternary? I don't know a specific answer to that, but I suspect it will be the integration / synthesis across many fields of study.

Who will emerge with the torch Wally passed? Look to someone with perspective of the three Quaternary organizations founded some 50 year ago.

Please join us in Seattle 2020 to celebrate the accomplishments over the last 50 years and ponder what the next 50 years may bring.

Tom

2020 Biennial AMQUA Meeting

- News -

By Colin Long
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I am happy to announce that the AMQUA council on March 27, 2019 accepted a proposal from the Quaternary Research Center (QRC) and the University of Washington (UW) to host the 2020 Biennial Meeting in Seattle June 17 to 20, 2020. Although there was interest from several groups, the QRC/UW proposal was the only one submitted for consideration. AMQUA has held its biennial meeting twice before on the UW campus with previous meeting themes of *Character and Timing of Rapid Environmental and Climate Changes* (1982), and *People and Process in the Quaternary Pacific Northwest* (2014). The specifics of this meeting are still being developed but 2020 represents the 50th anniversary of the relationship between AMQUA and the QRC and coincides with the new QRC project called "Quaternary Futures". More information about the meeting will be shared on the AMQUA website and through the AMQUA listserv but I anticipate another enlightening and enjoyable Biennial Meeting in Seattle.

Research Project Reports

Madagascan stalagmites cast doubt on ITCZ movement as the dominant control on tropical hydroclimate variability

By Nick Scroxton[1,2] and Stephen Burns[1]
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Some of the most iconic paleoclimate records in the tropics come from the stable oxygen isotopes of stalagmites, such as Hulu and Dongge caves in China, and Botuvera Cave in Brazil. These records demonstrate antiphase behavior between northern and southern hemisphere tropical hydroclimate. Anticorrelated time series at both the precessional timescale and in response to millennial scale events during the last glacial period are interpreted as showing latitudinal movements of the tropical rain belt, or the Inter Tropical Convergence Zone, through time.

At other timescales, this mechanism has often been invoked to explain wet and dry phases in tropical hydroclimate records. New discoveries from southern hemisphere climate archives are challenging the simplistic dipole narrative.

Professor Stephen Burns, postdoc Dr. Nick Scroxton, and Peterson Faina, a PhD student at the University of Antananarivo, have been using stalagmites from Madagascar to investigate past changes in rainfall on the island (Fig. 1). By comparing their records to other hydroclimate records from East Africa and the Arabian Peninsula they have discovered that rainfall variability in the region does not fit the dipole pattern.

Over the last 1,700 years, summer monsoon rainfall in Madagascar is in-phase with summer monsoon rainfall in Oman at multi-decadal scale variability. At the multi-centennial scale rainfall around the entire East Indian Ocean appears to be varying together.

Figure 1. *PI Stephen Burns and PhD student Peterson Faina investigate a cave in southwest Madagascar.*

This remarkable in-phase variability suggests that East Indian Ocean sea surface temperatures may be the dominant control on regional rainfall during the Holocene (Scroxton et al., 2017, doi:10.1016/j.quascirev.2017.03.017).

First order variability in the oxygen isotope record tracks sea surface temperatures between 22 and 12 kyr BP (Fig. 2). A response to movement of summer Hadley circulation is present in the record, forming a secondary influence on the stable isotopes, but a stronger control on speleothem growth phases (Scroxton et al., 2019, doi:10.1029/2018PA003466). Both the dynamic (atmospheric circulation patterns) and thermodynamic (sea surface temperatures) controls on rainfall have a role to play in modulating rainfall and monsoon strength in Madagascar.

Current targets for the group include extending this research to other time periods, including the 4.2 kyr event and millennial scale variability during the last glacial period.

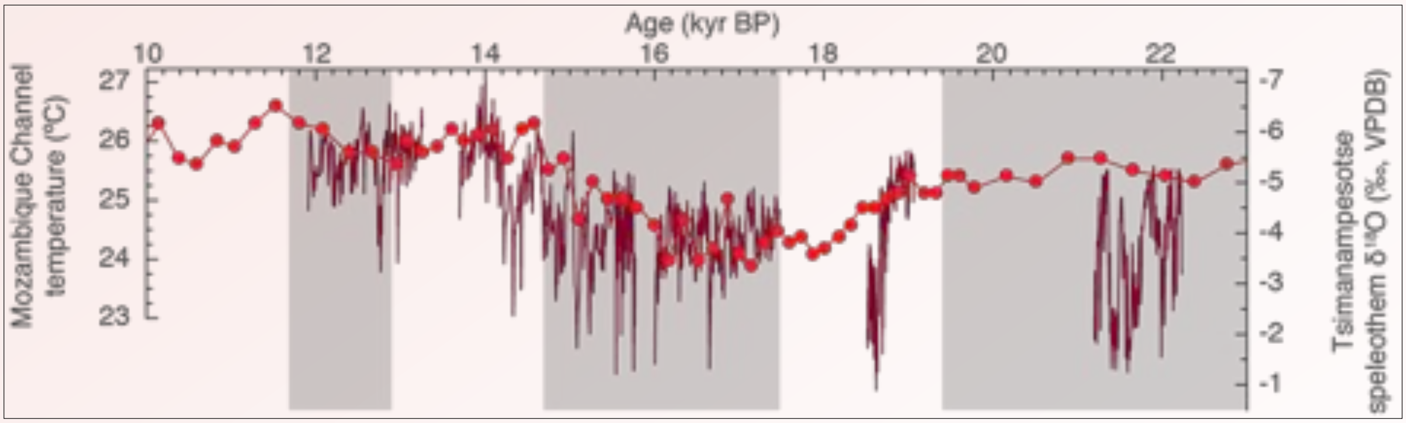

Figure 2. *New stalagmite data suggests rainfall variability in southwestern Madagascar might be controlled primarily by sea surface temperatures in the Mozambique Channel rather than a purely atmospheric control from summer Hadley Circulation variability (Scroxton et al., 2019, doi:10.1029/2018PA003466).*

The Macy Fork local fauna (11,550–11,000 ^{14}C yrs BP): exploring late Pleistocene vertebrate biodiversity on the Southern High Plains of Texas

By John Moretti and Eileen Johnson
Museum of Texas Tech University

The late Pleistocene vertebrate fauna of North America exhibits distinctive species composition and biogeographic patterns that are not analogous (i.e., non-analog) to the extant faunal communities. Documentation of these non-analog faunas provides evidence of the tempo and mode of biotic and abiotic changes during the late Quaternary. On the Southern High Plains, the diversity of the non-analog late Pleistocene vertebrate community is well documented by the Clovis local fauna of Lubbock Lake at ~11,100 ^{14}C yrs BP and less so by the Clovis local Fauna of Blackwater Draw Locality 1 from ~11,600 to 11,000 yrs BP (Johnson, 1986). The alluvial deposits of Macy Locality 100 offer an additional view of the latest Pleistocene vertebrate community from the eastern edge of the Southern High Plains, Texas (Fig. 1).

Figure 1. *Macy Locality 100 within the Macy Fork Valley of Spring Creek.*

Ongoing, interdisciplinary investigations at Macy Locality 100 have produced a large sample of vertebrate faunal remains. (Fig. 2). This material comes from two latest Pleistocene depositional units: the basal gravel (~11,550–11,300 ^{14}C yrs BP); and fluvio-lacustrine 1 (~11,300–11,000 ^{14}C yrs BP). Taphonomic processes are multi-faceted, with faunal remains being accumulated through a combination of processes, including flowing water and predator behavior. Taxonomic analysis of a sample of recovered faunal remains assigns 1,628 individual specimens to 63 vertebrate taxa. This faunal assemblage from Macy Locality 100 is termed the Macy Fork local fauna (~11,550–11,000 ^{14}C yrs BP).

The Macy Fork local fauna contains all vertebrate classes (i.e., fish, amphibians, reptiles, birds, and mammals) and a range of body sizes. The fauna is species rich, but highly uneven with *Rana pipiens* Complex (Plains leopard frog) and *Terrapene carolina putnami* (extinct box turtle) predominating. The *T. c. putnami* sample is one of the largest documented and includes several complete carapaces. Notable within the local fauna are a total of 14 new regional records, including extralimital forms. Among new records for the Southern High Plains are *Panthera atrox* (American lion; Johnson and Moretti, 2018) and *Zapus hudsonius* (jumping mouse; Moretti and Johnson, 2015). The Macy Fork avifauna is among the most species rich (n=14) from the late Pleistocene of the entire Great Plains of North America. Wetland birds in the assemblage, many of which are occur regionally as migrants today, offer important evidence of late Pleistocene biogeography. In total, the Macy Fork local fauna provides a detailed record of the vertebrate community composition from the Southern High Plains during the final centuries of the Pleistocene.

Figure 2. *On-going excavation in the late Pleistocene alluvial sand and gravel deposit at Macy Locality 100.*

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New evidence for Ice Age refugia in western Alexander Archipelago, southeastern Alaska

By Thomas A. Ager, Emeritus,
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Early reconstructions of glacial extent during the Last Glacial Interval (LGI) suggested that Cordilleran glaciers expanded from the coastal mountains to cover essentially all of southeastern Alaska. Subsequent studies indicate that there were some areas along the western edge of the Alexander Archipelago and the adjacent subaerially exposed continental shelf that escaped inundation by glacial ice. These areas provided refugia for many plant and animal species to survive the LGI, and were an early local source of species to begin recolonizing the region as deglaciation proceeded. This research reconstructs the history of vegetation development in southeastern Alaska since soon after deglaciation began. New pollen analysis and radiocarbon dating of lake sediments from the remote southwestern coast of Baranof Island, at Hummingbird Lake, in southeastern Alaska (Fig. 1) provides evidence for a well-established population of pine trees (*Pinus,* probably *Pinus contorta* subsp. *contorta*) by ~15,240 cal yr BP, before the onset of Bølling warming at ~14,700 yr BP.

Figure 1. *Map of the study region*.

The Hummingbird Lake coring site is located within an area that has been identified as a likely coastal refugium for plants and animals during the Late Glacial Interval (Carrara et al., 2007). Other sites in southwestern Alexander Archipelago contain evidence for the early appearances of pine, mountain hemlock (*Tsuga mertensiana*), and Sitka spruce (*Picea sitchensis*) in areas that cosmogenic exposure ages indicate deglaciated by ~17,000 ± 700 yr BP (Lesnek et al., 2018), suggesting nearby refugia that served as early, local seed sources for plants colonizing newly deglaciated terrain. Large areas of the inner continental shelf west of the Archipelago were subaerially exposed by eustatic sea level lowering during the LGI, and further enlarged by the development of a crustal forebulge resulting from lateral migration of upper mantle rocks in response to the heavy ice load on the Coast Mountains to the east of Alexander Archipelago (Fig. 2).

Radiocarbon dated vertebrate fossil assemblages from caves in southeastern Alaska indicate that glacial ice cover may have been of short duration (~20,000 to 17,000 cal yr BP) during the LGI (Lesnek et al., 2018).

Figure 2. *Juneau Icefield provides an analog for conditions that existed in Alexander Archipelago during the Late Glacial Interval.*

Figure 3. *Photo of western hemlock-Sitka spruce forest that blankets much of southeastern Alaska today.*

Identification of dated vertebrate remains indicate the presence of both marine and terrestrial animals in the region during much of the past ~45,000 years, with an arctic fauna during LGI, followed by a transitional fauna, and a forest-adapted terrestrial fauna during the warmer Holocene (Heaton and Grady, 2003; Lesnek et al., 2018). The recolonization of southeastern Alaska during and after deglaciation by plants involved an early lowland shrub-herb tundra stage with scattered conifers, followed by pine parkland with ferns, then alder-pine forests and shrublands during the Younger Dryas cool event. During the early Holocene, Sitka spruce colonized most of the region (Fig. 3), along with expanding populations of mountain hemlock, and followed by western hemlock (*Tsuga heterophylla*). As yet no sites have been found that provide evidence for dated full-glacial plant assemblages from this region, but there are likely areas yet to be investigated.

This study was funded by the U.S. Geological Survey in cooperation with the US Forest Service, Tongass National Forest, Alaska. The full report will be published in *Frontiers in Earth Science* as a contribution to the Research Topic "North Pacific Environment and Paleoclimate from the Late Pleistocene to Present".

More information is also available in References below.

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The sediment record from Fish Lake, Utah: new insights on Bonneville Basin hydroclimate and environment and the potential to extend the record through the Pleistocene

By Lesleigh Anderson and the Fish Lake Research Group
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The paleoenvironmental history of the Bonneville Basin during the Quaternary has been studied for over a century, yet the region continues to attract attention. This is not only because of the enigmatic nature of large pluvial lakes and high elevation glaciers, but because numerous uncertainties about the driving climatic processes and mechanisms still exist. Furthermore, a better understanding of paleohydrologic change during periods of large climatic variability provides insights into the global climate system that are relevant today.

The major paleohydrological shifts across western North America during the late Pleistocene, including the expansion and contraction of lakes and glaciers in the Bonneville Basin, are broadly consistent with millennial-scale trends in northern hemisphere temperatures. However, more variable spatial paleohydrologic patterns are evident during rapid de-glacial climate shifts, such as the Bølling/Allerød (14.6–12.8 ka) and Younger Dryas (12.8–11.7 ka), and the hydroclimatic mechanisms, such as atmospheric circulation patterns, precipitation source and seasonality, and net moisture balance (precipitation-evaporation) are debated. There are far fewer continuous geologic archives in the Bonneville Basin with sufficient duration, temporal resolution, and dating control to address hydroclimatic variations over multiple glacial-interglacial, including forcing and feedbacks, and relationships with local glacial extents and vegetation change. Some paleoclimate records suggest that Bonneville Basin paleoclimate was asynchronous with orbital variations and global boundary conditions, which raises important questions about the nature of previous interglacial periods. This is also relevant for understanding potential change for the region in the future.

To provide new constraints on late Quaternary Bonneville Basin hydroclimate, we are developing a multi-proxy sediment record from Fish Lake (38.56˚N, -111.69˚W, 2696 m elevation), located in south-central Utah, near its southeastern boundary and transition to the Colorado Plateau (Fig. 1).

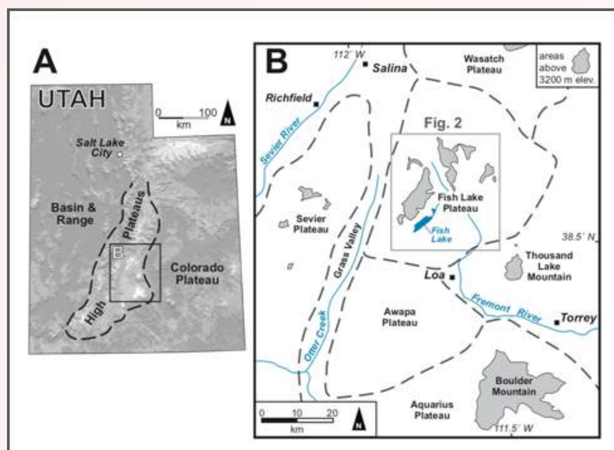

Figure 1. *Locator map for A. the high plateaus of Utah; B. Fish Lake (modified from Marchetti et al., 2011).*

The lake is moderate in size (~7x1.5 km), relatively deep (37 m), and located within the high elevation Fish Lake Plateau (3545 m), which was glaciated during the last two glacial periods (~15–23 ka and ~130–150 ka). The lake occupies a NE-striking tectonic graben and seismic and gravity measurements suggest the lake may contain sediment thickness as high as ~200 m.

One outlet glacier, in Pelican Canyon, deposited moraines and outwash into the northern margin of Fish Lake (Fig. 2), but the main basin was never glaciated. The site is also the location of the Pando aspen grove that is estimated to have had a metabolically alive root system for at least ~80,000 years.

Figure 2. *The Fish Lake Plateau, Pelican Canyon, and moraine viewed from Fish Lake, south central Utah.*

We have documented the bathymetry, limnology, and aqueous geochemistry of Fish Lake. Water depths increase abruptly several hundred meters from shore around most of the lake. Otherwise the lake bottom slopes gently towards the broad east-southeast tilting of the Thousand Lakes fault, which bounds the lake's eastern margins. At the northern end of the lake, downslope from the prominent Pelican Canyon moraine, a series of submerged arcuate ridges are interpreted to reflect more advanced glacial terminus. The lake is dimictic with numerous surface streams that flow into the lake. The one surface outflow is a tributary headwater of the Fremont River, which flows into the Upper Colorado River. High evaporative enrichment is indicated by lake water isotope ratios and conservative ions, which suggest significant evaporative water loss and lake water residence times of 15 to 30 years. Declines in dissolved silica concentrations between inflowing and lake waters, indicate substantial uptake by diatoms. During summer, epilimnion pH values of 8.7 contribute to slight oversaturation with respect to calcite/aragonite, which suggests that carbonate precipitates could form in minor concentrations. However, below the thermocline, pH is near neutral and nearly all carbonate mineral dissolution within the water column is likely.

We collected sediment cores through the ice in February of 2014 using a 9-cm-diameter UWITECH coring system in 31 m of water (Fig. 3). An 11.2-m-long composite core was constructed from overlapping 2 m drives, taken in triplicate, and dated using 12 radiocarbon measurements and 3 known-age tephras.

Figure 3. A. *Coring Fish Lake, Utah, with the UWITECH. Two days of continuous work was required to obtain 3 cores of ~11 m length with overlapping drives.* **B.** *Dave Marchetti and Western Colorado University students: proud of one of the tougher drives to obtain.*

Core lithology, CT scans (CT#), magnetic susceptibility (MS), sediment density, organic matter content, and biogenic silica concentrations were used to correlate drives and demonstrate complete recovery with three distinct sediment packages:

1) increasing MS and CT# >25 ka, which indicates glaciers advancing into the lake basin, 2) high MS and CT# glacier derived sediments reach a maximum around 24–21 ka, coincident with the moraine exposure ages. They then decrease slightly and persist until about 15 ka before a near complete loss of glacier-derived sediments into the lake basin. Comparison of climate at modern glacier ELAs to the Fish Lake paleoglacier ELAs suggest maximum LGM summer temperature depressions between -8.2 and -10.1 °C. 3). Lower MS and CT# s through the post-glacial and Holocene sections of the cores show a slight increase in minerogenic sediments from 13–11 ka, possibly associated with Younger Dryas cooling. A subtle change in autochthonous lake sedimentation also occurs around 8–7 ka. The paleomagnetic record, though weak in the Holocene, compares well with the high-quality record from proximal Fish Lake, Oregon and Bear Lake, Utah. Beyond the Holocene, a much stronger MS signal is preserved that compares well with a paleomagnetic secular variation correlation template developed from Northeast Pacific marine records.

These data and extrapolation of the age model to the maximum estimated sediment thickness suggests that the complete Fish Lake record may be older than 500–700 ka and thereby spans multiple glacial cycles. Work is currently in progress to develop additional proxy records from our cores, including vegetation and fire (pollen, charcoal, and macrofossils), hydroclimate (oxygen isotope ratios of cellulose and silica), and watershed processes (elemental chemistry, XRF, and mineralogy, XRD). We envision that these data will make a significant contribution to expanding our knowledge about Bonneville Basin paleoenvironments. Our work is currently a collaborative in-kind volunteer effort. The longer term goal is to propose a drilling project in order to recover and study the complete sediment record.

Fish Lake Research Group members are L. Anderson (USGS Denver), D. Marchetti (Western Colorado University), M.B. Abbott (Univ. of Pittsburgh), S. Harris (College of Charleston), J. Stoner and B. Reilly (Oregon State University), A. Brunelle, M. Power, and V. Carter (University of Utah), J. Donovan (West Virginia University), D. Larsen (Occidental College), E. Grimm (University of Minnesota), and C. Bailey (College of William and Mary).

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Student Research Projects

Acquiring a biomarker-based temperature reconstruction from the Norse settlements of southern Greenland

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Climate change is an urgent, complicated, and challenging issue for human societies today. Changing climate may have large and unexpected influences on the global environment, leading to more severe living conditions for billions of people on our planet. To better understand relationships between climate change and human societies, we can look back and try to disentangle Climate–Human–Environment interactions in the past. One example is the role that climate may have played in the initial success, and the subsequent demise of Norse (Viking) settlements in southern Greenland (in the 10^{th} and 15^{th} centuries, respectively). To understand this, high resolution, robust climate reconstructions based on multiple archives are very necessary.

We are currently using branched glycerol dialkyl glycerol tetraethers (brGDGTs), a group of relatively new compounds, to reconstruct temperature at a decadal-scale resolution for the last 2000 years, utilizing lake sediment cores collected from southern Greenland lakes. Although the exact source organisms of brGDGTs have not yet been clearly identified, by analyzing global soil samples, Weijers et al. (2007) found a significant relationship between the degree of methylation and cyclization in the brGDGTs with local temperature and pH. De Jonge et al. (2014) improved the method and presented a pH-independent temperature proxy, MBT'_{5ME}. Then, in 2018, Russell et al. established a calibration between MBT'_{5ME} and mean annual air temperature from African lakes. Thus, brGDGTs have become a promising proxy to reconstruct temperature conditions in the past.

In 2016 summer, we obtained sediments cores from lake Igaliku (61.01°N, 45.44°W, Fig. 1) and several other lakes where Norse settlers had established farming communities. We deployed sediment traps to collect modern samples, and thermistors at various depths in the water column, aiming to establish a site-specific calibration to better understand the relationship between the MBT'_{5ME} index and temperature.

Figure 1. *Lake Igaliku. This is a fresh water lake, about 24 m deep, stratified during summer time with anoxic bottom water.*

The sediment traps (Fig. 2) were placed at different water depths to collect yearly and monthly sediments. A fixed sediment trap (Fig. 2A) was assembled, using a funnel and a centrifuge tube attached at the bottom to collect sediments deposited through the funnel.