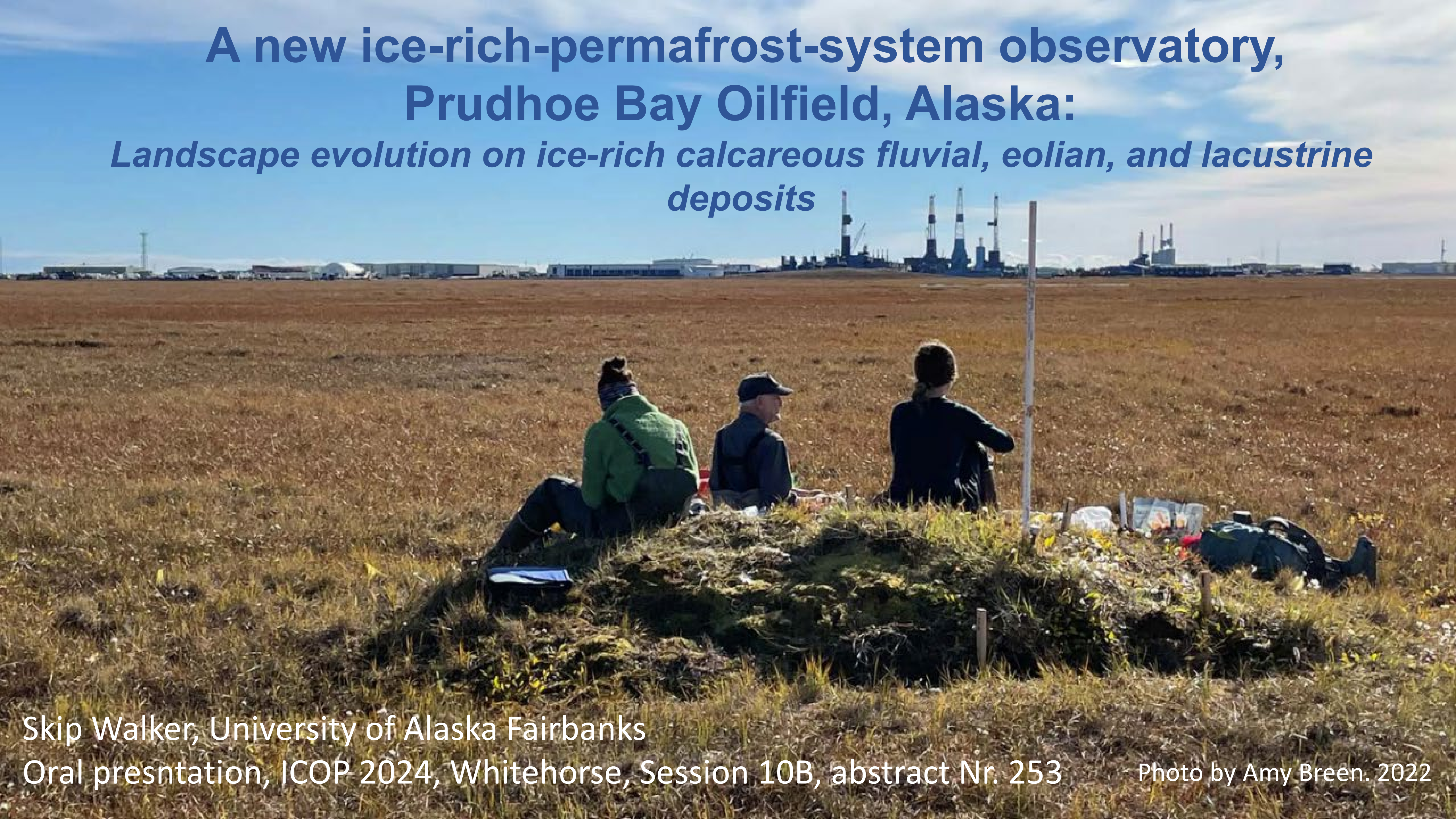
A new ice-rich-permafrost-system observatory, Prudhoe Bay Oilfield, Alaska:

Landscape evolution on ice-rich calcareous fluvial, eolian, and lacustrine deposits



Skip Walker, University of Alaska Fairbanks

Oral presntation, ICOP 2024, Whitehorse, Session 10B, abstract Nr. 253

Photo by Amy Breen. 2022

NSF Navigating the New Arctic (NNA) Program

Landscape evolution in Ice-Rich Permafrost Systems (NNA-IRPS)

NNA-IRPS Landscape Evolution component contributors: Skip Walker, Amy Breen, Ronnie Daanen, Nick Hasson, Olivia Hobgood, Torre Jorgenson, Anja Kade, Benjamin Jones, Mikhail Kanevskiy, Anna Liljedahl, Dmitry Nicolsky, Jana Peirce, Stuart Rawlinson, Martha Raynolds, Vladimir Romanovsky, Sergei Rybakov, Yuri Shur, Emily Watson-Cook, Julia White, Simon Zwieback

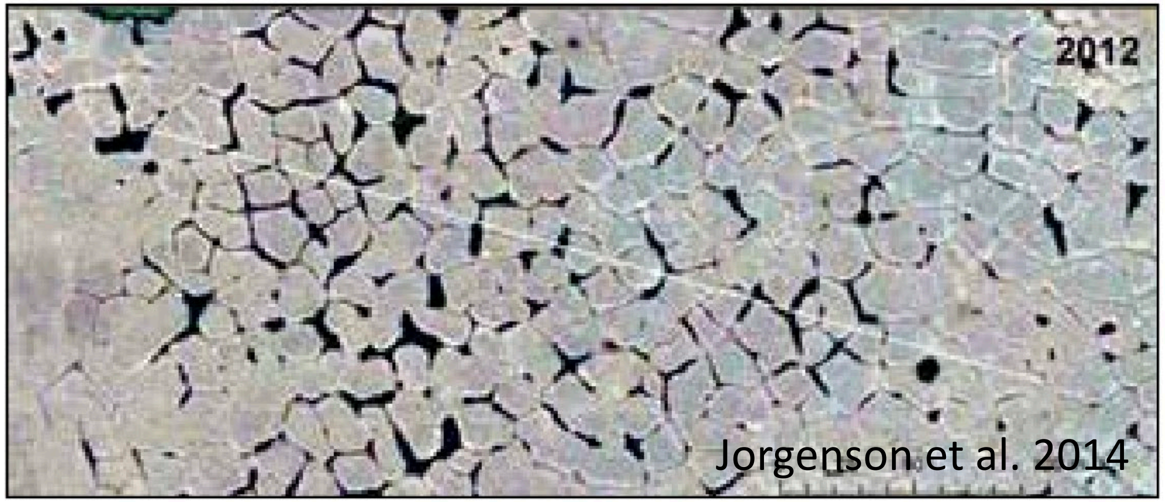
Main points of the talk

1. An update on the new ice-rich permafrost observatory at Deadhorse, Alaska.
2. Application of rediscovered surficial geology maps to the analysis of permafrost and landscape evolution in the Prudhoe Bay region.
3. New landform and vegetation legends and maps.
4. The unique nature of the nonacidic calcareous permafrost ecosystems of the Central Arctic Coastal Plain.

How to put the dramatic changes to Prudhoe Bay landscapes due to ice-wedge degradation in the context of the underlying surficial geology?

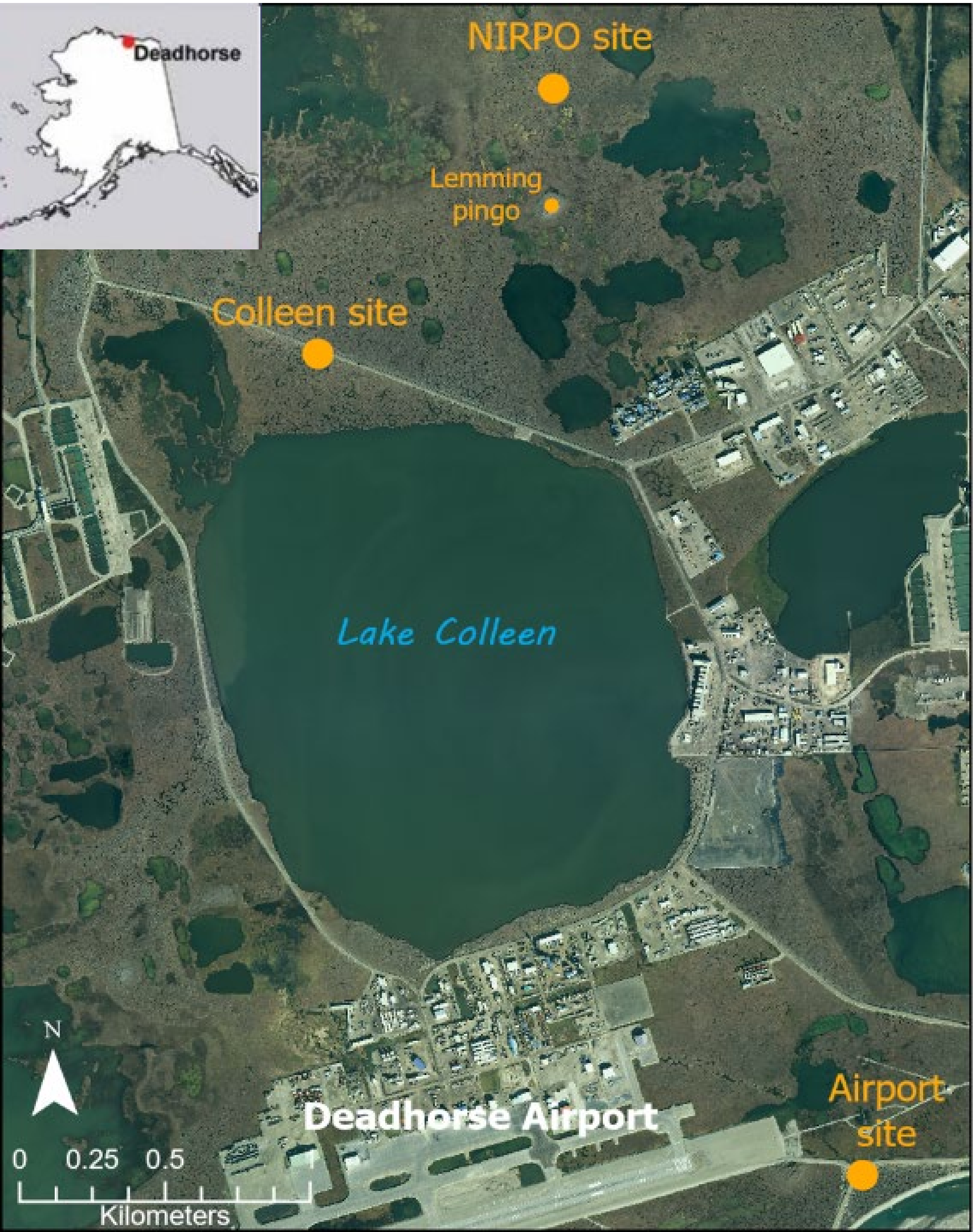
Abrupt transformation of tundra ecosystems from ice-wedge degradation in the Prudhoe Bay region

Jorgenson et al. 2006, GRL, 25, L02503
Raynolds et al. 2014, GCB,
Jorgenson et al. 2015, JGR, 120, 2280-2297
Kanevskiy et al. 2017, Geomorphology, 297:20-42
Jorgenson et al. 2022, Global and Planetary Change 216: 203921



Alluvial gravel surficial deposits of the Central Arctic Coastal Plain

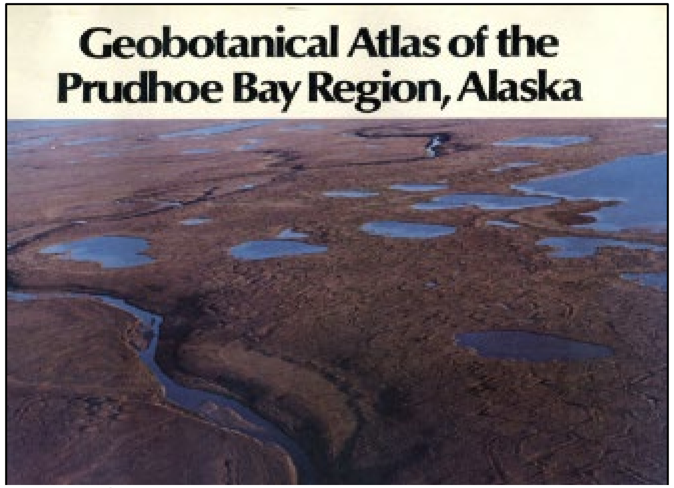
Everett and Parkinson, 1977, AAR, 9, 1–19
Walker et al. 1980, CRREL Report 80-14
Walker et al. 1985, AAR, 17, 321-336
Walker, D.A. 1985, CRREL Report 85-14
Rawlinson, 1993, DGGS 93-1
Walker et al. 2001, QSR, 20, 149-163



Locations of the three primary NNA-IRPS research sites, Deadhorse AK

- Eastern part of the Prudhoe Bay Oilfield
- Northern end of the Dalton Highway
- Natural Ice-Rich Permafrost Observatory (NIRPO, focus of this talk)
- Roadside disturbance observatories
  - Colleen site
  - Airport site

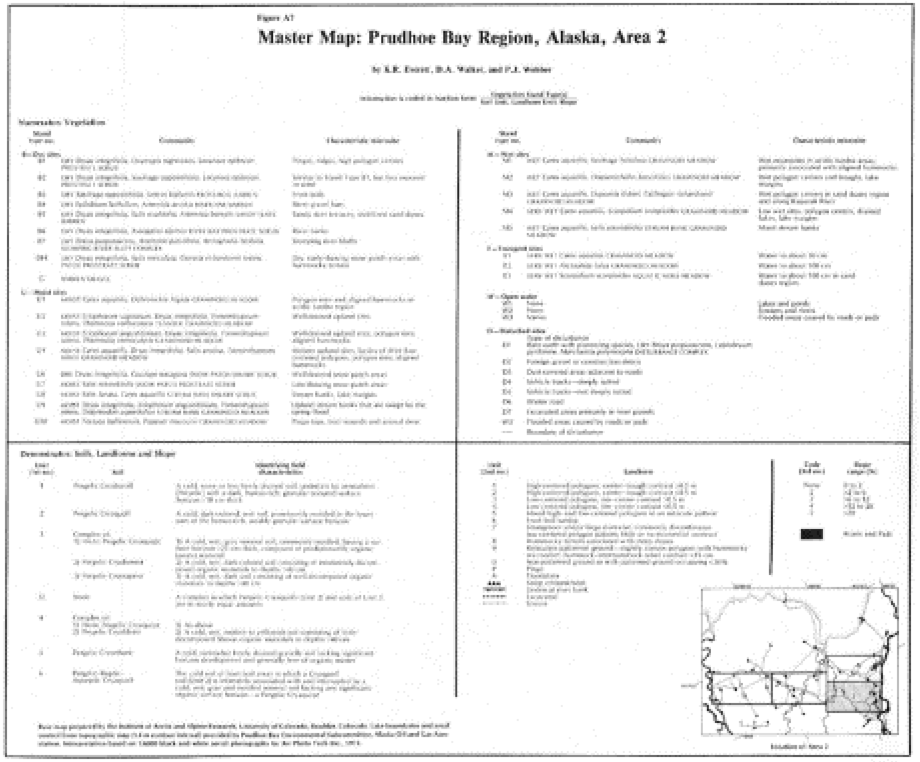
The Prudhoe Bay region has a long history of permafrost and ecosystem research.

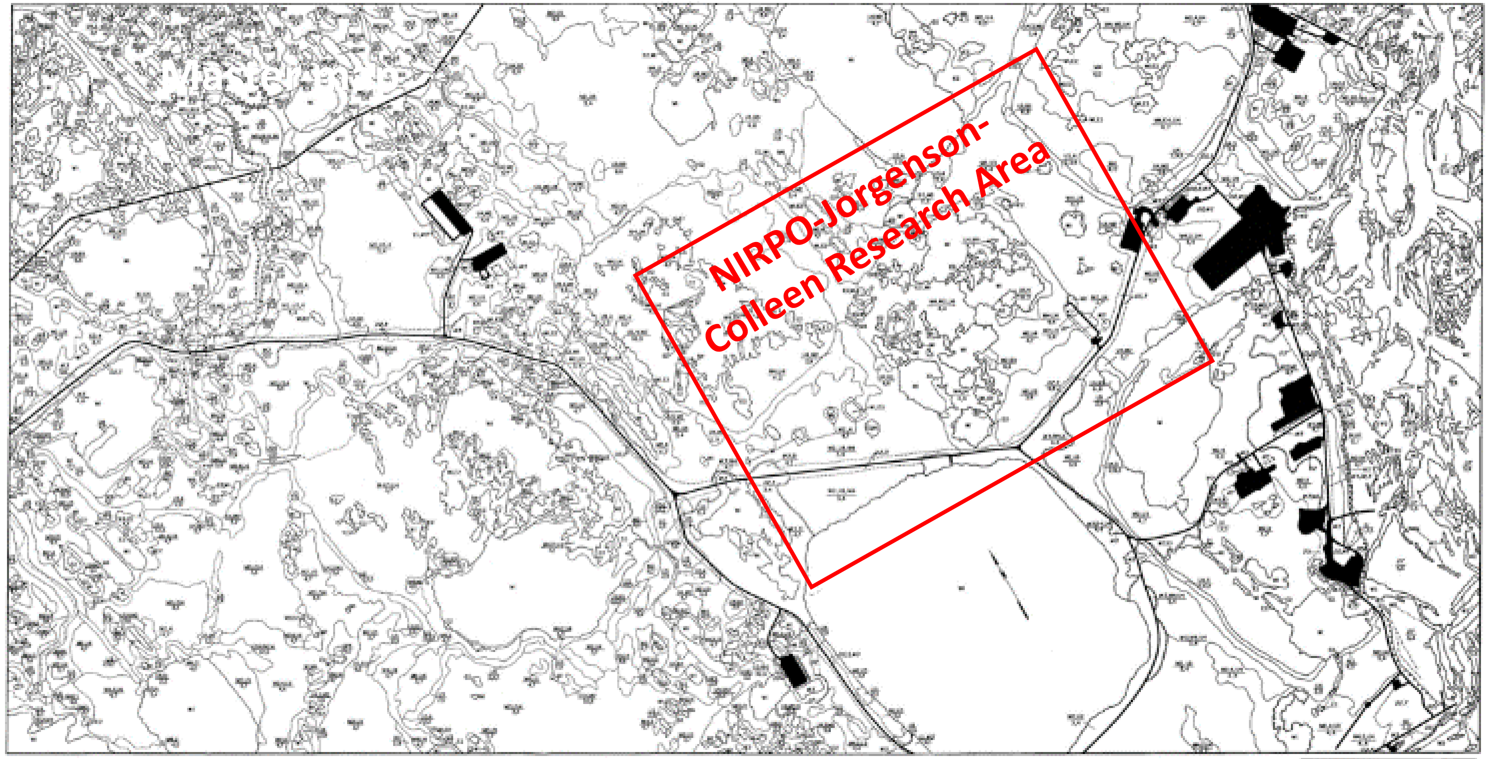


Geobotanical Atlas of the Prudhoe Bay Region, CRREL Report 80-14

Geobotanical Master Map: Map Sheet 2

Mapped in 1973 at 1:6000 scale; polygon coding: 1˚, 2˚, 3˚ veg / surf. landform, soil



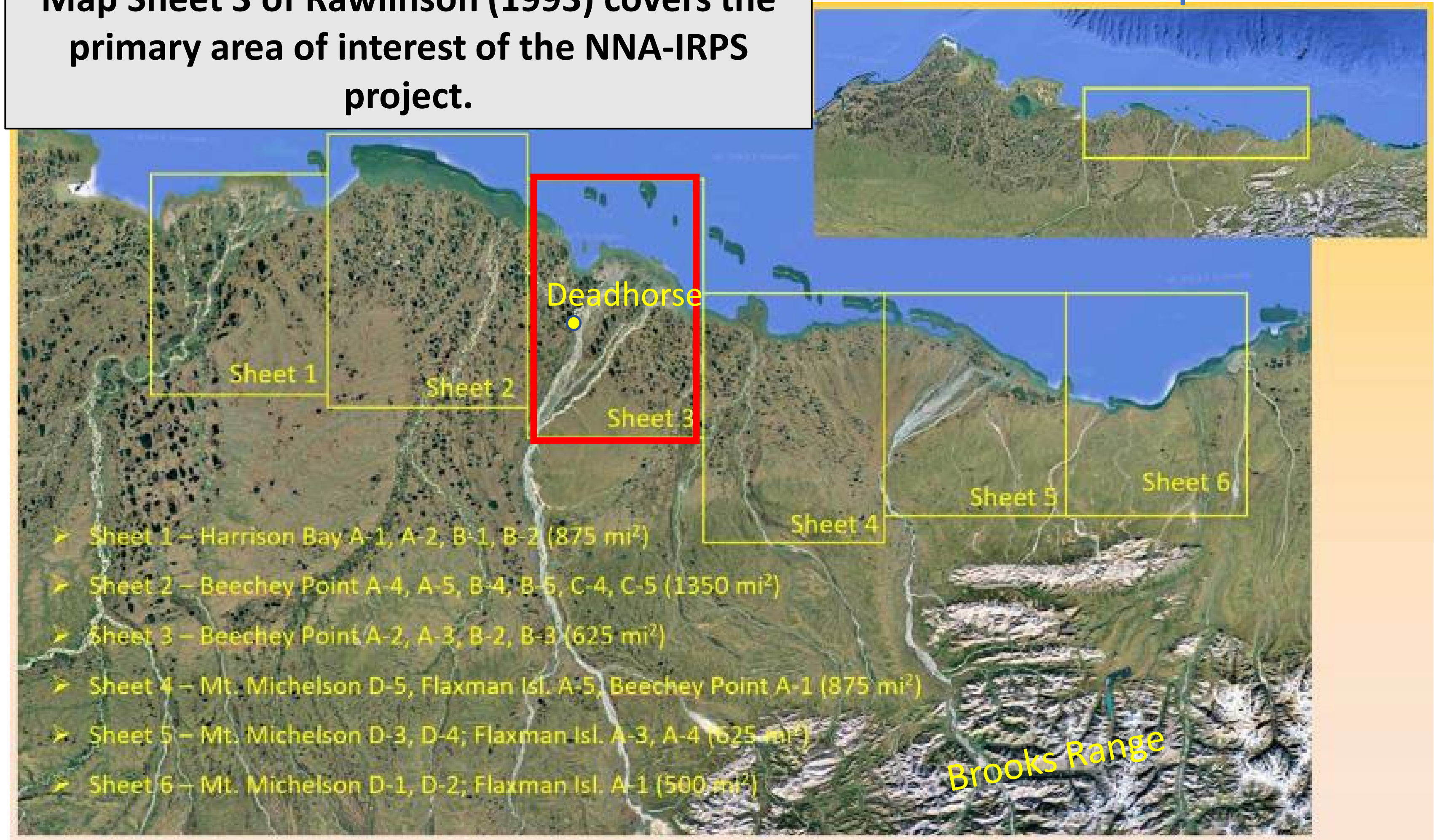


Walker, D. A., K. R. Everett, P. J. Webber, and J. Brown. 1980. Geobotanical Atlas of the Prudhoe Bay Region, AK, U.S. Army Cold Regions Research and Engineering Laboratory, CRREL Report 80-14.

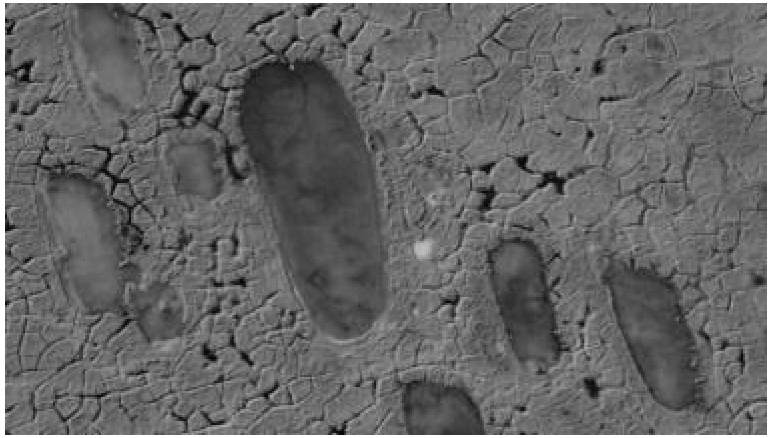
Surficial geology maps: Rawlinson (1993)

Deadhorse and the Prudhoe Bay Oilfield are in the Central Arctic Coastal Plain (CACP) on calcareous gravelly alluvial plains associated with braided rivers flowing out of limestone deposits in the Central Brooks Range.

Map Sheet 3 of Rawlinson (1993) covers the primary area of interest of the NNA-IRPS project.



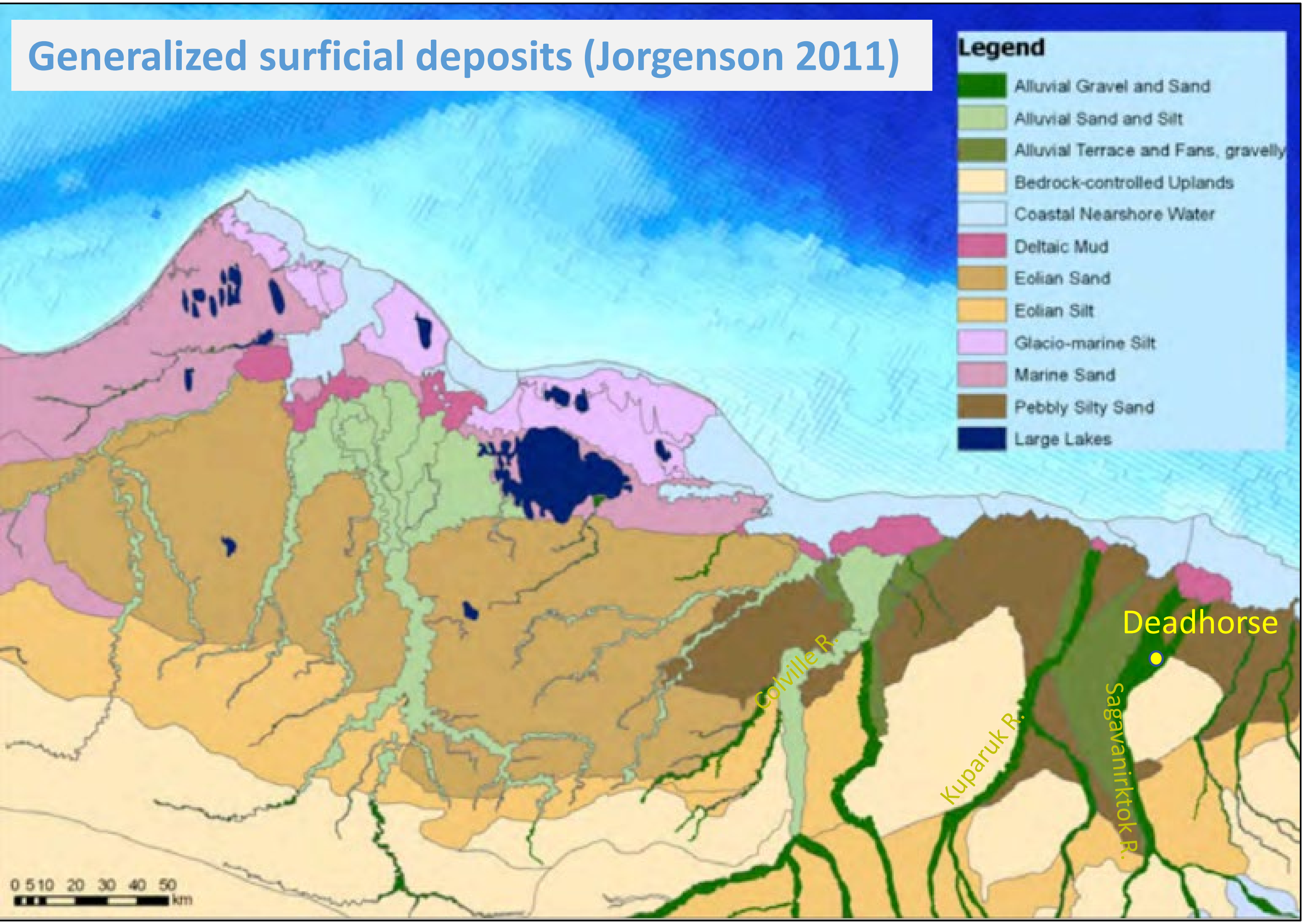
Recent alluvial gravel and sand deposits



Holocene alluvial deposits overlain by eolian sand and silt, thaw lakes and thaw-lake deposits

Rawlinson, Stuart E., 1993. Surficial geology and morphology of the Alaskan Central Arctic Coastal Plain. Alaska Division of Geological and Geophysical Surveys, Report of Investigations (RI) 93-1. 172 p, six sheets, 1:63,360.

The surficial geology of the Central Arctic Coastal Plain region is quite different from the western portion of Arctic Coastal Plain which has received more recent attention

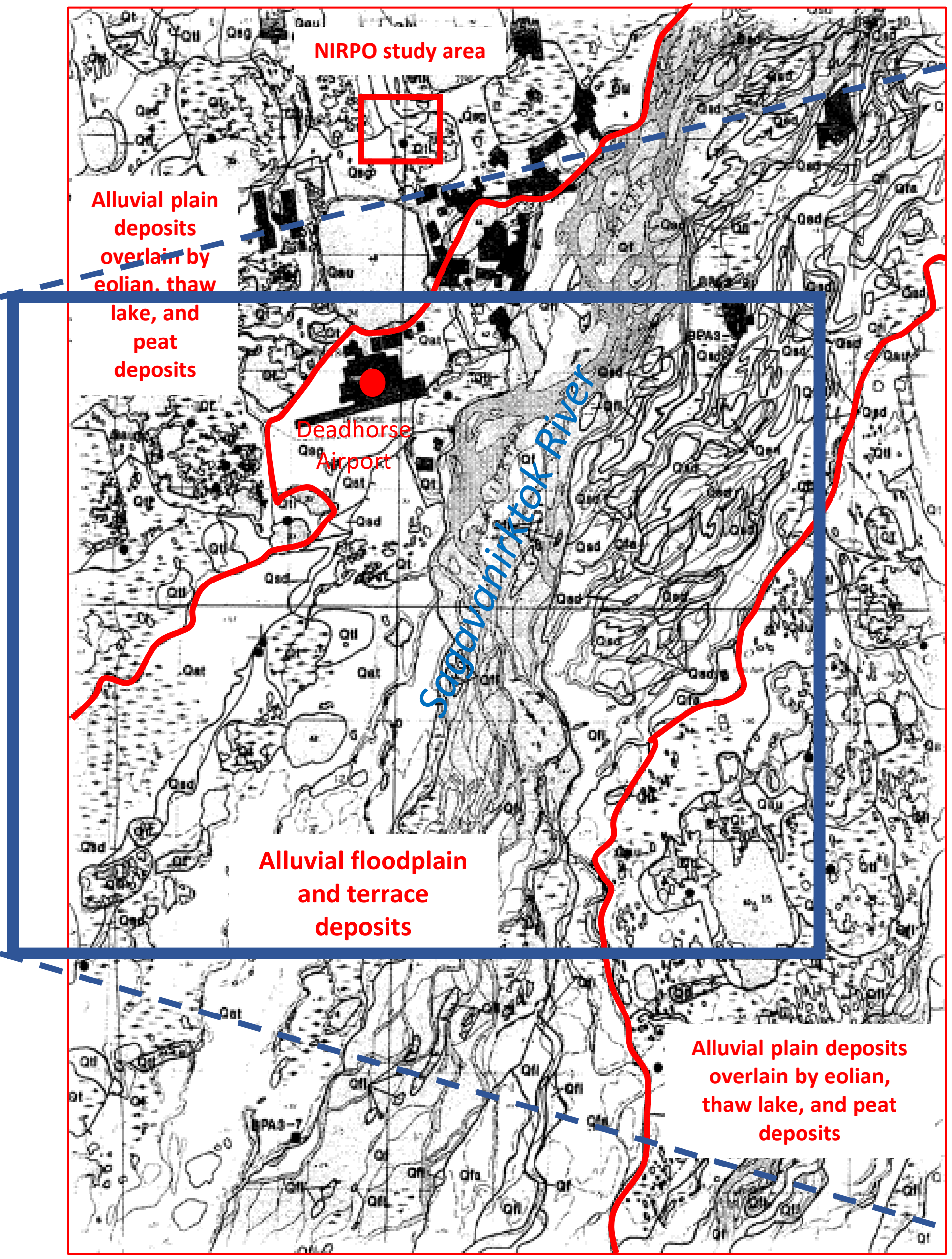


This map by Torre Jorgenson focuses on the western Arctic Coastal plain, an area dominated by sandy and silty eolian and marine deposits and is dominated by thaw lakes.

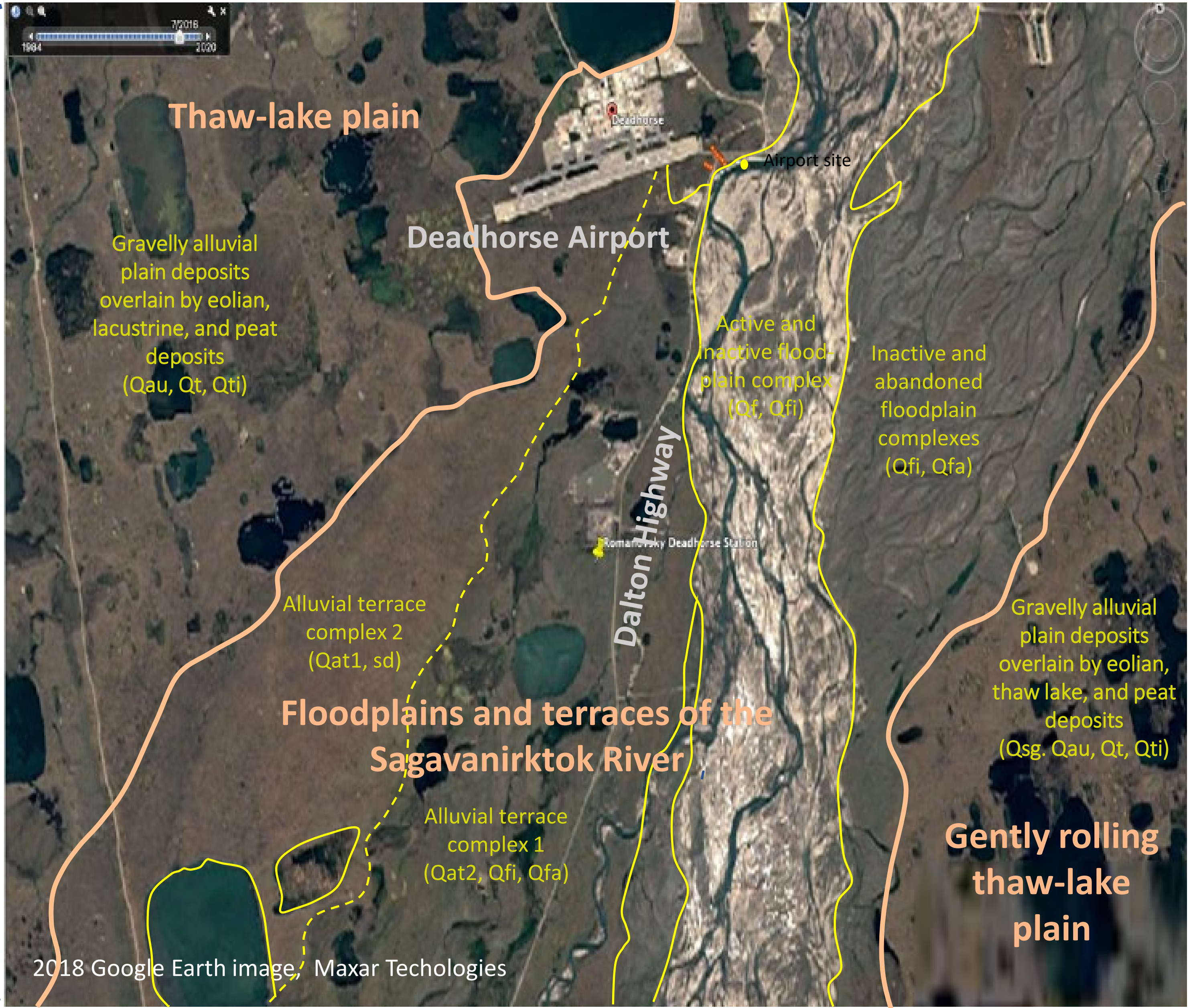
Jorgenson, M. T. (ed.). 2011. Coastal region of northern Alaska: Guidebook to Permafrost and Related Features. Guidebook 10. Ninth International Conference on Permafrost, June 29–July 3, 2008, Fairbanks, AK. State of Alaska Division of Geological and Geophysical Surveys.

Fluvial and thaw-lake landscapes of the Prudhoe Bay region

Section of Map Sheet 3 (Rawlinson 1993)



Fluvial, eolian, lacustrine, and peat deposits, eastern Prudhoe Bay Oilfield



The historical mapping and research in the loess ecosystems and alluvial floodplains is helping to understand the past and future permafrost evolution in the Prudhoe Bay region.

LOESS ECOSYSTEMS OF NORTHERN ALASKA:
REGIONAL GRADIENT AND TOPOSEQUENCE AT
PRUDHOE BAY

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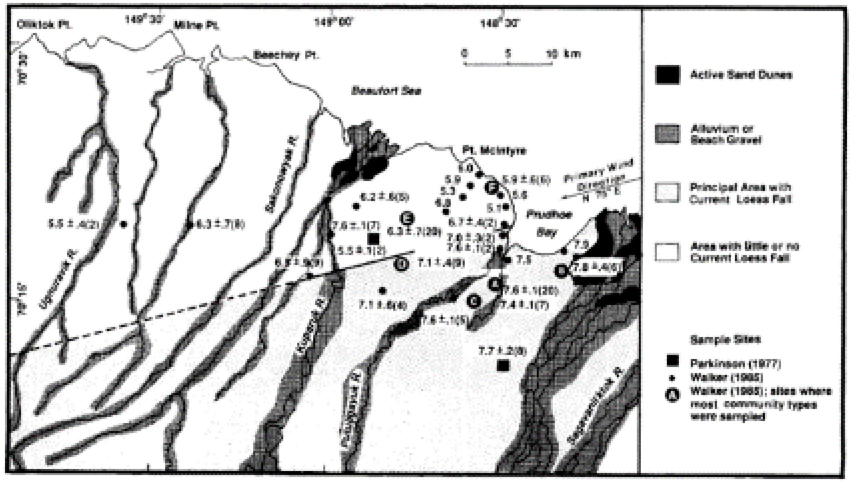
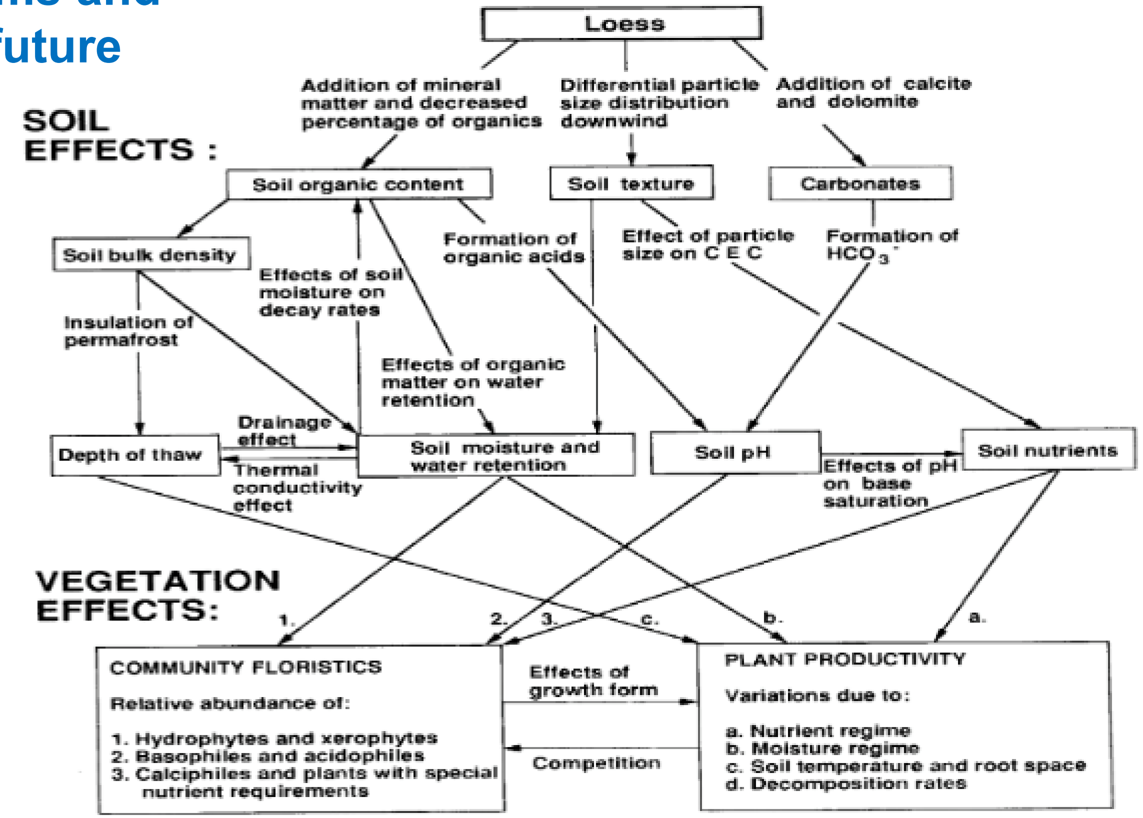
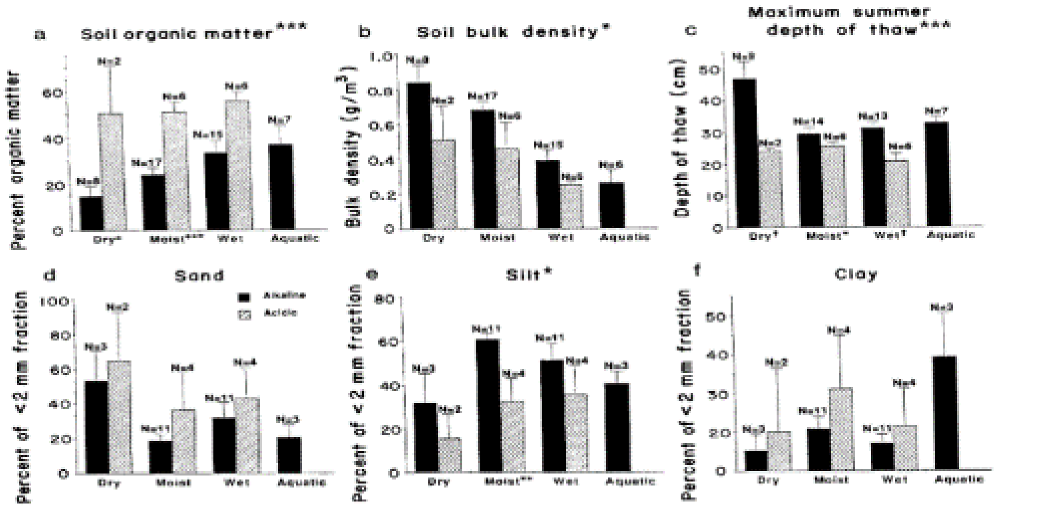
Joint Facility for Regional Ecosystem Analysis, Institute of Arctic and Alpine Research and Department of Environmental Population and Organismic Biology, University of Colorado, Boulder, Colorado 80309 USA

K. R. Everett
Byrd Polar Research Center and Department of Agronomy, The Ohio State University, Columbus, Ohio 43210 USA

Abstract. Loess-dominated ecosystems cover ≈14% (11 000 km²) of the Arctic Coastal Plain and much of the northern portion of the Arctic Foothills. Knowledge of this poorly known ecosystem is important for sound land-use planning of the expanding developments in the region and for understanding the paleoecological dynamics of eolian systems that once dominated much of northern Alaska. A conceptual alkaline-tundra toposequence includes eight common vegetation types and associated soils that occur near the arctic coast. A model of the regional loess gradient describes soils and vegetation downwind of the Sagavanirktok River. The addition of calcareous loess affects numerous soil properties, including bulk density, pH, water retention properties, concentrations of soil nutrients, and seasonal thaw depths. Many plant taxa, particularly cryptogams, increase in abundance





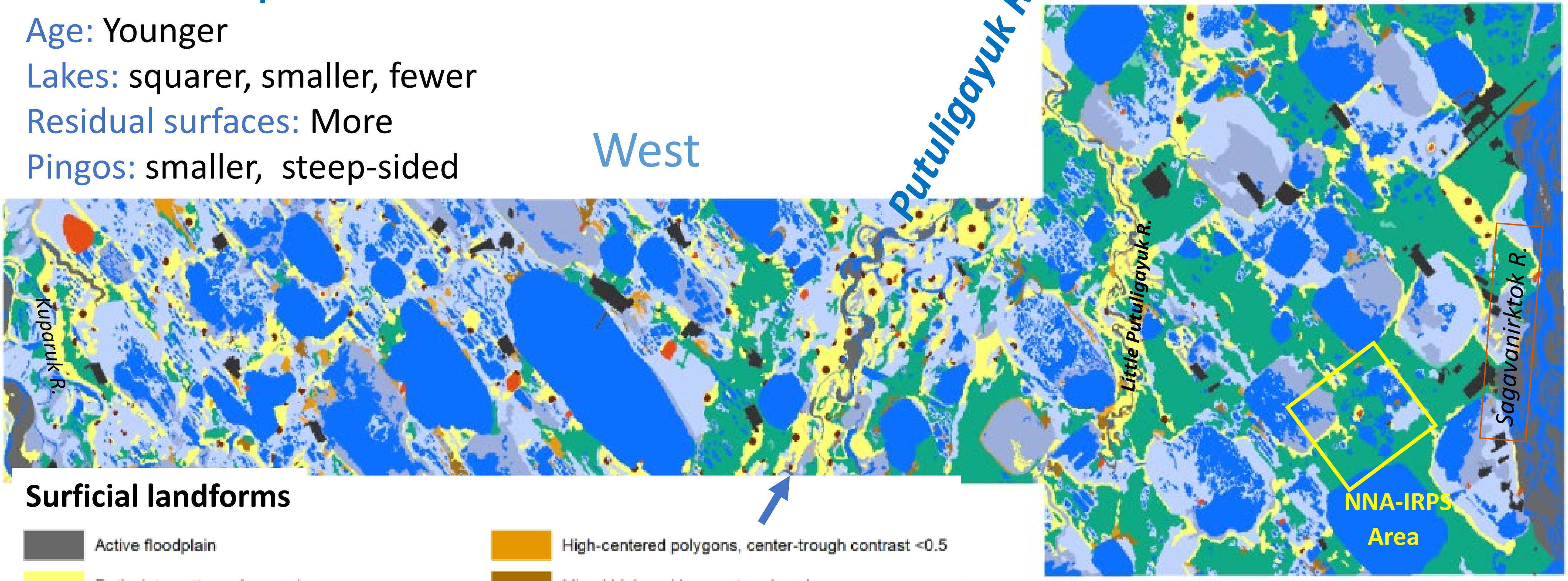


Walker and Everett 1991, *Ecological Monographs*

Distribution of surficial landforms across the Prudhoe Bay Oilfield is associated with different age alluvial floodplains east and west of the Putuligayuk R.

East vs. west comparison:

- Age: Younger
- Lakes: squarer, smaller, fewer
- Residual surfaces: More
- Pingos: smaller, steep-sided

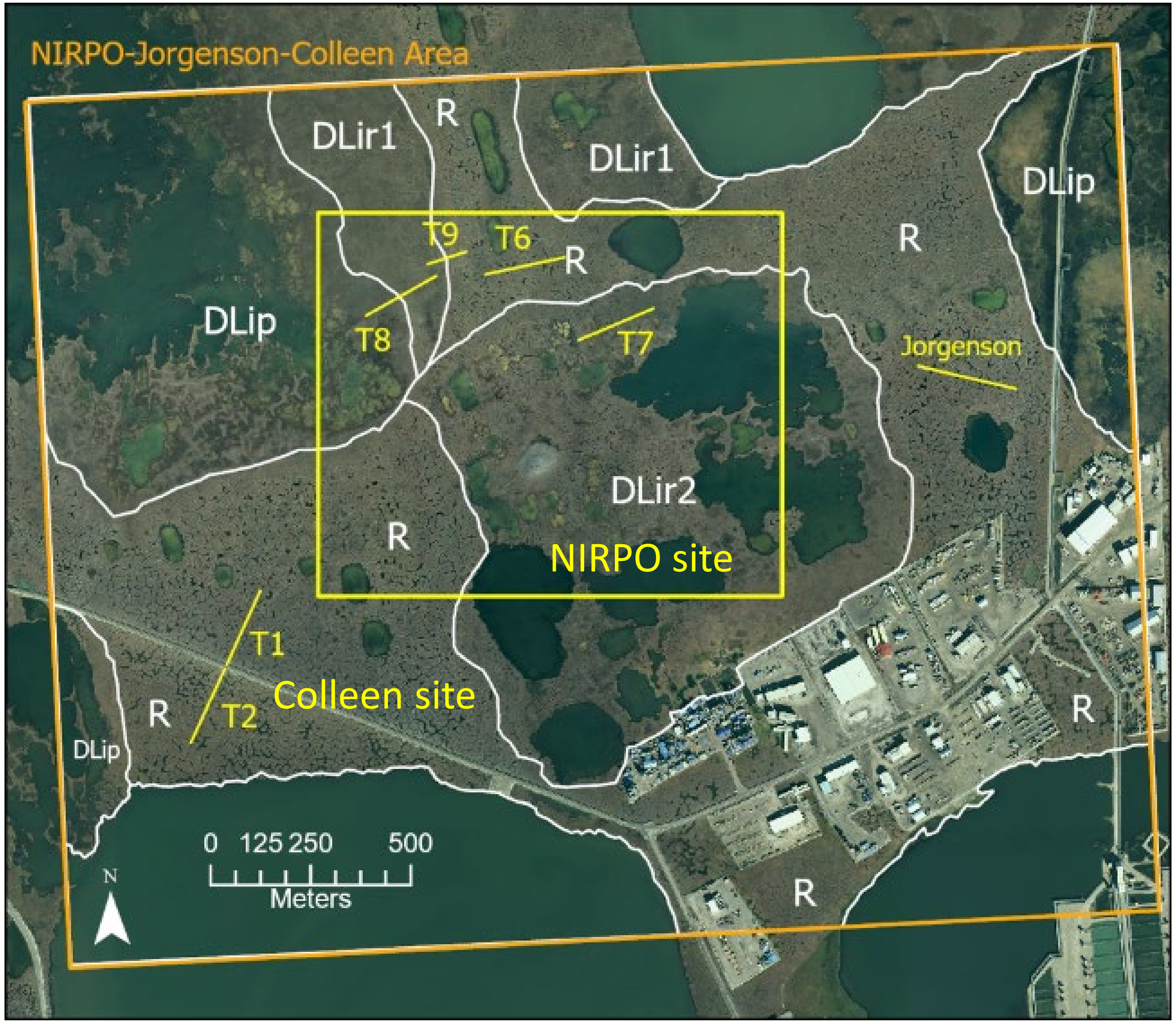


Surficial landforms

- Active floodplain
- Reticulate patterned ground
- Frost boil tundra
- Hummocky terrain assoc. with steep slopes
- Low-centered polygons, rim-center contrast <0.5
- Low-centered polygons, rim-center contrast >0.5
- High-centered polygons, center-trough contrast >0.5
- High-centered polygons, center-trough contrast <0.5
- Mixed high and low-centered poylgons
- Lakes
- Featureless
- Disjunct polygon rims
- Pingo
- Infrastructure

Derived from Everett. 1980. Interpretation based on 1973 1:6000 scale aerial photos, courtesy of Alaska Oil and Gas Assoc.

Colored map derived from 4 master maps in the Prudhoe Bay Geobotanical Atlas by Amelia Boyd.



Landforms and transects in the main NNA-IRPS research area

R, Residual surface

5 transects [T1, T2, T6, T9 east, and Jorgenson transect]

DLip, Drained Lake basin, ice poor

1 transect (T8 west)

DLir1, Drained Lake basin, ice rich, phase 1

2 transect (T8 east, T9 west)

DLir2, Drained Lake basin, Ice rich, phase 2

1 transect (T7)

Code	Primary landform and surface features		Surficial geology
R	Residual surface, with transitional polygons, and ice-wedge thermokarst ponds	Corresponding surficial geology units →	Qsg, Undifferentiated alluvial deposit overlain by overbank deposits, eolian silt, and peat
DLip	Drained lake basin basin, ice poor, mostly featureless		Qt, Thaw lake deposit , ice poor (includes lakes)
DLir1	Ice-rich drained-lake basin, phase 1, disjunct ice-wedge polygons		Qti1, Ice-rich thaw-lake deposit
DLir2	Ice-rich drained-lake basin, phase 2, well developed low-center polygons and pingos		

NIRPO transects: A gradient of different age surficial-geology deposits, permafrost landforms, and vegetation

Older surfaces

Youngest, ice-poor, drained-lake basin with two phases of lake drainage (T8)

- Phase 1 (right figure, west end of T8), few disjunct polygon rims or other polygonal features
- Phase 2 (left figure, east end of T8), initial stages of ice-wedge-polygon development, disjunct ice-wedge polygons, small ice wedges, and discontinuous polygon rims..

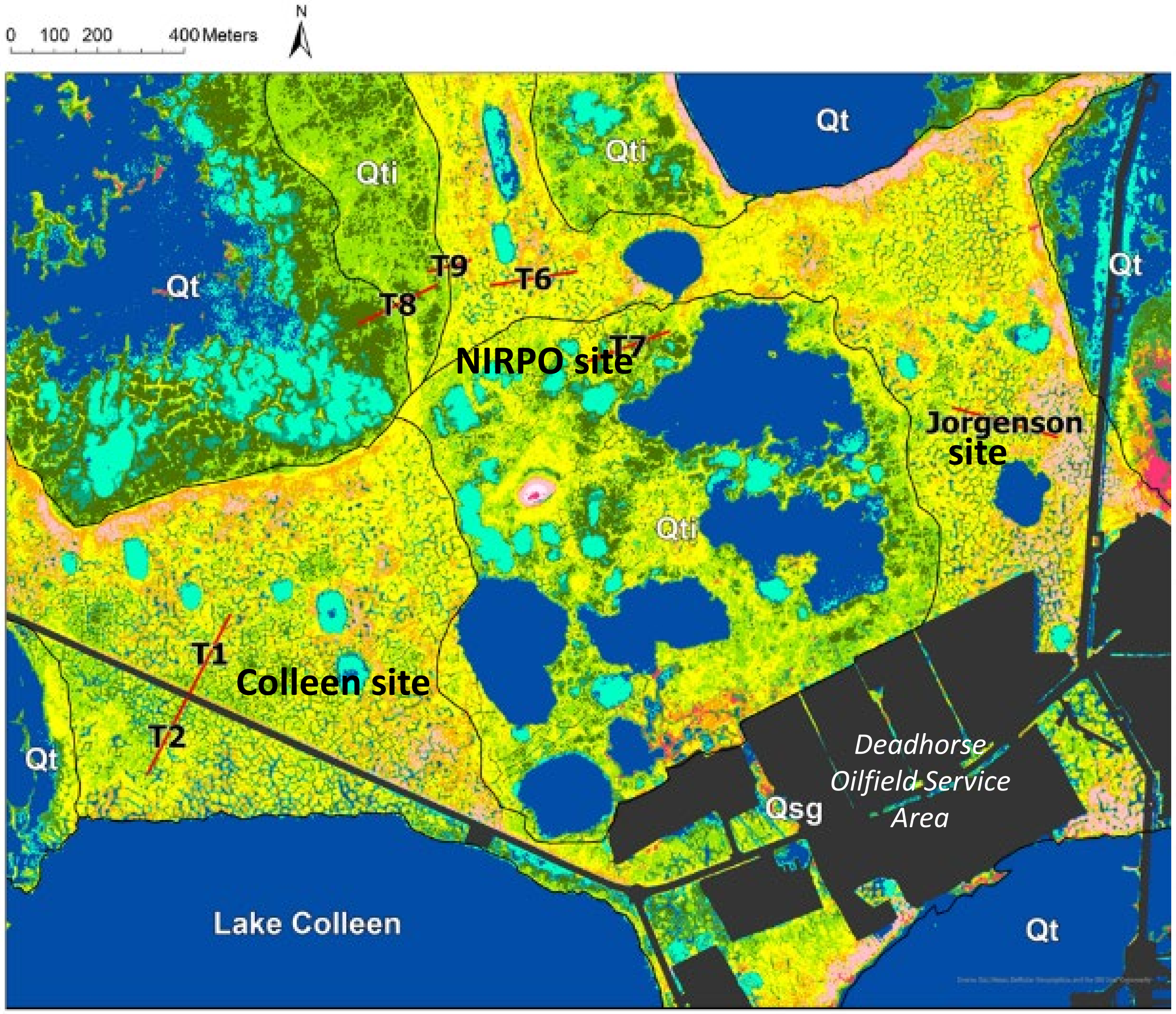
Older ice-rich drained-lake basin (T7)

- Heterogeneous landscape
- Remnant marl ponds (left figure, west end),
- East end (right figure, east end) well-developed low-center ice-wedge polygons, intermediate-width ice wedges and polygon trough, and some thermokarst in polygon troughs.
- Pingo in western side of lake basin

“Residual” surface (T6 and Jorgenson transect):

- Oldest surface with no evidence of thaw-lake processes.
- Extensive wide ice-wedge thermokarst ponds (left figure)
- Extensive degraded ice-wedges, subsiding polygon troughs, and “transitional” polygons with remnant polygon rims

Landcover map of the main NNA-IRPS research area (Olivia Hobgood, 2024, MS thesis research)



Landcover (Veg.-habitat codes)

- Infrastructure
- Dry nonacidic tundra, gravelly substrates (D1)
- Dry/moist nonacidic tundra, organic substrates and snowbeds (D2, D2t, Dsn)
- Moist nonacidic tundra, abundant lichens (M1)
- Moist nonacidic tundra, few lichens (M3, M3t)
- Wet nonacidic tundra, saturated soils (W1, W1t)
- Very wet nonacidic tundra, shallow water (W2, W2t)
- Aquatic vegetation, shallow water (A1, A1t)
- Aquatic vegetation, deeper water (A2, A3t, A4t)
- Shallow lakes and ponds with marl bottoms, some emergent vegetation (A1, L2)
- Deeper lakes and ponds with little or no emergent vegetation
- Enriched vegetation (Dz, Mz, Wz)

The new vegetation-habitat legend is organized around the site-moisture gradient

Dry to aquatic site-moisture gradient

D. Dry nonacidic tundra

- D1 Dry nonacidic tundra, gravelly substrates
- Dsn Dry nonacidic snowbeds
- Dz Dry zoogenic vegetation (pingo summit)

M. Moist nonacidic tundra

- M1 Moist nonacidic tundra, abundant lichens
- Mz Moist zoogenic vegetation (bird mound)
- M3 Moist nonacidic tundra with few lichens
- M3t Transitional moist nonacidic tundra

W. Wet nonacidic tundra

- W1 Wet nonacidic mires (saturated aoils)
- W2 Very wet nonacidic mires (standing water)

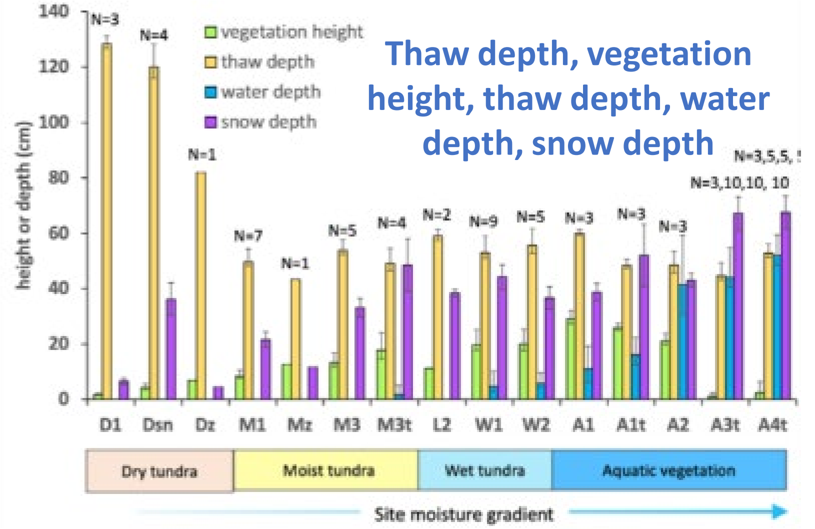
A. Aquatic minerotrophic vegetation

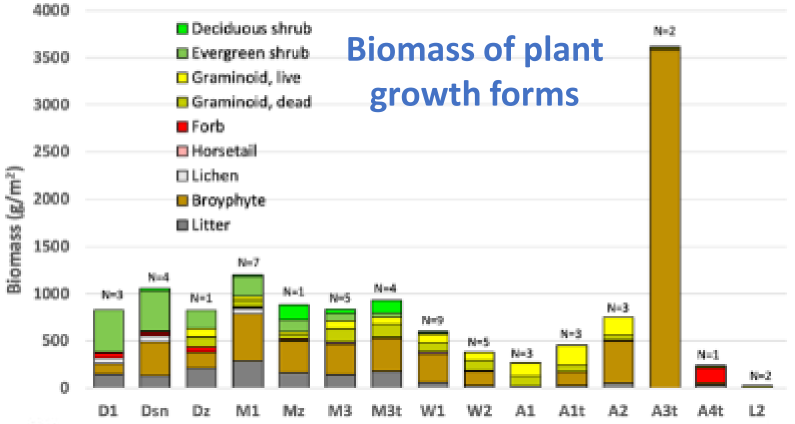
- A1 Aquatic sedge marsh
- A1t Transitional aquatic vegetation
- A2 Aquatic grass marsh
- A3t Aquatic moss marsh
- A4t Aquatic forb marsh

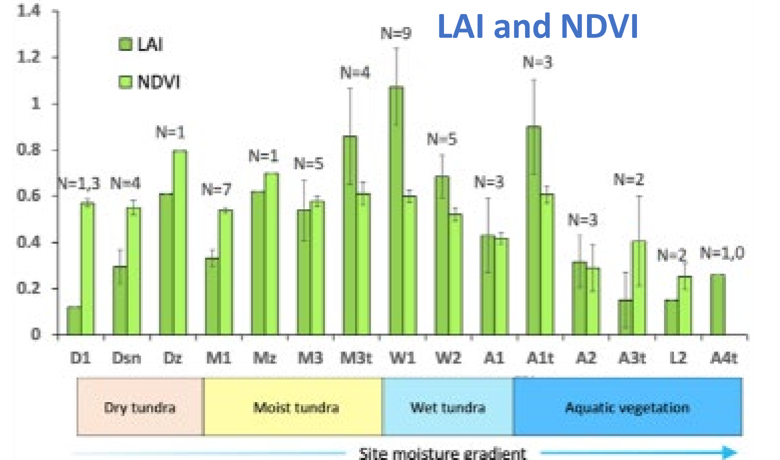
L. Lakes and ponds

- L2 Shallow ponds and lakes with marl bottoms, sparse vegetation

Used to examine trends in ecosystem variables across the site-moisture gradient



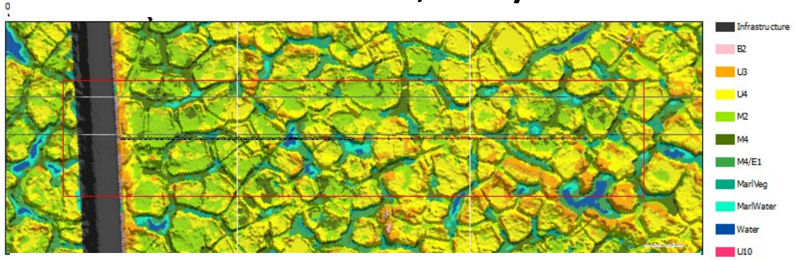




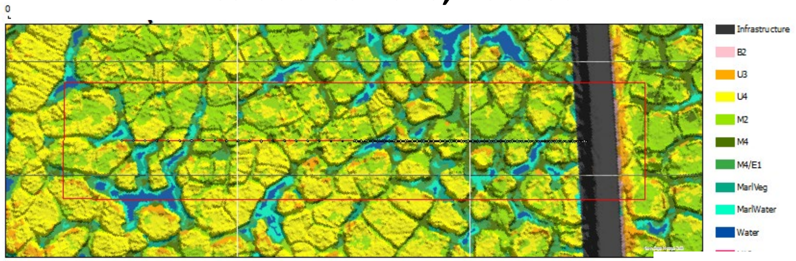
Landcover maps of the transect areas within the NJC research area

Colleen site

T1- Residual surface, heavy dust

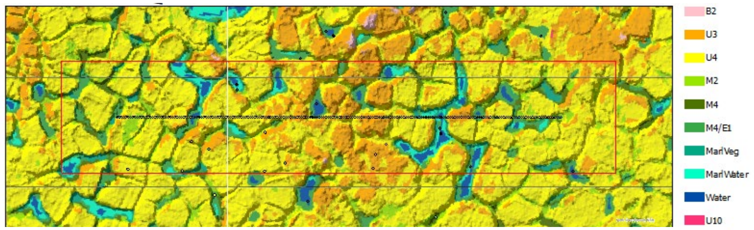


T2- Residual surface, flooded

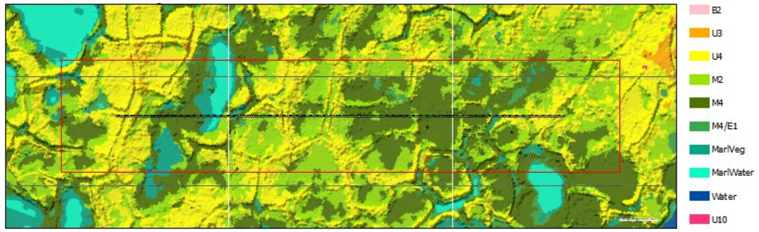


NIRPO site

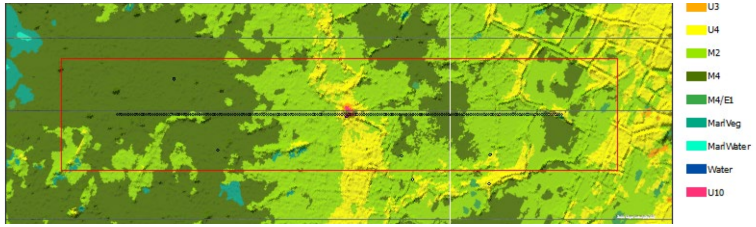
T6 – Residual surface



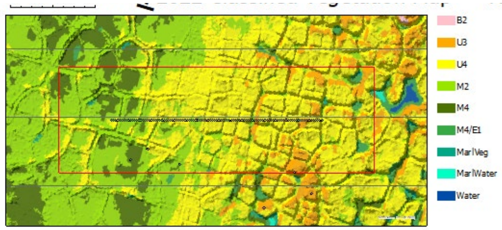
T7 – Ice-rich drained lake basin, phase 2



T8 – Ice-poor (left), and ice-rich, phase 1 drained lake basin (right)

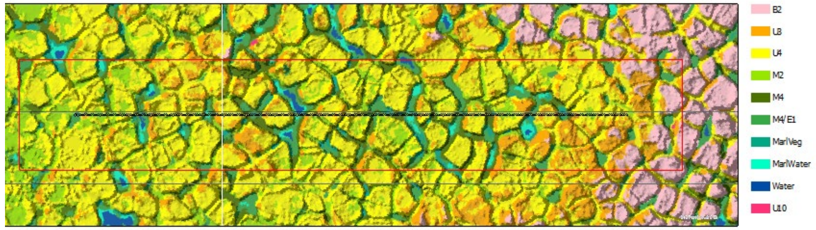


T9 – Ice-rich, phase 1 drained lake basin (left) and Residual surface (right)



Jorgenson site

JS – Residual surface

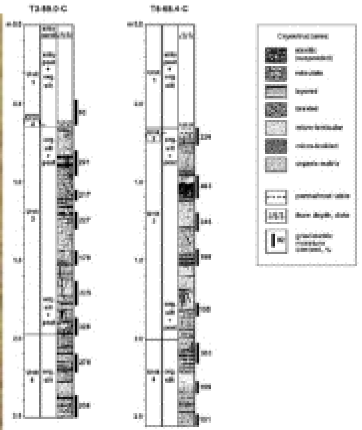


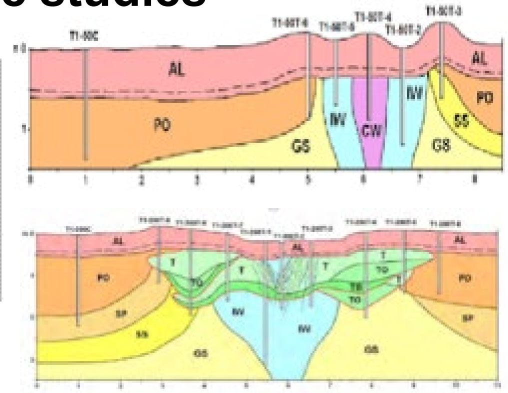
Maps by Olivia Hobgood,
M.S. thesis, in progress

Permafrost research along the transects

D. Nicolsky, V. Romanovsky, M. Kanevskiy, Y. Shur, S. Rybakov,
N. Hasson, T. Jorgenson

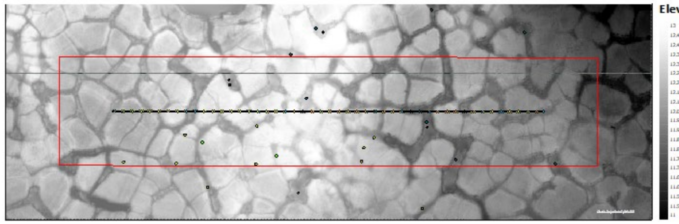
Cryostratigraphy and ice-wedge studies



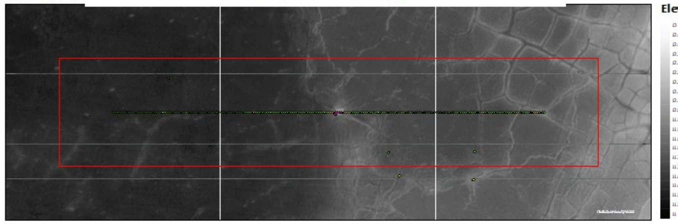


Micro-topography surveys: d-GPS, helicopter-based LiDAR, and drone-based SFM

T6 (Qau)

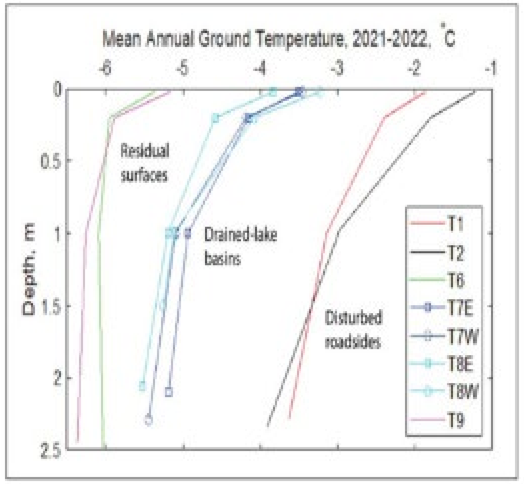


T8 (Qt — Qti$_1$)



Active-layer, water depth, dust-layer thickness surveys

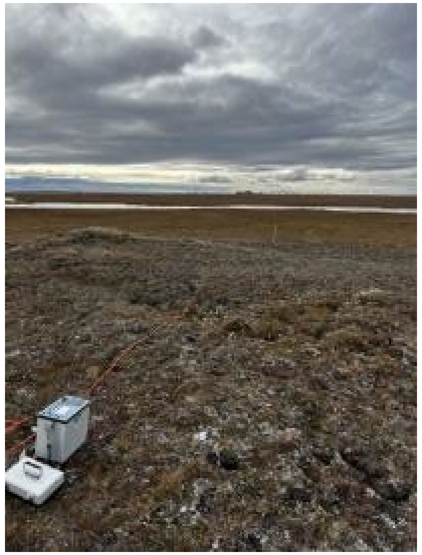
Ground-temperatures



Permafrost cores from lake basins and residual surfaces

Geophysical research: ERT and CCR surveys

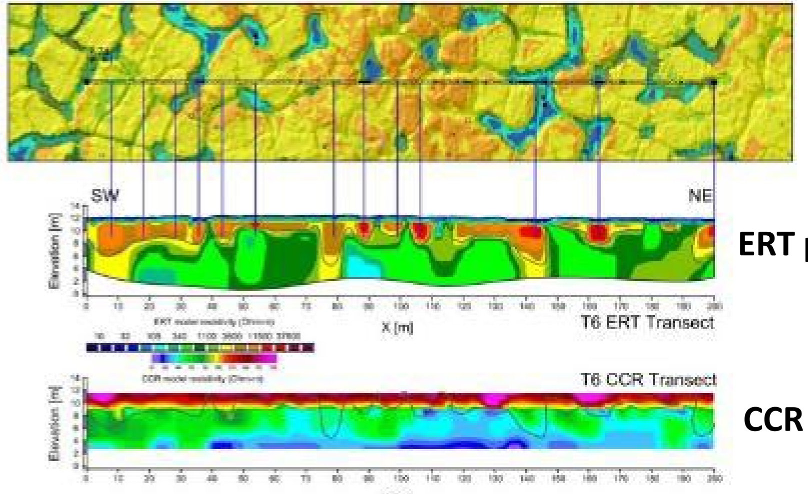
Summer survey 2022-23: Electrical Resistivity Tomography (ERT)



Dmitry Nicolsky
Sergei Rybakov,
Esther Babcock,
Nick Hasson

Winter survey 2024: Three dimensional Capacity Coupled Resistivity (3D-CCR) across a gradient of two thaw lakes and a residual surface

Comparison of the ERT and CCR surveys with vegetation map, T6 residual surface



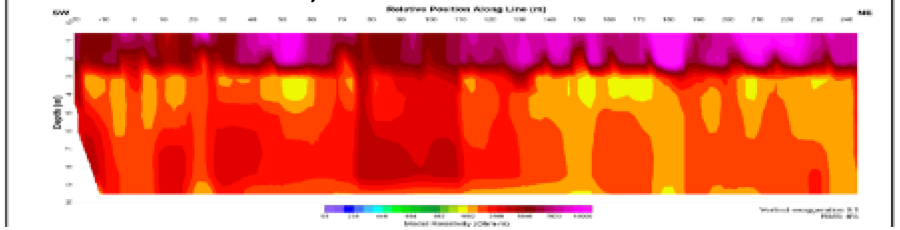
Veg-habitat map

ERT profile

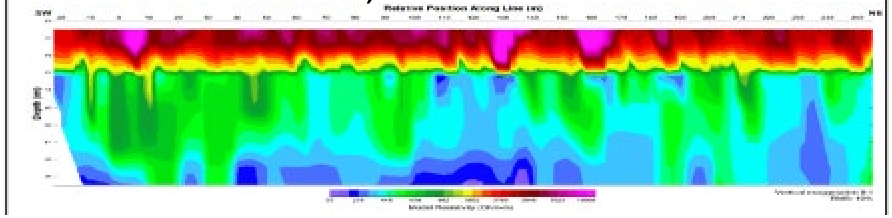
CCR profile

CCR surveys in 2 recent drained lake basins (T7 & T8) and a residual surface (T6)

T8, recent drained lake basin



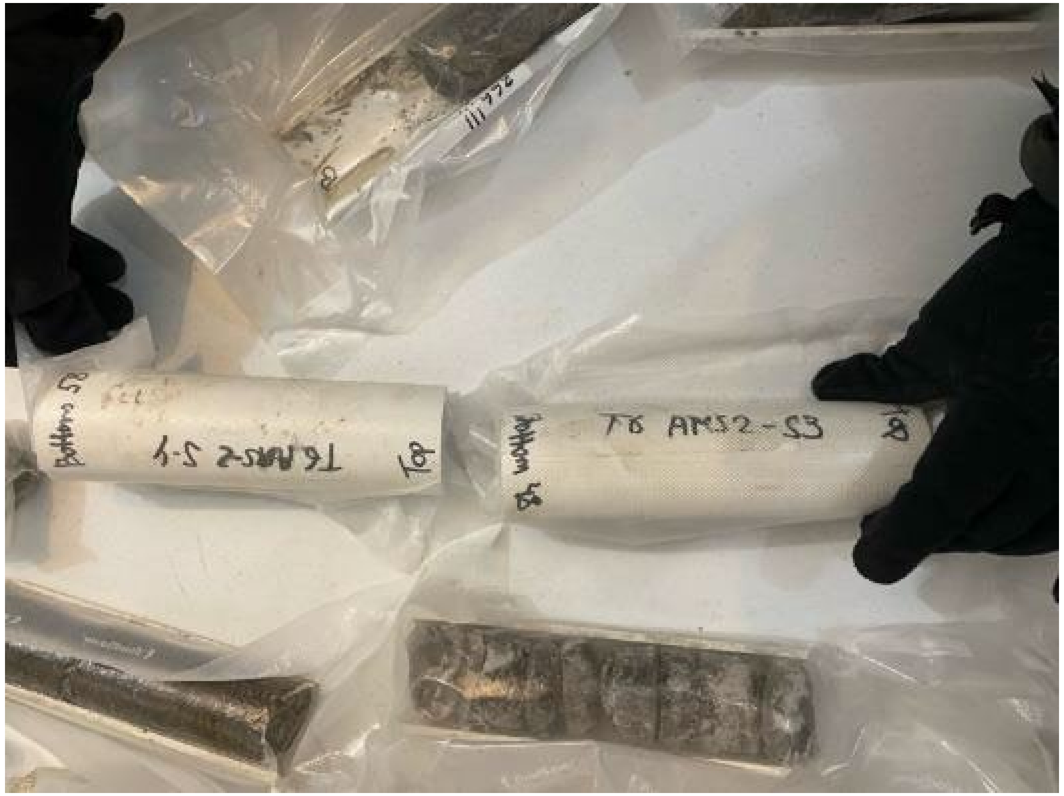
T6, residual surface



Photos and surveys by Sergei Rybakov (UAF, GI) and Esther Babcock (Logic Geophysics and Analytics)

Permafrost cores along the transects in lake basins and residual surface

Dmitry Nicolsky, Sergei Rybakov, Nick Hasson

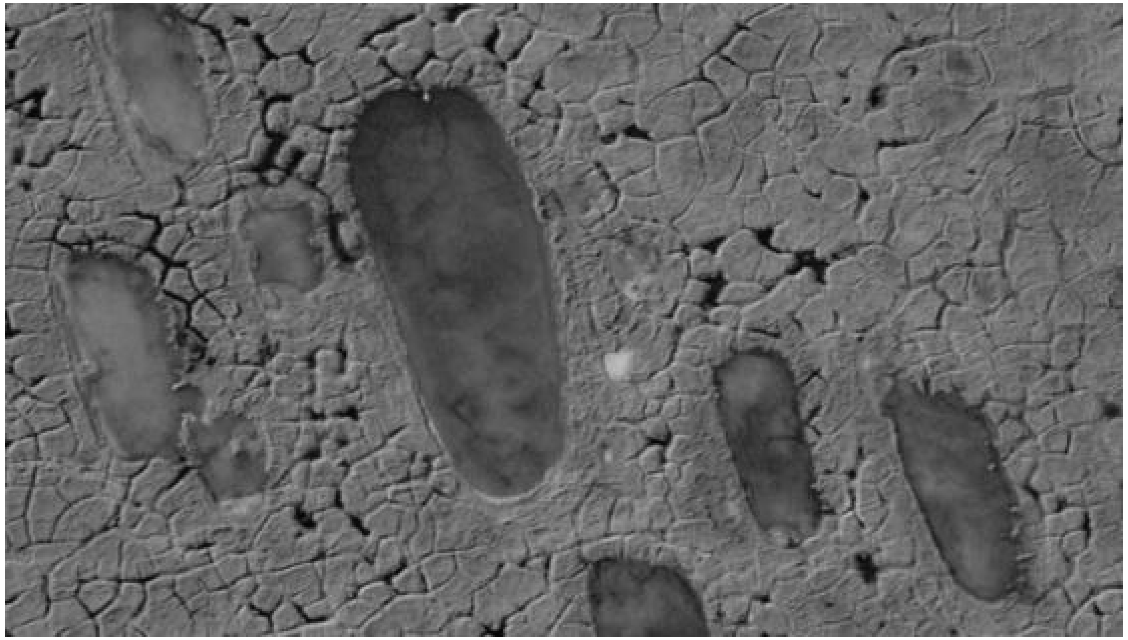


9 cores, approximately 20 meters total

The analysis of the resistivity results and the cores will be the primary focus of the Landscape Evolution studies during the last year of the project.

Conclusion 1. The patterns of Prudhoe Bay landforms, vegetation, and permafrost are strongly controlled by surficial geology.

Active alluvial floodplain of the Sagavanirktok River



Alluvial plain deposits overlain by eolian silt, and thaw lakes

Active and inactive alluvial floodplains and terraces

Qf, Active flood-plain deposits	Qfi, Inactive floodplain deposits	Qfa, Abandoned floodplain deposits	Qat, Qsd. Alluvial-terrace and sand-dune deposits	Qau, Qsg Alluvial-plain deposits

Older alluvial deposits overlain by eolian silts and thaw-lake deposits

Qau, Qsg Alluvial-plain deposits	L, Thaw lakes	Qt, Ice-poor drained-lake basins	Qti1, Ice-rich drained-lake basins, phase 1	Qti2, Ice-rich drained-lake basins, phase 2	Qti3, Ice-rich drained-lake basins, phase 3

Based on Rawlinson 1993

The histories of the floodplains and thaw-lake landscapes intersect in the alluvial-plain deposits.

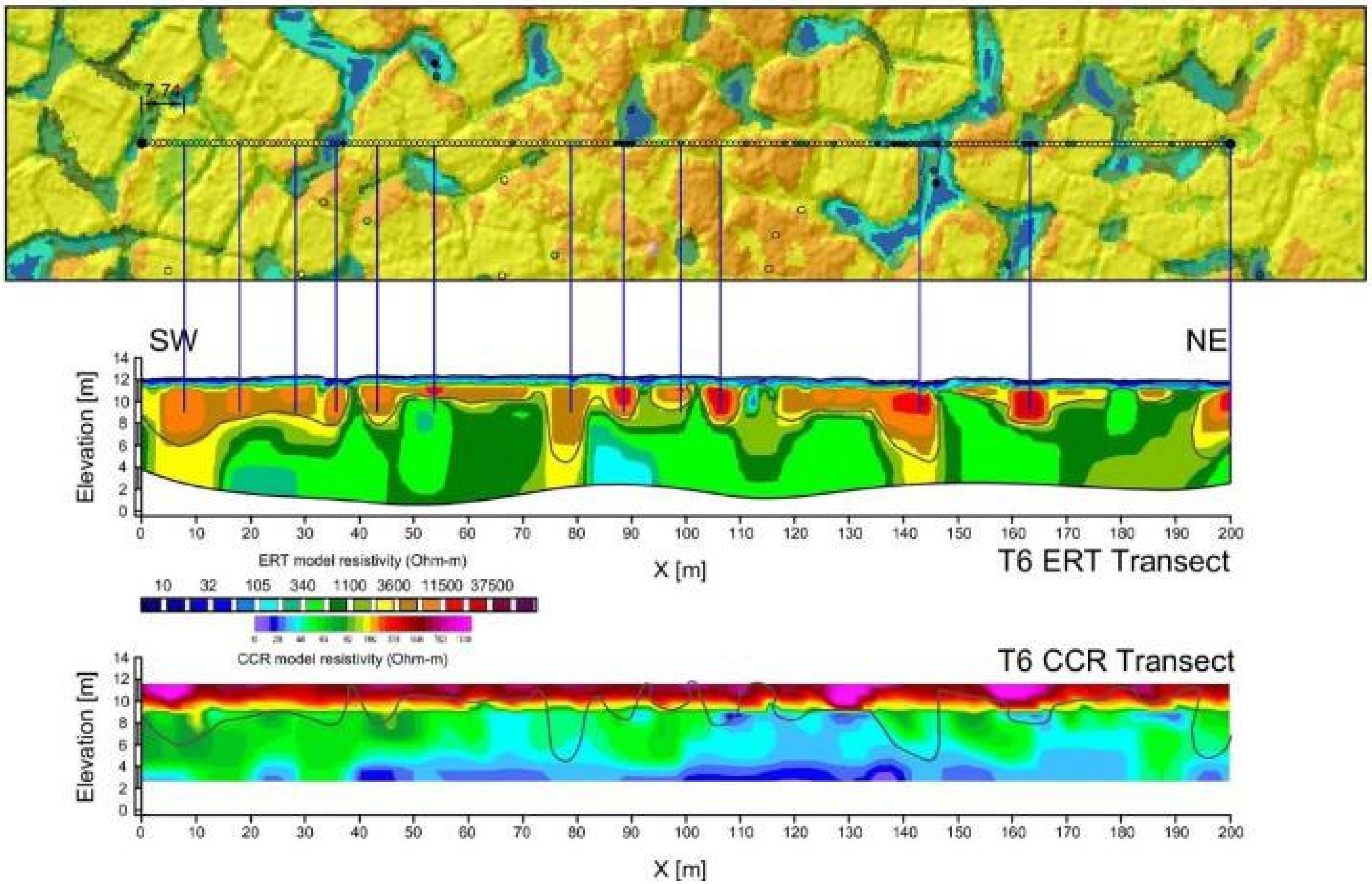
Conclusion 2. Unique aspects of the calcareous alluvial-plain ecosystems are worthy of more detailed studies and conservation.

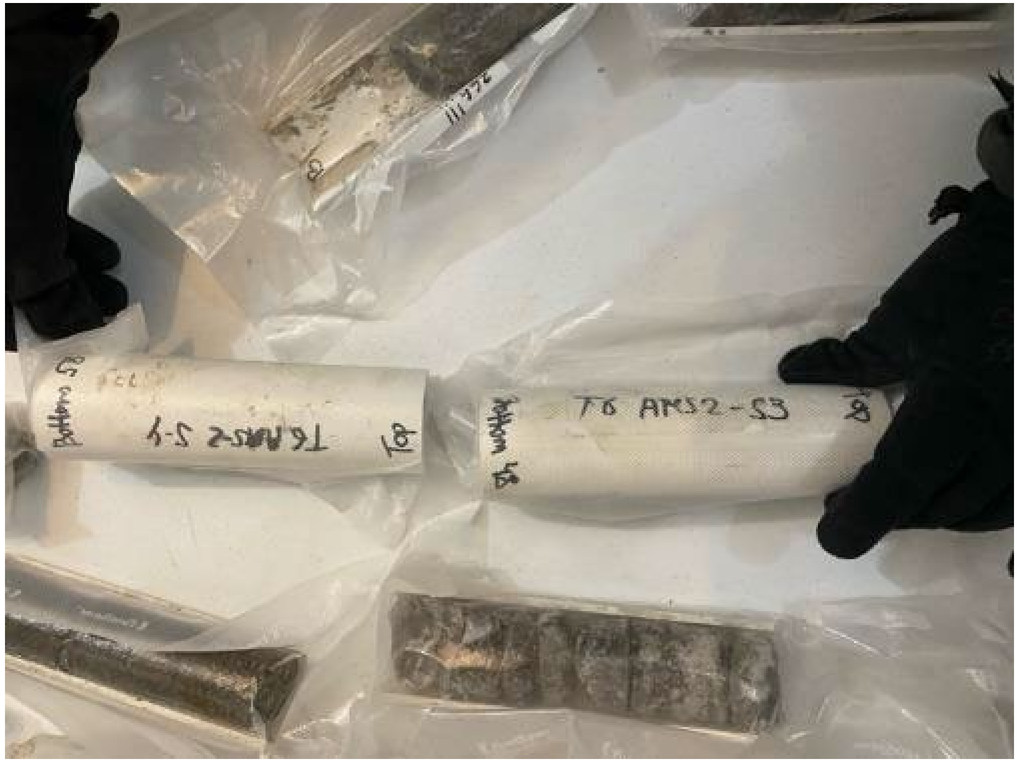
Many Beringian species

Abundant megafauna

Rich waterfowl and shorebird nesting grounds

Conclusion 3. Future integrated NNA-IRPS studies of surficial geology, landforms, soils, vegetation, and permafrost will likely lead to new understanding of past and potential future permafrost evolution and aid in developing permafrost sensitivity maps.





Thank you!

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Photo by Amy Breen, May 2024