ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

766
2022

Berichte
zur Polar- und Meeresforschung
Reports on Polar and Marine Research

The Expedition West-Alaska 2016 of the ERC group PETA-CARB to permafrost regions in western Alaska 2016

Edited by

Josefine Lenz, Matthias Fuchs, Ingmar Nitze, Jens Strauss and Guido Grosse

HELMHOLTZ

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Titel: Flussdelta und Seen in West-Alaska, welche die Mission der Expedition PETA-CARB 2016 repäsentieren
Foto: Josefine Lenz, AWI

Cover: River delta and lakes in West-Alaska representing the mission of the Expedition PETA-CARB in 2016
Photo: Josefine Lenz, AWI

The Expedition West-Alaska 2016 of the ERC group PETA-CARB to permafrost regions in western Alaska 2016

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Please cite or link this publication using the identifiers

https://hdl.handle.net/10013/epic.feb82cda-49dd-466a-ab19-76f9b350947e

https://doi.org/10.57738/BzPM_0766_2022

ISSN 1866-3192

West-Alaska 2016

06 August 2016 – 24 August 2016

Potsdam – Kotzebue – Nome – Potsdam

Chief scientist
Guido Grosse

CONTENTS

ZUSAMMENFASSUNG UND EXPEDITIONSVERLAUF

Josefine Lenz
Alfred Wegener Institute

Die Expedition der ERC Gruppe PETA-CARB unter der Leitung von Guido Grosse führte im Sommer 2016 nach West-Alaska, um Landschaftsveränderungen in dieser Permafrostregion und die Kohlenstoffspeicher verschiedener Landschaftseinheiten zu untersuchen.

Die Reise führte am 6. August 2016 vom AWI Potsdam über Berlin-Tegel und Anchorage nach Kotzebue. Von hier aus wurden die Untersuchungsgebiete Kobuk Delta, Noatak Delta und Selawik Delta, sowie die Baldwin-Halbinsel und Nördliche Seward-Halbinsel mit dem Wasserflugzeug erreicht. Am 17. August wurde die Expeditionsbasis von Kotzebue nach Nome verlegt. Von dort aus erreichte das Team die zentrale Seward Halbinsel per Jeep und Helikopter. Am 21. August verließ das Team Nome wieder Richtung Anchorage und trat die Heimreise an.

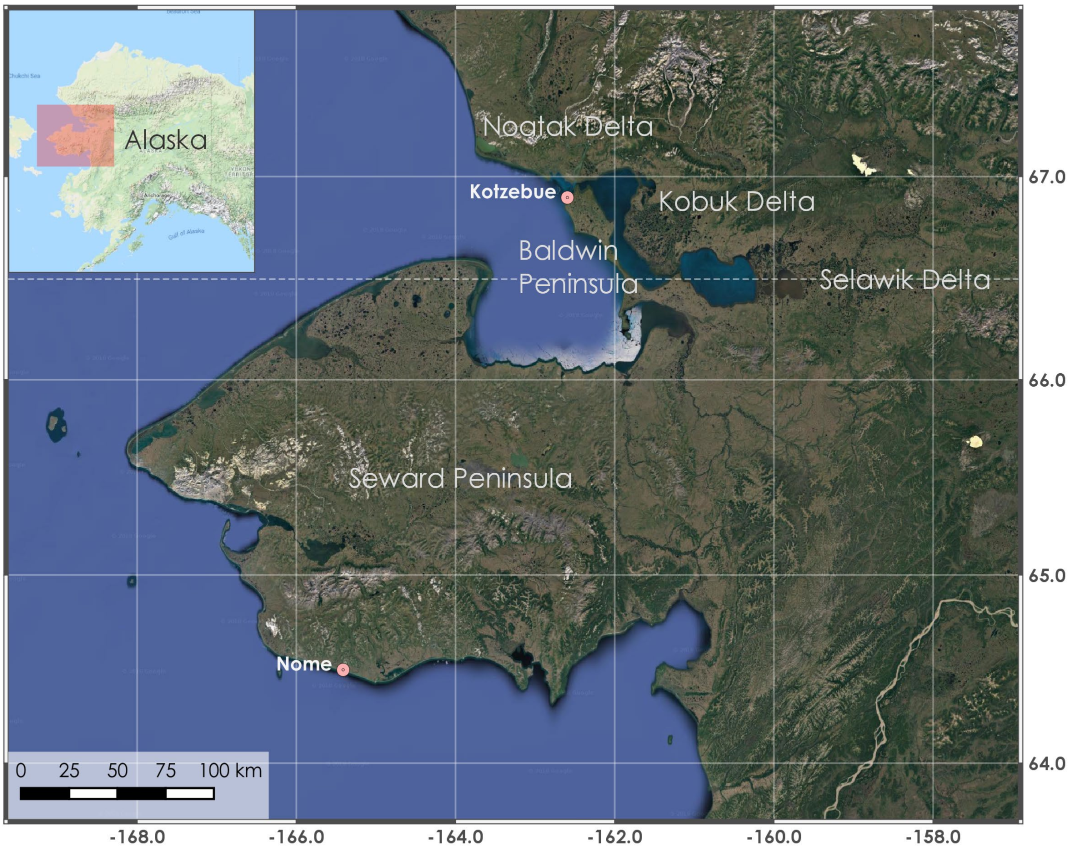

Abb. 1*: Untersuchungsgebiet der Expedition PETA-CARB West Alaska 2016 (Google Satellite and Terrain)*

Fig. 1*: Study area of the expedition PETA-CARB West Alaska 2016 (Google Satellite and Terrain*

SUMMARY AND ITINERARY

Josefine Lenz
Alfred Wegener Institute

Field work of the ERC group PETA-CARB led by Guido Grosse was carried out in western Alaska in summer 2016. The aim of the research group was to investigate landscape changes in permafrost regions and to quantify carbon stocks of different landscape units.

On August 6th 2016, the AWI team started its journey from AWI Potsdam via Berlin-Tegel and Anchorage to Kotzebue. Field sites in the Kobuk, Noatak and Selawik river deltas, as well as on the Baldwin Peninsula and on the northern Seward Peninsula were accessed by floatplane based out of Kotzebue. On August 17th, the base camp was moved from Kotzebue to Nome. From here, the research group reached the central Seward Peninsula by jeep and helicopter. The team left Nome on August 21st 2016, traveling via Anchorage back to Germany.

1. INTRODUCTION

Guido Grosse and Josefine Lenz
Alfred Wegener Institute

1.1 Scientific rationale and objectives

Permafrost is changing in a warming Arctic and some regions are affected stronger than others. Western Alaska in particular is interesting for a better understanding of permafrost degradation due to the presence of broad climatic, environmental and permafrost gradients spanning the sporadic, discontinuous, and continuous permafrost regions. In addition, the region is characterized by many different landscapes types that are of interest for a better understanding of the permafrost carbon pool and its dynamics, including yedoma deposits, thermokarst lakes and basins, and river deltas. Within the ERC PETA-CARB project at AWI, studies of landscape dynamics and permafrost carbon pools are combined to enhance assessments of deep carbon pools, their vulnerability to mobilization, and the potential feedbacks of permafrost changes on the global scale. As part of this project, the West-Alaska 2016 expedition targeted various field sites (Fig. 1) to collect samples for permafrost carbon pool quantification in yedoma, thermokarst and river delta deposits. Reconnaissance overflights were conducted with aerial photography for ground truthing Landsat satellite-derived land cover trends for important landscape disturbances such as thermokarst, thermo-erosion, thermokarst lake formation, growth and drainage, wetting and drying, and wildfires.

The objectives of the expedition were to

- identify and sample yedoma deposits in western Alaska
- collect sediment cores of multiple thermokarst lakes in western Alaska
- collect soil and permafrost cores in thermokarst basins and river deltas in western Alaska
- collect water samples from a range of lakes, other aquatic environments, and permafrost ground ice
- conduct aerial surveys across a wide variety of landscape types and disturbances
- visit and sample maar lakes on the Seward Peninsula.

1.2 Expedition itinerary and general logistics

Six scientists from the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) and the US Geological Survey (USGS), as well as two floatplane pilots (Jim Webster from Webster's Flying Service and Jim Kincaid from Northwestern Aviation) took part in the field work in western Alaska, 6-24 August 2016 (Tab. A1 and A2, Fig. 2). The expedition itinerary is shown in Table 1.

The USGS in Anchorage provided the base for preparing and organizing logistics before and for preparing samples for shipping after field work.

Access to the Kobuk, Noatak and Selawik river deltas, as well as the Baldwin Peninsula and northern Seward Peninsula, was enabled based out of the town of Kotzebue during the first part of the expedition, 7-17 August. Most sites were reached by floatplane and within walking distance from the landing lakes; survey flights were conducted with a more cost- and time-efficient plane on wheels (Fig. 3). Part of the Baldwin Peninsula was also reached by boat (Fig. 3). In Kotzebue, accommodation was kindly provided by the U.S. Fish and Wildlife Service.

To access the central Seward Peninsula during the second part of the expedition (17-21 August) based out of the city of Nome, the participants drove with a 4-wheel drive jeep along the Kougarouk Road. On 19 August, a helicopter chartered from Bering Air (R44 Raven II, N776BH, Fig. 3) provided access to more remote field sites near Last Bridge.

Field work was completed on 20 August, all participants arrived in Anchorage on 21 August, and all samples and core material left in 9 boxes of checked luggage with two participants (Strauss, Fuchs) on 23 August. The expedition lead (Grosse) left 2 scheduled days earlier and two participants (Nitze, Lenz) stayed in Alaska for further field work and meetings.

***Fig. 2**: Participants of the expedition West Alaska 2016 from left to right: Jens Strauss, Ingmar Nitze, Matthias Fuchs, Guido Grosse (all AWI), Benjamin M. Jones (USGS), Jim Webster (Webster's Flying Service) and Josefine Lenz (AWI); not in the picture: Jim Kincaid (Northwestern Aviation). Photo: J. Lenz*

Tab. 1: Time table for the expedition West Alaska 2016

Date	Day	Location	Travel or Scientific task	Mode of travel
06.08.2016	Sat	Potsdam/ Berlin/ Anchorage	*Travel BER-ANC*; Logistical preparation (food, equipment, baggage)	intern. flight, USGS jeep
07.08.2016	Sun	Anchorage/ Kotzebue	Logistical preparation (food, equipment, baggage); Travel ANC-OTZ	USGS jeep domestic flight
08.08.2016	Mon	Kotzebue	Survey flight #1 Kobuk	wheel plane
09.08.2016	Tue	Kotzebue	Permafrost coring Kobuk delta (KOB16-T6)	float plane
10.08.2016	Wed	Kotzebue	Permafrost coring Kobuk delta (KOB16-T7), exposure sampling Baldwin Peninsula (BAL16-01,02 and 03)	float plane, boat
11.08.2016	Thu	Kotzebue	Lake coring Kobuk delta (KOB16-T6 and T7), survey flight #2 Seward Peninsula	float plane, wheel plane
12.08.2016	Fri	Kotzebue	Permafrost coring Kobuk delta (KOB16-T2), lake coring Kobuk delta and upland (KOB16-T2 and T1, KOB16-UPL1 and UPL2) and Baldwin Peninsula (BAL16-UPL1)	float plane
13.08.2016	Sat	Kotzebue	Permafrost coring Noatak delta (NOA16-T3), lake coring Noatak delta (NOA16-T3 and T4), exposure sampling Baldwin Peninsula (BAL16-02, 04 and 05)	float plane
14.08.2016	Sun	Kotzebue	Permafrost coring Noatak delta (NOA16-T4), Survey flight #3 Selawik	float plane, wheel plane
15.08.2016	Mon	Kotzebue	Permafrost coring Selawik delta (SEL16-T2), lake coring northern Seward Peninsula (NSP16-DMM)	float plane
16.08.2016	Tue	Kotzebue	DTLB coring Baldwin Peninsula (BAL16-DTLB-1 to 4), lake coring Selawik delta (SEL16-T1 and T2)	float plane
17.08.2016	Wed	Kotzebue/Nome	*Travel OTZ-OME*	domestic flight
18.08.2016	Thu	Nome	DTLB coring (CSP16-DTLB-1), lake coring (CSP16-L-1) and data logger reading central Seward Peninsula	jeep
19.08.2016	Fri	Nome	DTLB coring (CSP16-DTLB-2, -5, and -8 to -10), lake coring (CSP16-L-10, CSP16-L-5, CSP16-L-7) and data logger reading central Seward Peninsula	jeep, helicopter
20.08.2016	Sat	Nome	DTLB coring (CSP16-DTLB-3 and -4) and lake coring (CSP16-L-4, CSP16-L-31)	jeep
21.08.2016	Sun	Nome/ Anchorage	Logistical preparation (packing samples, cleaning equipment), *Travel OME-ANC*	domestic Flight
22.08.2016	Mon	Anchorage	Logistical preparation (re-packing samples for shipping, packing equipment)	USGS jeep
23.08.2016	Tue	Anchorage	*Travel ANC-BER*	intern. Flight

Fig. 3: *Modes of transportation to access field sites during the expedition West Alaska 2017: Planes on wheels and floats, boat, 4-wheel drive jeep and helicopter (Photos: Matthias Fuchs, Jens Strauss, Josefine Lenz)*

2. STUDY REGION AND GEOLOGICAL BACKGROUND

Josefine Lenz and Guido Grosse
Alfred Wegener Institute

The study region stretches between N 67.7° W 167.5° to N 64.5° W 156.7°. It is part of the western Alaska region and features a range of ecoregions, including Seward Peninsula and the Subarctic Coastal Plains in the Kotzebue Sound Area (Gallant et al. 1995). In this region, permafrost ranges from continuous in the northern part to discontinuous in the southern part (Jorgenson et al. 2008) and is relatively warm with mean annual permafrost temperatures of - 5 to -1 °C (Romanovsky et al. 2010). Discontinuous and warm permafrost can also be assumed for the valleys of the Kobuk, Selawik and Noatak rivers. The permafrost in the region is relatively thin with less than 100 m on the northern Seward Peninsula (Jorgenson et al. 2008).

The region is characterized by subarctic climate with mean annual air temperatures of -6 °C in Kotzebue. Summers are cool to moderate warm with a mean July temperature of 12 °C and winters are cold with mean January temperatures of -20 °C. Precipitation averages 230 mm/a with more than half the precipitation falling as rain in summer and early fall (US National Weather Service data, http://www.ncdc.noaa.gov/).

The vegetation of the study region ranges from Bering lowland tundra on the northern Seward Peninsula to shrub tundra in the central and southern Seward Peninsula, the Baldwin Peninsula, and the Noatak and Kobuk river deltas, and transitions to boreal forest upstream in the Kobuk and Selawik river valleys (Nowacki et al. 2002).

2.1 Kotzebue region

In the Kotzebue Sound area, marine deposits were exposed during the Illinoian transgression, which were overridden by large glaciers from the Kobuk, Noatak and Selawik valley. As a result, the Baldwin Peninsula was formed to a large push moraine complex composed of marine, fluvial and glacial sediments during the middle Pleistocene (Huston et al. 1990). After the glacier retreat, loess was deposited over till and outwash deposits (Hopkins 1965).

The bedrock of the Kobuk river delta is of sedimentary origin (Beikman 1980) and overlain by mainly coastal sedimentary deposits (Karlstrom 1964). Active and stabilized dune fields cover more than 750 km^2 of the Kobuk river valley which have formed during glacial periods. In contrast to the Kobuk delta, the bedrock dominating Noatak river delta is of igneous origin (Beikman 1980) and mainly covered by glacial or fluvial deposits (Karlstrom 1964). The upper Noatak river valley is characterized by large till and glacio-lacustrine deposits. The Selawik river delta is situated on similar extrusive igneous units as the Noatak river delta (Beikman 1980) but covered by coastal deposits (Karlstrom 1964).

The Kobuk, Selawik and Noatak river delta cover an area of approx. 1,300 km^2, 365 km^2, and 193 km^2, respectively.

While the Kobuk and Noatak River delta are underlain by continuous permafrost, the Selawik river delta is characterized by discontinuous permafrost (Brown et al. 1997) and prone to lake drainage events of small lakes (Lindgren et al. 2016). Overall, the region is considered to be among the 20 major lake districts in Alaska (Fig. 4).

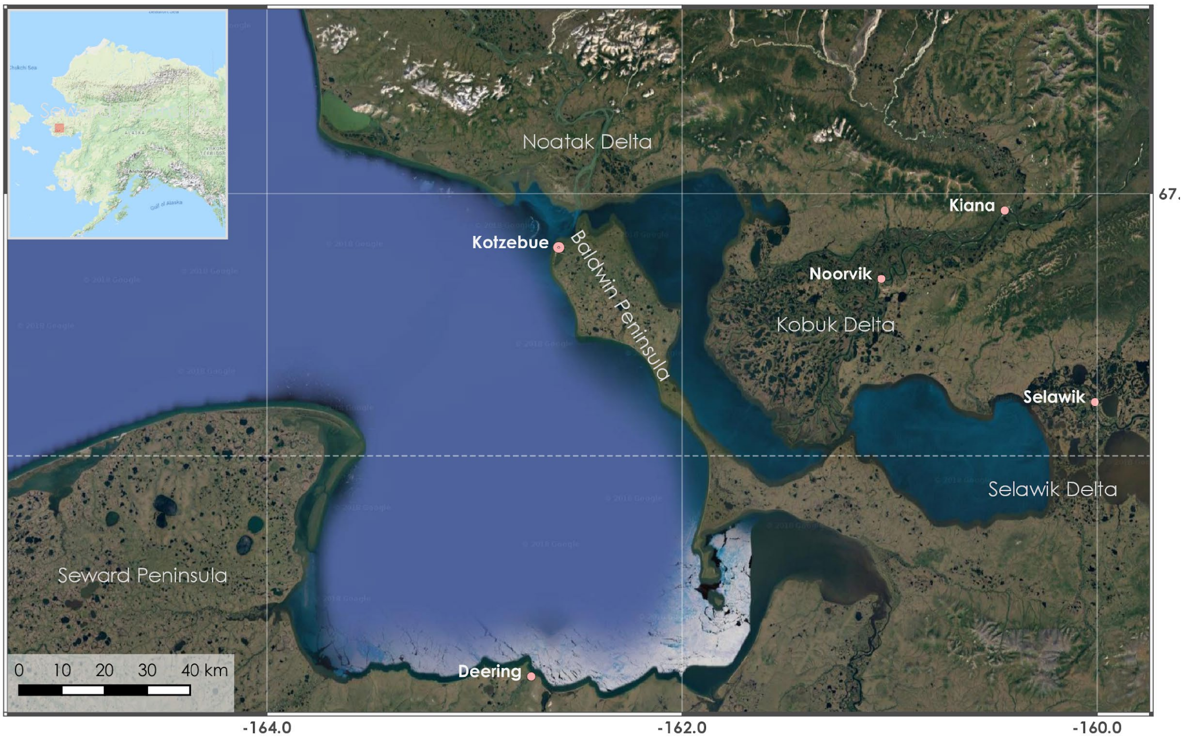

***Fig. 4**: The Kotzebue region with the Baldwin Peninsula and the Noatak, Kobuk and Selawik deltas (Google Satellite and Terrain)*

2.2 Northern Seward Peninsula

The northern Seward Peninsula (Fig. 5) is part of the Bering Land Bridge National Preserve and has not been glaciated during the Last Glacial Maximum. Thick syngenetic permafrost of the ice-rich yedoma suite accumulated in the region during the Late Pleistocene (Kanevskiy et al. 2011). During deglacial to early Holocene warming the global sea-level rise shifted the regional environmental setting from highly continental to more maritime and abundant thermokarst lakes formed due to thaw of ice-rich yedoma permafrost (Hopkins & Kidd 1988; Lenz et al. 2016a). Today, about 7.1 % of the surface area is covered by extant lakes > 1 ha (Arp & Jones 2009) and more than 75 % of the Cape Espenberg lowlands in the NE corner of the Seward Peninsula are reworked by thermokarst lake formation and drainage (Jones et al. 2012). The local geomorphology is not only characterized by periglacial features such as thermokarst lakes, drained thermokarst lake basins, remnants of yedoma uplands, erosional gullies, small streams, pingos and polygonal patterned ground (Jones et al. 2011; Regmi et al. 2012; Lenz et al. 2016b), but also by volcanic landforms including the Devil Mountain Volcano, several smaller Quaternary volcanic cone remnants and the four large Espenberg Maar lakes (Hopkins 1988; Begét et al. 1996). Devil Mountain Maar Lake (30 km²), South Killeak Maar (20 km²), North Killeak Maar (12 km²), and Whitefish Maar (8 km²) are the largest maar lakes on Earth and were estimated to have formed 17.5 ka, ~42 ka, >125 ka and 100-200 ka before present, respectively (Hopkins 1988; Begét et al. 1996).

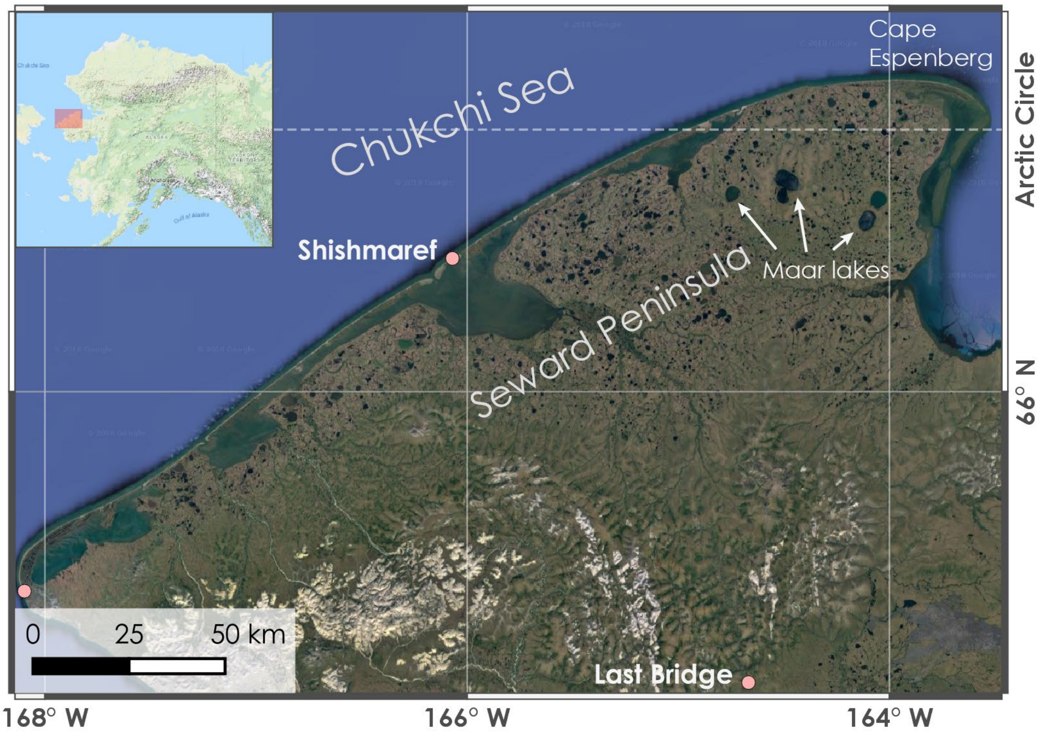

Fig. 5: *The northern Seward Peninsula (Google Satellite and Terrain)*

2.3 Central Seward Peninsula

The southern and central Seward Peninsula (Fig. 6) is characterized by river valleys and rolling uplands, to rugged and ice-sculptured peaks in smaller mountain ranges and the Kigluaik Mountains as largest range (Kaufman et al. 1987). Bedrock geology is composed of sedimentary limestones and schists that were locally intruded by igneous rocks, in particular greenstones, granite and rocks of granitic character (Brooks et al. 1901; Collier 1902). The region was glaciated in the Middle Pleistocene (~580-280 ka; Kaufman et al. 1991) and to a smaller extent during the Late Pleistocene (Kaufman and Manley 2004).

Unconsolidated beds of Pleistocene gravels, sands and clays are present in current river shores and older beds on high river terrace deposits, as well as in marine terraces and coastal plain sediments (Daniels 1905). Streams, hillslopes, glacial and marine sediments were mined for placer gold, producing 150 t gold between 1898 and 1993 in the Nome District (Bundtzen et al. 1994).

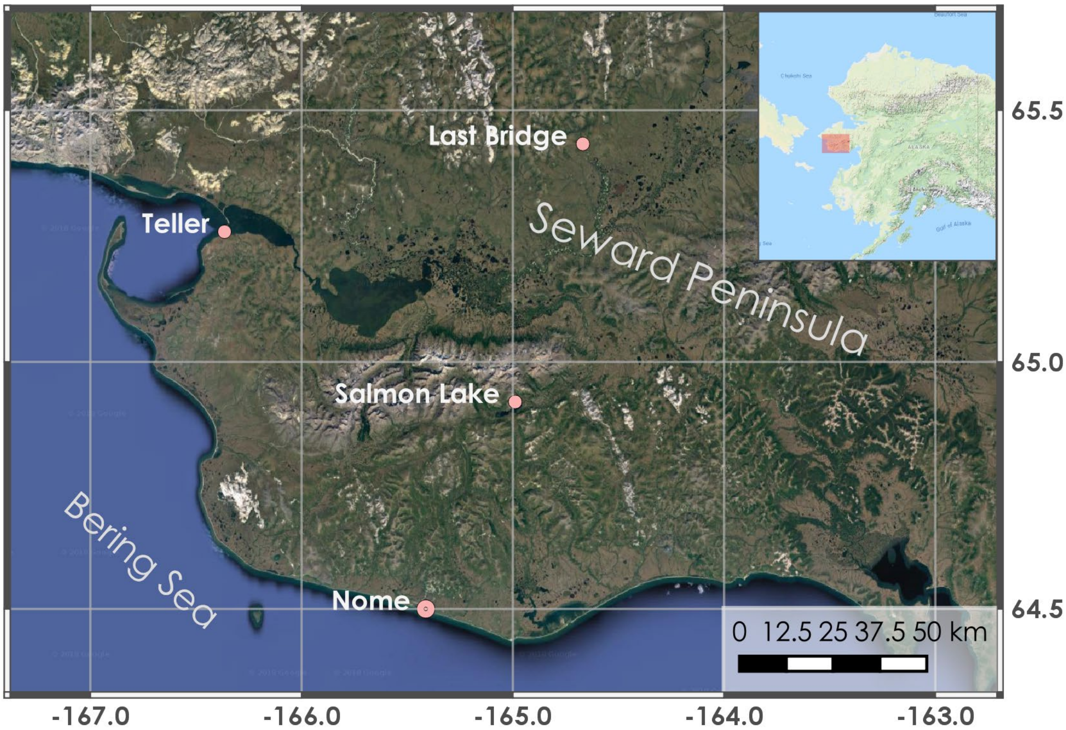

Fig. 6*: The southern and central Seward Peninsula (Google Satellite and Terrain)*

3. FIELD METHODS

3.1 Ground truth surveys

Ingmar Nitze
Alfred Wegener Institute

Aerial survey flights were conducted starting from Kotzebue to validate landscape changes observed in Landsat satellite disturbance trend maps (*cf.* Nitze & Grosse 2016). The flight paths were planned to overpass specific locations and landscape features, such as potential sites for changes in surface hydrology (e.g. lake formation, expansion and drainage), geomorphology or vegetation patterns among many other potential disturbances and landscape altering processes. During these survey flights, oblique GPS-located photos were taken. Furthermore, a camera (GoPro Hero 4 Session) was attached to the wing of the plane for most of the flights (Fig 7). This setup allowed for a systematic and continuous acquisition of aerial imagery.

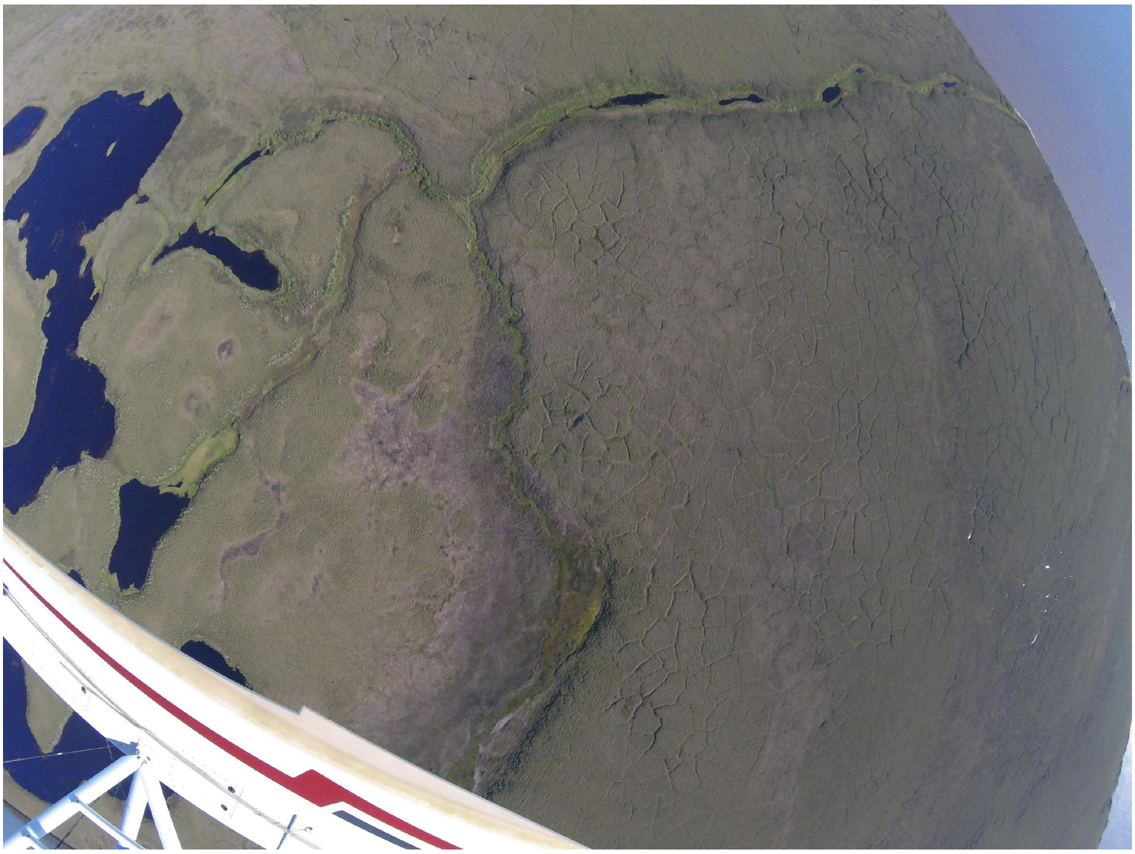

Fig. 7: *Aerial image acquired from an underwing-mounted GoPro camera over western Alaska*

3.2 Permafrost coring

Matthias Fuchs
Alfred Wegener Institute

For estimating organic carbon and nitrogen storage in Arctic delta deposits, multiple permafrost cores were collected in the Noatak, Kobuk and Selawik deltas. Sample sites were chosen along transects of about 600-1,200 m length (Fig. 9) according to preliminary GIS analysis of SPOT 5 satellite images to cover the geomorphological landscape units present in Arctic river deltas. In addition, site accessibility such as the proximity to a lake with sufficient size and depth for landing with the float plane, as well as wetness of the locations had to be taken into consideration.

Samples were collected by drilling with a modified, snow, ice, and permafrost (SIPRE) auger (Jon Holmgren's Machine Shop, Fairbanks) down to two meters below surface (Fig. 8). Prior to drilling, soil pits were excavated by shovels to the top of permafrost. The active layer was sampled with fixed volume cylinders. Soil permafrost cores were described and photographed in the field. The visual core description included cryostratigraphy, sedimentology and plant macrofossils. Cores were subsampled in 5-10 cm increments according to facies horizons and later transported to laboratory facilities at Alfred Wegener Institute Potsdam.

At AWI Potsdam, samples are freeze-dried, homogenized and analyzed for total carbon, total nitrogen, total organic carbon, grain size analysis and ice content. A subset of samples will be submitted to an external radiocarbon laboratory.

***Fig. 8**: Excavating the active layer and drilling permafrost cores in the Noatak river delta with the SIPRE auger and a permafrost core from the Kobuk river delta*

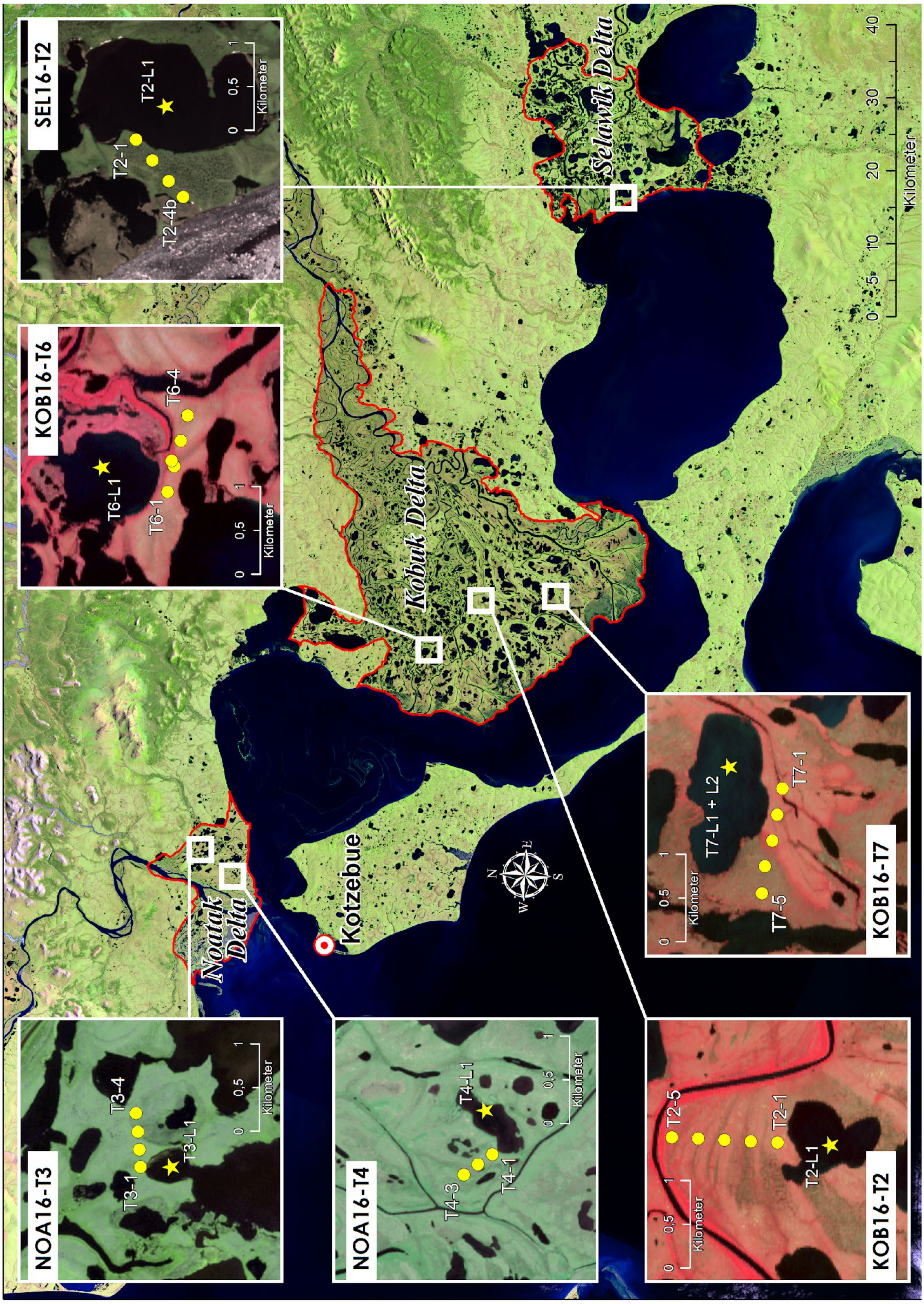

Fig. 9: *Sampling sites in the deltas. Yellow dots indicate the locations for permafrost sampling and yellow stars show the locations of lake sediment cores.*

3.3 Permafrost exposure sampling

Jens Strauss
Alfred Wegener Institute

In addition to the permafrost coring transects, exposures were sampled for retrieving sample material deeper than 3 m. In total, 5 exposures were sampled that were exposed by erosion along the Chukchi Sea coast on the Baldwin Peninsula (Fig 10).

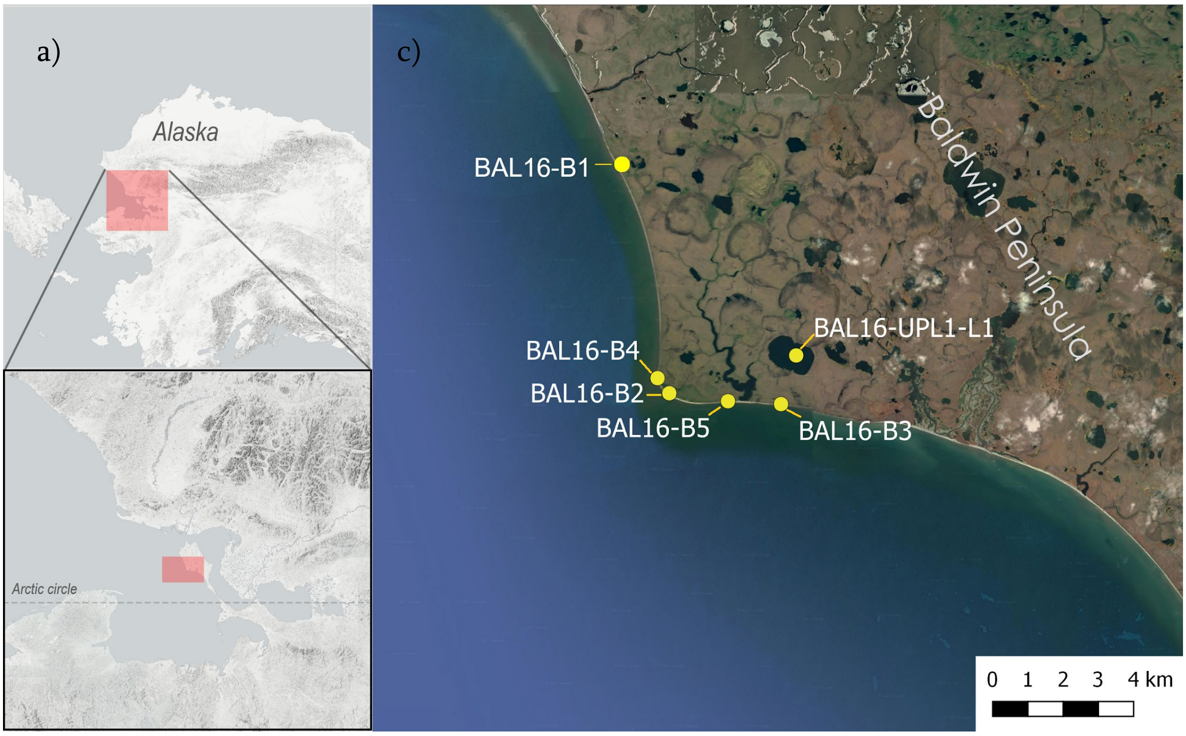

Fig. 10*: Map of study area. Overview map of Alaska (a) indicating in red the Kotzebue area. b) Detail map indicating in red the Baldwin Peninsula (c). Study sites are marked with yellow dots. The BAL16-UPL1-L1 core is a lake core described in the following chapter 3.4. (From Google Earth and CartoDB, from Jongejans 2017)*

One short profile covered glacial till sediments (BAL16-B1; Fig. 11); one Yedoma exposure (BAL16-B2) in a thaw slump exposure was sampled; one long drained lake basin profile (BAL16-B4) was sampled in detail; two short profiles from drained thermokarst lakes (BAL16-B3 and -B5) were sampled. The chosen sequences were surveyed, described, photographed, and sketched according to organic matter, sediment- and cryostructures.

Before sampling, the frozen exposure was cleaned with a hammer or a pick. One sample at each sampling depth (sample interval 20 to 50 cm) was taken for multidisciplinary studies (sedimentology, paleoecology, geochronology, biogeochemistry) using a hand held electric drill and a core-drill of 53 mm diameter. Drilling mud was removed for all samples.

The sample name code for the sediment samples is comprised of:

- study area and year: BAL16 for Baldwin Peninsula during 2016
- B for bluff: e.g. BAL16-B
- a number for each bluff: e.g. BAL16-B2
- a sample number: e.g. BAL16-B2-01

All samples were kept frozen during fieldwork and transfer to the laboratories at AWI Potsdam.

Fig. 11*: Profile BAL16-B1 description (left) before (right) sampling with a hand held drill (Photos: Josefine Lenz)*

3.4 Lake sediment coring

Josefine Lenz
Alfred Wegener Institute

All target lakes were selected based on their location in line with the permafrost coring transects or based on their location in specific landscape units, e.g. Yedoma uplands. The lakes were accessed by floatplane.

Short cores of thermokarst lakes were taken by using either one of two coring systems: A piston corer with extension rods was used for shallow lakes < 2 m and an UWITEC gravity corer was used for lakes with greater water depth. A custom-built coring platform was used for the first set of lake cores (Fig. 12). Here, a wooden coring platform lashed on two pack rafts with three anchors was held in place of the coring location. Although this coring set-up was easy to pack, transport and build in the field, largely calm weather conditions allowed for even more straightforward and faster coring from the floats of the floatplane.

Field sites were described (water depth, visibility, lake shape, shore stability, vegetation) and water samples were collected for laboratory analysis (see 3.5).

The surface of the lake sediment was sampled at the top of the PVC tubes (and at the bottom where applicable) for analyses of methane concentration. Here, a sample volume of 2-3 cm³ was taken with a syringe, filled in a glass vial with a NaCl solution for preservation, closed quickly with a rubber stopper and sealed with a metal ring applied with a crimping tool.

***Fig. 12**: Self-built coring platform with two rafts and floatplane on a thermokarst lake in the Kobuk river delta (left) and piston corer system with a short core from the floats of the floatplane on a very shallow thermokarst lake (right)*

3.5 Water sampling

Josefine Lenz
Alfred Wegener Institute

Water samples were taken from all thermokarst lakes where sediment cores were taken as well as from additional surface waters (e.g. ponds) for the analysis of dissolved organic carbon, anions, cations, stable water isotopes, pH and electrical conductivity. In addition, water samples were taken for isotope analyses from texture ice and ice-wedge ice in permafrost outcrops, from very ice-rich samples in permafrost cores, and from the active layer, as well as from rain and ocean water for reference.

Sample bottles were rinsed with the lake water for at least 3 times, and then filled to the top with the sampled water. Back in the field laboratory in Kotzebue, the samples were split and subsampled for the above mentioned analyses. The samples for analyses of dissolved organic carbon were filtered into a glass vial through a 0.7 µm GF/F filter and acidified with 20-50 µl HCl solution. Isotope samples were filled into 30 ml narrow mouth bottle leaving no air in the sample bottle. When sample material was left, it was filled into another 30 ml narrow mouth bottle for analyses of pH and electrical conductivity which was not performed in the field. All water samples were kept cool and shipped to AWI Potsdam for further analysis.

4. PRELIMINARY RESULTS AND INITIAL FINDINGS

4.1 Ground truth surveys

Ingmar Nitze
Alfred Wegener Institute

Three separate survey flights were conducted, all based out of Kotzebue in north-western Alaska (Tab. 2). Two flights in a Cessna 206 wheelplane were headed in easterly direction towards the Kobuk Dunes (#1 Kobuk) and the Selawik Slump (#3 Selawik) as the most distant destinations. A third flight was flown with a Cessna 185 floatplane over the northern Seward Peninsula southwest of Kotzebue (Fig. 13).

For Flight #1 georeferenced photos were acquired towards both sides of the plane. Additionally, for Flights #2 and #3, a GoPro Hero was mounted to the wing and acquired aerial imagery every two seconds. Battery capacity limited the acquisition to around the first 80 % of flight time.

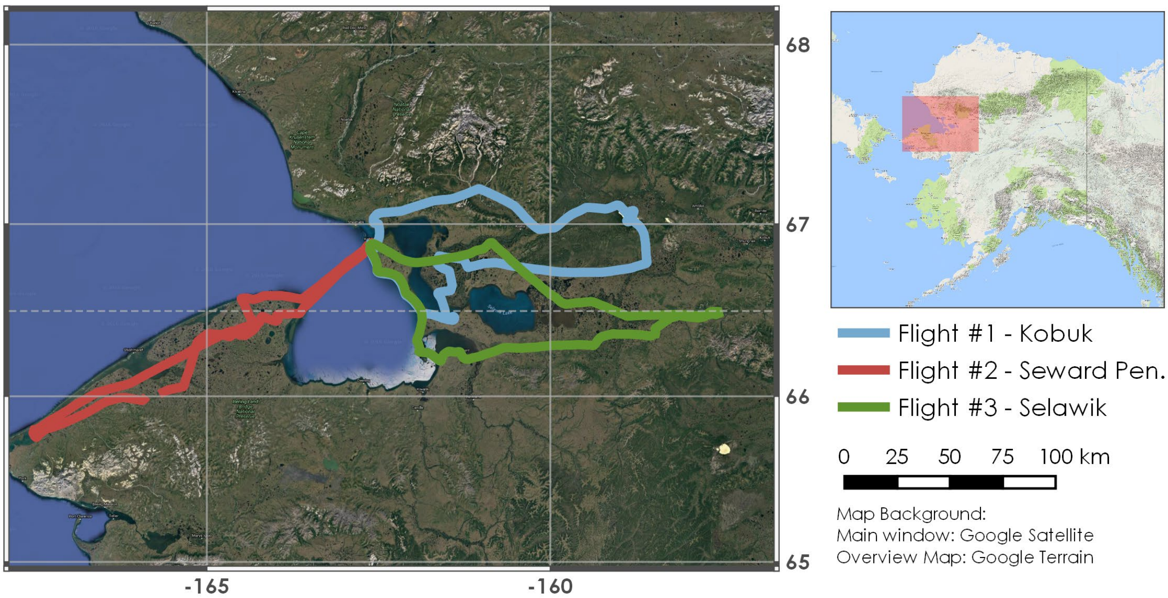

***Fig. 13**: Overview map of survey flights based from Kotzebue*

Tab. 2: Overview of survey flights with main flight parameters.*GoPro aerial images available for most of the flight time, due to restricted battery capacity

Flight ID	Date	Start	End	geo-tagged photos	GoPro	Weather
#1 Kobuk	08.08.2016	15:24	18:59	Yes	No	Sunny to cloudy with scattered showers
#2 Seward Peninsula	11.08.2016	11:12	15:10	Yes	Yes*	Mostly overcast with showers
#3 Selawik	14.08.2016	10:40	13:42	Yes	Yes*	Sunny to cloudy

4.2 Permafrost cores

Delta sediments

Matthias Fuchs
Alfred Wegener Institute

In total 25 soil permafrost cores were collected which resulted in 311 subsamples for sedimentological analyses and 62 additional samples for radiocarbon dating. 14 cores (Tab. 3) were collected along three transects (KOB16-T2, KOB16-T6, KOB16-T7) in the Kobuk river delta, 7 cores were collected along two transects (NOA16-T3, NOA16-T4) in the Noatak river delta and 4 cores were sampled along one transect (SEL16-T2) in the Selawik river delta.

The aim was to core down to two meters depth to capture some of the deeper permafrost soil carbon quantity and variability. For 19 out of 26 locations we were able to core to 2 m or deeper. Mean profile depth of the permafrost cores was 193 cm (median: 208 cm) with an average of 14 subsamples per site. Maximum depth reached was 241 cm (NOA16-T3-3). Altogether, the expedition crew cored about 50 m of permafrost sediment in the three river deltas.

Tab. 3: Sample locations in the Kobuk, Noatak, and Selawik river delta

ID	Latitude	Longitude	Date of collection	Profile depth [cm]	Active layer depth [cm]	Samples [n]
KOB16-T2-1	66.72263	-161.49969	12.08.2016	234	43	17
KOB16-T2-2	66.72532	-161.49960	12.08.2016	221	35	16
KOB16-T2-3	66.72801	-161.49950	12.08.2016	205	30	17
KOB16-T2-4	66.73070	-161.49940	12.08.2016	218	42	16
KOB16-T2-5	66.73339	-161.49930	12.08.2016	218	38	15
KOB16-T6-1	66.63101	-161.46895	09.08.2016	137	69	8
KOB16-T6-2	66.63145	-161.47582	09.08.2016	179	44	14
KOB16-T6-3	66.63185	-161.48258	09.08.2016	209	41	14
KOB16-T6-4	66.63248	-161.48923	09.08.2016	125	50	7
KOB16-T6-5	66.63270	-161.49624	09.08.2016	235	40	18
KOB16-T7-1	66.78189	-161.67030	10.08.2016	225	46	18
KOB16-T7-2	66.78133	-161.66345	10.08.2016	110	54	8
KOB16-T7-3	66.78073	-161.65694	10.08.2016	114	39	7
KOB16-T7-4	66.78015	-161.65028	10.08.2016	203	41	11
KOB16-T7-5	66.78159	-161.66218	10.08.2016	96	96	5
NOA16-T3-1	67.05343	-162.32569	13.08.2016	222	37	19
NOA16-T3-2	67.05368	-162.32114	13.08.2016	211	36	15
NOA16-T3-3	67.05392	-162.31659	13.08.2016	241	34	23
NOA16-T3-4	67.05418	-162.31173	13.08.2016	215	37	18
NOA16-T4-1	67.00857	-162.39964	14.08.2016	203	31	15
NOA16-T4-2	67.00997	-162.40252	14.08.2016	217	34	15
NOA16-T4-3	67.01137	-162.40540	14.08.2016	205	31	15
SEL16-T2-1	66.56392	-160.23835	15.08.2016	207	42	17
SEL16-T2-2	66.56221	-160.24358	15.08.2016	211	55	17
SEL16-T2-3	66.56051	-160.24882	15.08.2016	141	48	12
SEL16-T2-4b	66.55901	-160.25286	15.08.2016	204	42	16

Drained Thermokarst Lake Basins (DTLBs)

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Drained thermokarst lake basins (DTLB) are abundant in the study region and are an important component of thaw affected permafrost landscapes in western Alaska. To better understand the age distribution of lake drainage and the potential soil carbon dynamics following thermokarst lake drainage, we selected two regions for intense sampling of spatially overlapping DTLB, one on the Baldwin Peninsula (BAL) and one on the central Seward Peninsula (CSP). A total of 4 DTLB were sampled on the Baldwin Peninsula and 9 on the Seward Peninsula using a combined soil pit and SIPRE corer approach similar to the work conducted in the river deltas (Tab. 4). The soil pit was dug with a shovel and described, followed by SIPRE drilling starting on the permafrost table down to a minimum depth of 1 m. First, the total thickness of the terrestrial peat overlaying lacustrine sediments in the basin was recorded. Second, the soil pit and permafrost cores were visually characterized for lithology, colour, ice content, cryostructure, and then subsampled in the same way as the sites in the river deltas. Further, samples for radiocarbon dating the basal layer of peat were extracted.

Tab. 4: Sample locations on the Baldwin Peninsula and Central Seward Peninsula

ID	Latitude	Longitude	Date of collection	Profile depth [cm]	Active layer depth [cm]	Surface peat thickness [cm]	samples [n]
BAL16-DTLB-1	66.74554	-162.43087	16.08.2016	122	40	39	9
BAL16-DTLB-2	66.74727	-162.44057	16.08.2016	112	40	25	10
BAL16-DTLB-3	66.74915	-162.42340	16.08.2016	120	40	36	11
BAL16-DTLB-4	66.74673	-162.40511	16.08.2016	127	44	34	10
CSP16-DTLB-1	65.39249	-164.65349	18.08.2016	195	22	72	54
CSP16-DTLB-2	65.32206	-164.44366	19.08.2016	123	27	29	11
CSP16-DTLB-3	65.23336	-164.82108	20.08.2016	123	40	30	11
CSP16-DTLB-4	65.16696	-164.81131	20.08.2016	129	38	25	12
CSP16-DTLB-5	65.36743	-164.68073	19.08.2016	129	59	1	12
CSP16-DTLB-8	65.32206	-164.44366	19.08.2016	123	54	38	12
CSP16-DTLB-9	65.31904	-164.43872	19.08.2016	115	37	34	10
CSP16-DTLB-10	65.31674	-164.43909	19.08.2016	111	33	39	8
CSP16-DTLB-11	65.31614	-164.44735	19.08.2016	126	36	32	11

4.3 Permafrost exposures

Jens Strauss
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The exposure studies of this expedition were planned as a reconnaissance to find evidence of yedoma and ice-rich drained thaw lake basins. We found an approximately 16 m thick yedoma layer in the upper part of the exposed section at Cape Blossom on the Baldwin Peninsula. We were able to sample more than 10 m of it. Some results on this sampling campaign are published in a master thesis of Loeka Jongejans (2017), as well as in Jongejans et al. (2018).

BAL-B1 (till)

We assume that sediments at this site with its 7 subsamples (Fig. 14a) are a glacial till, characterized by greyish colour composed of silty sand. The uppermost 2 samples at 600 and 630 cm bs (below surface, surface referred as cliff top) showed reticulate cryostructures (Fig. 14b), otherwise no cryostructures were visible in the outcrop. At the lowermost sample we found a gravel layer and pebbles, rounded with a size of 3-4 cm diameter (Fig. 14a). Below sample 5, at ~ 730 to 740 cm depth, a brighter sandy layer was visible (next to the handle of the hammer, Fig. 14a). Brownish inclusions or oxidized parts were visible at subsample 4 and 5 (690 and 720 cm bs).

a) b)

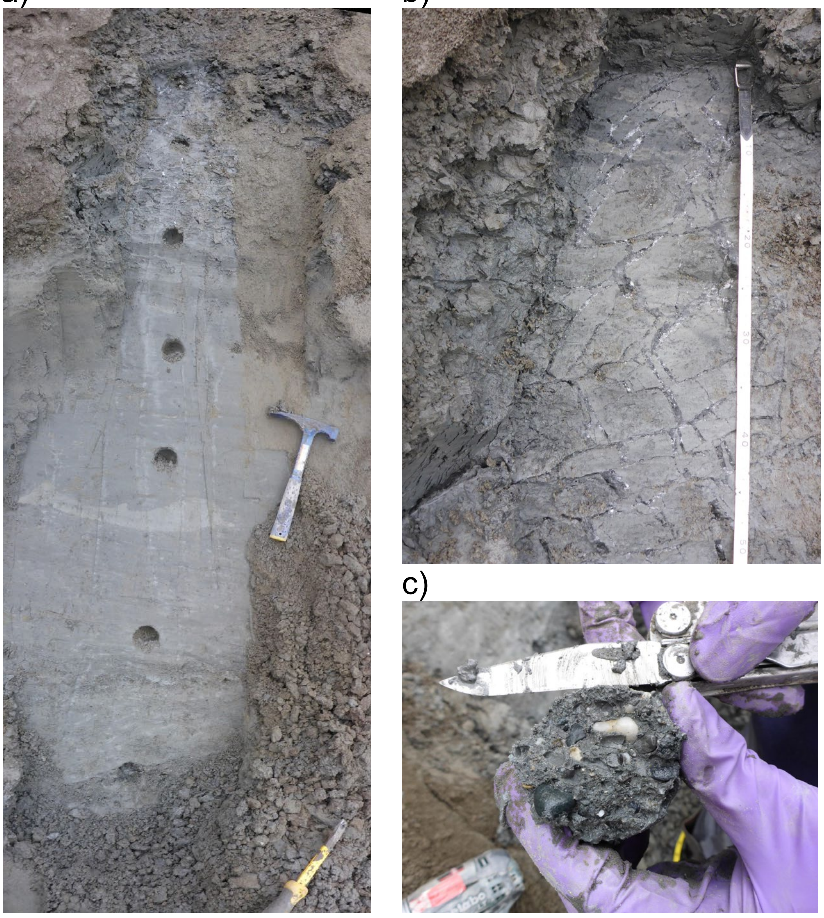


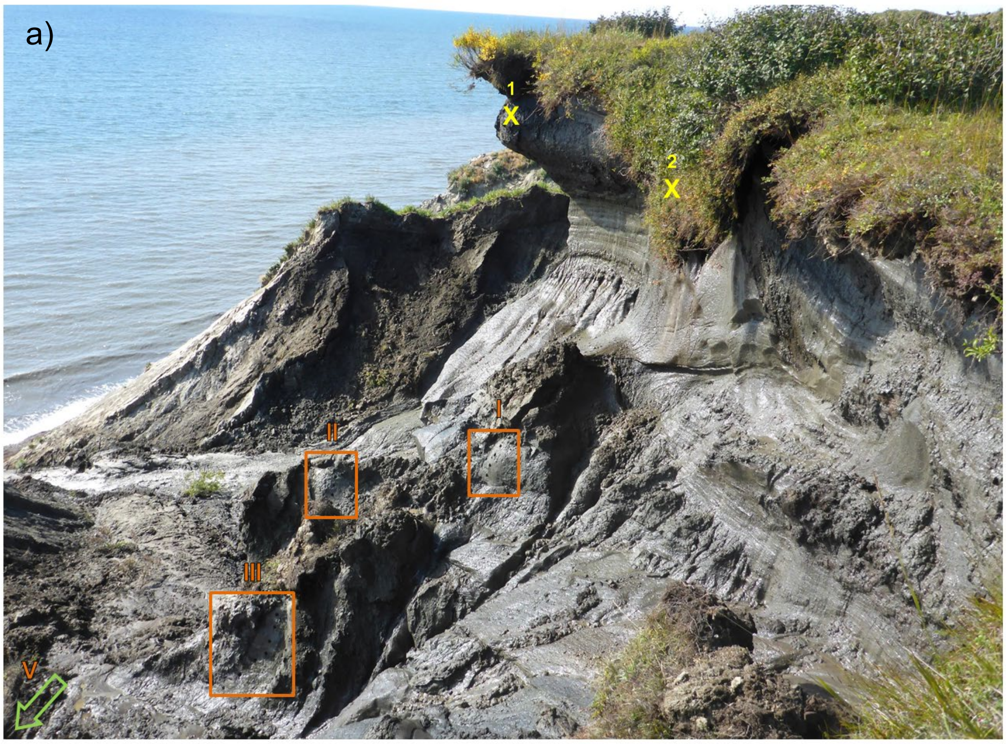
__Fig. 14__: Profile BAL16-B1: a) Complete section with sampling locations (each drilling whole is 57 mm); b) reticulate cryostructures at the uppermost samples at ~600 to 650 cm bs; c) gravel and pebbles at the lowermost sample at 795 cm bs

BAL16-B2 (yedoma section)

BAL16-B2 is a yedoma bluff of about 16 m thickness on top of medium silty sediments. The exposure was sampled in five different sampling zones I-V (Tab. 5). This classification is based on spatial variation in the exposure geometry and no stratigraphical differences are implied. The distinction into sampling zones I-V was made to clarify that the record is not continuous but rather a compilation of the exposure. Zones I, II, III and V are shown in Figure 15 and zone IV in Figure 17; for orientation similar points in the pictures are marked with yellow crosses 1 and 2. Depths are measured from the cliff top. Zone III contains small ice bands (< 2 mm) and macro lenses. Zone IV is brownish-grey and ice-rich; ice bands and ice lenses are present, as well as sparse organic remains and an organic band at 1,594 cm. Zone V is located in the sediments under the yedoma (not visible in the picture, hence the green arrow) and includes mega-lenses (< 30 cm long, 1-3 cm thick) with very clear ice.

Tab. 5: BAL16-B2 samples with corresponding depths in sampling zones I-V

Sampling zone	Sample ID	Depth [cm below surface]
I	BAL16-B2-20 to 27	620-965
II	BAL16-B2-28 to 32	1065-1142
III	BAL16-B2-33 to 39	1242-1399
IV	BAL16-B2-1 to 5	1500-1600
V	BAL16-B2-40 to 42	1700-1870



b)

Fig. 15: *Yedoma deposits at Cape Blossom, Baldwin Peninsula: a) Exposure BAL16-B2 (perspective 1). Sampling zone I, II and III indicated with orange rectangle and zone V indicated with green arrow. Yellow crosses 1 and 2 indicate similar points in the landscape as indicated in Fig. 4.2.; b) Exposure BAL16-B2 (perspective 2, person of 168 cm for scale), sampling zone IV indicated with orange rectangle. b) Close-up of sampling zone IV. Yellow crosses 1 and 2 indicate similar points in the landscape as indicated in a). Photos by Jens Strauss, figure compiled by Loeka Jongejans and published in Jongejans (2017)*

BAL16-B3 (drained thermokarst basin)

Exposure BAL16-B3 (Fig. 16) is about 4 m high and consists mainly of peat or peat inclusions. The upper three samples (B3-1 to B3-3) were taken from the active layer, whereas the other samples were taken from permafrost deposits. The permafrost is characterized by ice bands.

***Fig. 16**: Exposure BAL16-B3 with sampling locations*

BAL16-B4 (drained thermokarst basin)

Exposure BAL16-B4 (Fig. 17) is about 8 m high and contains different cryotextural features such as ice inclusions, lenses and veins. Further, inclusions of peat and organic remains are visible. The sediments are mostly laminated; the lower part (798 to 583 cm) contains pebble layers.

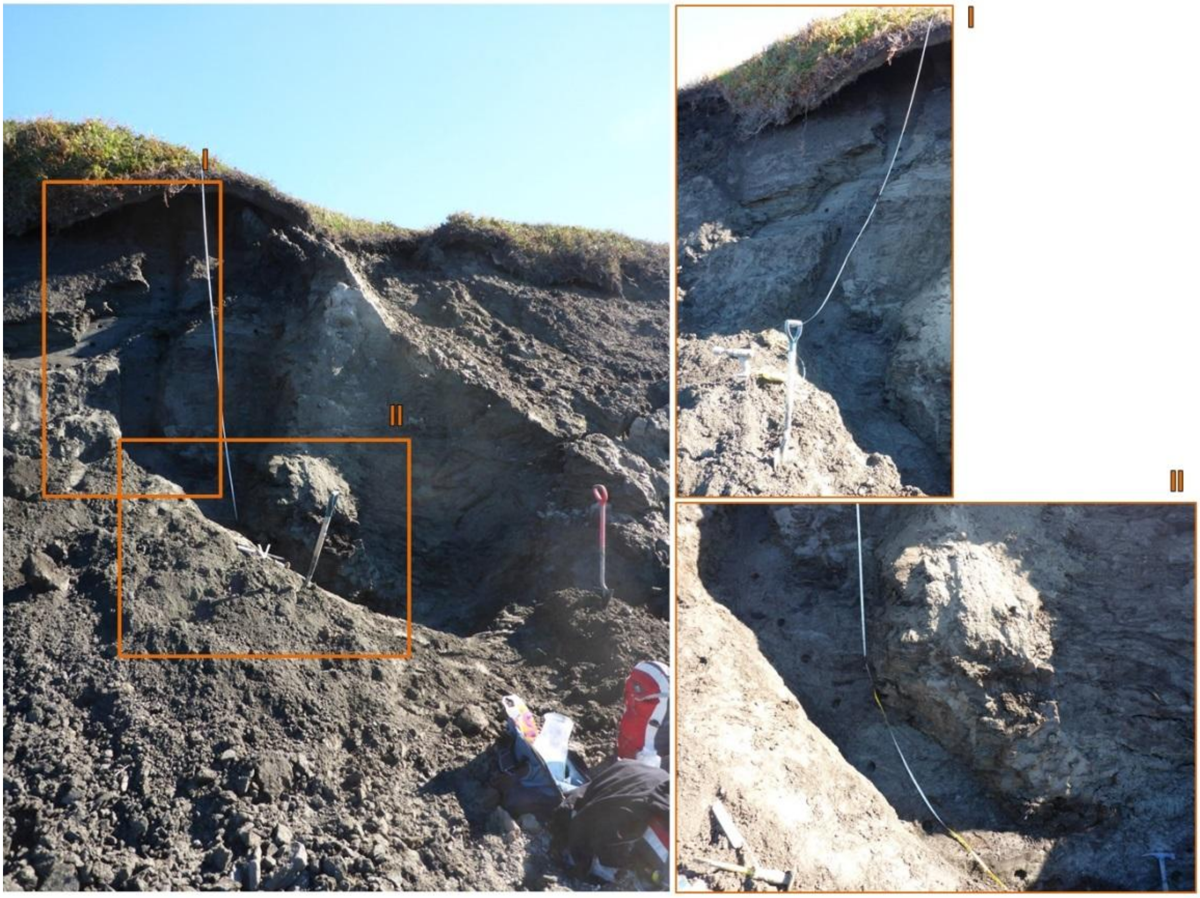


***Fig. 17**: Exposure BAL16-B4 and sampling areas I and II indicated with orange rectangles (left), close up of sampling areas I and II (right). Photos by Jens Strauss, figure compiled by Loeka Jongejans and published in Jongejans (2017)*

BAL16-B5 (drained thermokarst basin)

Exposure BAL16-B5 is about 3 m high and the deposits are very peaty (Fig 18). The uppermost meter was prepared for sampling. The active layer depth at this point was ~45 cm. On the top (first sample 0-8.5 cm) we found a dark reddish brown organic layer, dominated by sedge peat. The second sample at 16-22 cm was described as well decomposed sedge peat of same colour like above. Sample B5-03 was taken at 30-36 cm and included silt and peat layers. At 70-71 cm we identified the basis of a cryoturbation layer. At 80 cm a permafrost sample with silty ice rich sediment including macro remains was collected.

***Fig 18**: Exposure of profile BAL16-B5*

Tab. 6: List of samples taken at 5 exposures on Baldwin Peninsula

Exposure ID	Latitude	Longitude	Date of collection	depth uppermost sample [cm]	depth lowermost sample [cm]	n
BAL16-01	66.79088	-162.52790	10.08.2016	600	795	7
BAL16-02-*yedoma*	66.73261	-162.49450	10.08.2016 and 13.08.2016	620	1400	26
BAL16-02-*below yedoma*	66.73261	-162.49450	13.08.2016	1700	1885	3
BAL16-03	66.72987	-162.42284	10.08.2016	5	200	9
BAL16-04	66.73645	-162.50208	13.08.2016	0	798	40
BAL16-05	66.73060	-162.45685	13.08.2016	0	82	6

4.4 Lake sediment cores

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Twenty short lake sediment cores were collected from 17 thermokarst lakes and one maar lake (Tab. 7). Two thermokarst lakes were cored with both lake coring systems (UWITEC gravity corer and piston corer). 8 cores were taken from lakes in the Kobuk river delta, 2 from Noatak river delta and 2 from the Selawik river delta, one from the Baldwin Peninsula, 6 from the central Seward Peninsula and one on the northern Seward Peninsula from the Devil Mountain Maar Lake. The overall core length was 695 cm with 78 cm being the longest core and 12 cm the shortest core (average of 35 cm).

Mean water depth of all sampled thermokarst lakes was 152 cm with waters as shallow as 75 cm and deep as 315 cm. A 50 cm short core was retrieved from Devil Mountain Maar Lake in about 70 m depth with the UWITEC gravity corer from the floatplane.

Tab. 7: Sediment cores from 18 lakes in the Kobuk, Noatak, Selawik river delta, Baldwin Peninsula, Central and Northern Seward Peninsula

ID	Latitude	Longitude	Date of collection	Core length [cm]	Water depth [cm]
KOB16-T1-L1	66.73325	-161.58003	12.08.2016	78	170
KOB16-T2-L1	66.71720	-161.49977	12.08.2016	44	205
KOB16-T6-L1	66.63663	-161.46395	11.08.2016	54	185
KOB16-T7-L1	66.78876	-161.66473	11.08.2016	17.5	195
KOB16-T7-L2	66.78876	-161.66473	11.08.2016	47	195
KOB16-UPL1-L1	66.67647	-161.00629	12.08.2016	28	95
KOB16-UPL2-L1	66.68071	-161.10687	12.08.2016	34	315
KOB16-UPL2-L2	66.68070	-161.10677	12.08.2016	35	300
NOA16-T3-L1	67.05038	-162.32536	13.08.2016	33	125
NOA16-T4-L1	67.00958	-162.38828	13.08.2016	37	85
SEL16-T2-L1	66.56104	-160.22960	16.08.2016	27	125
SEL16-T1-L1	66.58853	-160.17230	16.08.2016	37	180
BAL16-UPL1-L1	66.74220	-162.41310	12.08.2016	34	135
CSP16-L-1	65.39178	-164.65263	18.08.2016	45	120
CSP16-L-10	65.31858	-164.42291	19.08.2016	31.5	130
CSP16-L-31	65.23412	-164.82037	20.08.2016	16	85
CSP16-L-4	65.16657	-164.80814	20.08.2016	12	75
CSP16-L-5	65.36746	-164.68105	19.08.2016	21	80
CSP16-L-7	65.31622	-164.45276	19.08.2016	14	80
NSP16-DMM-L1	66.37222	-164.52237	15.08.2016	50	~7,000

4.5 Water samples

Josefine Lenz
Alfred Wegener Institute

A total of 66 water samples were taken in the field from diverse sites and water types (Tab. 8): 40 samples were taken from lakes (thermokarst lakes, oxbow lakes, maar lakes), 6 samples from ponds, 4 from permafrost ice, 5 from ice-wedge ice, 7 from active layer waters, 2 from ocean water and 2 from rain.

Tab. 8: Water samples taken from various sites in Western Alaska

ID	Latitude	Longitude	Date of collection	Water isotopes	DOC	LF [µS/cm]	pH	Water type
KOB16-T1-W1	66.73325	-161.58003	12.08.2016	x	x	227.4	7.82	lake
KOB16-T2-3-AL	66.72800	-161.49950	12.08.2016	x	x	-	-	active layer
KOB16-T2-W1	66.71720	-161.49977	12.08.2016	x	x	88.1	7.29	lake
KOB16-T6-W1	66.63070	-161.47093	09.08.2016	x	x	-	-	lake
KOB16-T6-W2	66.63230	-161.48952	09.08.2016	x	x	-	-	pond
KOB16-T6-W3	66.49932	-161.49998	09.08.2016	x	x	-	-	lake
KOB16-T6-W4	66.63248	-161.46955	09.08.2016	x	x	-	-	lake
KOB16-T6-W5	66.78876	-161.66473	09.08.2016	x	x	167.1	7.25	lake
KOB16-T7-2-AL	66.78133	-161.66345	10.08.2016	x	-	-	-	active layer
KOB16-T7-3-6 IW	66.78072	-161.65693	10.08.2016	x	x	-	-	ice-wedge
KOB16-T7-W1	66.78283	-161.66937	10.08.2016	x	x	175.0	7.40	lake
KOB16-T7-W2	66.78060	-161.67005	10.08.2016	x	x	157.6	7.49	lake
KOB16-T7-W3	66.78007	-161.65057	10.08.2016	x	x	47.5	4.68	pond
KOB16-T7-W4	66.78137	-161.65442	10.08.2016	x	x	-	-	oxbow lake
KOB16-T7-W5	66.63663	-161.46395	11.08.2016	x	x	162.1	7.66	lake
KOB16-UPL1-W1	66.67647	-161.00629	12.08.2016	x	x	29.6	6.18	lake
KOB16-UPL2-W1	66.68071	-161.10687	12.08.2016	x	x	117.1	6.71	lake
NOA16-T3-4-13_ice	67.05418	-162.31174	13.08.2016	x	-	-	-	permafrost
NOA16-T3-W1	67.05038	-162.32536	13.08.2016	x	x	375	7.62	lake
NOA16-T3-W2	67.05605	-162.30212	13.08.2016	x	x	350	7.72	lake
NOA16-T4-W1	67.00958	-162.38828	13.08.2016	x	x	3,490	9.11	lake
SEL16-T1-W1	66.56201	-160.22960	16.08.2016	x	x	174.2	7.31	lake
SEL16-T2-1-W1	66.56385	-160.23833	15.08.2016	x	-	-	-	pond
SEL16-T2-2-AL	66.56222	-160.24358	15.08.2016	x	-	-	-	active layer
SEL16-T2-4B_Pond	66.55901	-160.25285	15.08.2016	x	-	-	-	pond
SEL16-T2-L1	66.38002	-160.23750	15.08.2016	x	x	217.9	7.25	lake
SEL16-T2-W1	66.58853	-160.17230	16.08.2016	x	x	198.7	7.40	lake
SEL16-T2-W2	66.55677	-160.25494	15.08.2016	x	x	358	7.36	lake

BAL16-B1-W1	66.79088	-162.52790	10.08.2016	x	x	-	-	permafrost
BAL16-B2-IW-1	66.73262	-162.49450	10.08.2016	x	-	-	-	ice-wedge
BAL16-B2-IW-2	66.73263	-162.49451	10.08.2016	x	-	-	-	ice-wedge
BAL16-B2-IW-3	66.73264	-162.49452	10.08.2016	x	-	69.7	6.69	ice-wedge
BAL16-B2-outflow	66.73264	-162.49452	13.08.2016	x	-	-	-	permafrost
BAL16-B2-Ti-1	66.73264	-162.49452	10.08.2016	x	-	-	-	permafrost
BAL16-B2-W1	66.73265	-162.49453	10.08.2016	x	x	-	-	ocean water
BAL16-B3-W1	66.72987	-162.42284	10.08.2016	x	x	-	-	ice-wedge
BAL16-B3-W2	66.72988	-162.42285	10.08.2016	x	x	-	-	ocean water
BAL16-DTLB-1-AL	66.74554	-162.43087	16.08.2016	x	-	-	-	active layer
BAL16-DTLB-2-AL	66.74727	-162.44057	16.08.2016	x	-	-	-	active layer
BAL16-DTLB-3-AL	66.74915	-162.42340	16.08.2016	x	-	-	-	active layer
BAL16-DTLB-4-AL	66.74673	-162.40511	16.08.2016	x	-	-	-	active layer
BAL16-DTLB-CBL	66.74486	-162.43060	17.08.2016	x	x	107.3	6.29	lake
BAL16-DTLB-pond	66.74858	-162.43143	16.08.2016	x	x	-	-	pond
BAL16-UPL1-W1	66.74220	-162.41310	12.08.2016	x	x	101.2	6.32	lake

NSP16-DMM-L1-W1	66.37222	-164.52237	15.08.2016	x	x	-	-	lake
NSP16-DMM-L1-W2	66.37222	-164.52237	15.08.2016	x	x	123.0	7.28	lake
NSP16-NKM-W1	66.38201	-164.04045	16.08.2016	x	x	2,554	8.29	lake
NSP16-PRP-W1	66.54679	-164.44714	14.08.2016	x	x	406	7.92	lake
NSP16-RHL-W1	66.55822	-164.47587	14.08.2016	x	x	218.8	7.56	lake
NSP16-RHL-W2	66.55713	-161.47065	14.08.2016	x	x	133.6	6.79	lake
NSP16-SKM-W1	66.34602	-164.11681	15.08.2016	x	x	61.8	7.23	maar lake
NSP16-TIL-W1	66.54708	-164.44888	15.08.2016	x	x	628	8.07	lake
NSP16-UPP-W1	66.54907	-164.46185	14.08.2016	x	x	102.5	6.77	lake
NSP16-W1	66.39072	-164.49969	11.08.2016	x	x	-	-	maar lake
NSP16-W2	66.39133	-164.49969	11.08.2016	x	x	134.7	7.61	maar lake
NSP16-WFM-W1	66.39273	-164.27458	16.08.2016	x	x	832	7.63	maar lake
NSP16-YEP-W1	66.58213	-164.19273	16.08.2016	x	x	475	8.01	pond

CSP16-L-10-W1	65.31858	-164.42291	19.08.2016	x	x	53.5	6.60	lake
CSP16-L-1-W1	65.39178	-164.65263	18.08.2016	x	x	71.2	6.29	lake
CSP16-L-31-W1	65.23412	-164.82037	20.08.2016	x	x	64.2	6.49	lake
CSP16-L-4-W1	65.16657	-164.80814	20.08.2016	x	x	58.8	6.26	lake
CSP16-L-5-W1	65.36746	-164.68105	19.08.2016	x	x	61.2	6.26	lake
CSP16-L-7-W1	65.31622	-164.45276	19.08.2016	x	x	42.8	6.44	lake
CSP16-LBR-Rain	65.40479	-164.65411	20.08.2016	x	-	-	-	rain
CSP16-SAL-W1	64.91734	-164.99832	18.08.2016	x	x	158.0	7.34	lake

SSP16-NOM-Rain	64.50089	-165.39812	21.08.2016	x	-	-	-	rain

5. Concluding remarks

Data from this expedition have been used so far in one Master thesis (Jongejans 2017), two PhD theses (Nitze 2018, Fuchs 2019), and several conference abstracts. Several publications fully or partially built on results from this expedition, including Nitze et al. 2017 (Remote Sensing), Nitze et al. 2018 (Nature Communications), Jongejans et al. 2018 (Biogeosciences) and Jones et al. 2020 (Environmental Research Letters), Nitze et al. 2020 (The Cryosphere), Stolpmann et al. 2020 (Biogeosciences), Strauss et al. 2021 (Frontiers in Earth Sience), Strauss et al. 2022 (Nature Communications). Several additional publications are in preparation.

Acknowledgements

This field research was carried out by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research and the U.S. Geological Survey, Anchorage. Financial support was gratefully received from the European Research Council (#338335) and the Helmholtz Association Development and Networking Fund (ERC-0013). We wish to thank Bering Air, the U.S. Fish and Wildlife Service in Kotzebue, NANA Regional Cooperation and the U.S. National Park Service for their support of this fieldwork or their permissions granted.

Field work in this remote area would not have been possible without great aviation service of Northwestern Aviation and Webster`s Flying Service. We wish to express our deepest gratitude to Jim Webster of Webster`s Flying Service – we are grateful to have worked many years with Jim, before he passed away in the field in 2020.

In Memoriam Jim Webster,
pilot of Webster's Flying Service,
who passed away in spring 2020.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

Results from this expedition contribute to the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 5, Subtopic 3.

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APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

Affiliation	Address
AWI	Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung in der Helmholtz-Gemeinschaft Postfach 60 01 49 14401 Potsdam Germany
USGS	US Geological Survey 4210 University Dr. Anchorage AK 99508-4626 United States of America

A.2 FAHRTTEILNEHMER:INNEN / FIELD PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession
Grosse	Guido	AWI Potsdam	Geologist, Group lead
Strauss	Jens	AWI Potsdam	Geoecologist, Postdoc
Lenz	Josefine	AWI Potsdam	Geographer, Postcoc
Fuchs	Matthias	AWI Potsdam	Geographer, PhD student
Nitze	Ingmar	AWI Potsdam	Geographer, PhD student
Jones	Benjamin M.	USGS (now UAF)	Geographer, Senior Researcher
Webster	Jim	Webster's Flying Service	Floatplane Pilot
Kincaid	Jim	Northwestern Aviation	Floatplane Pilot

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