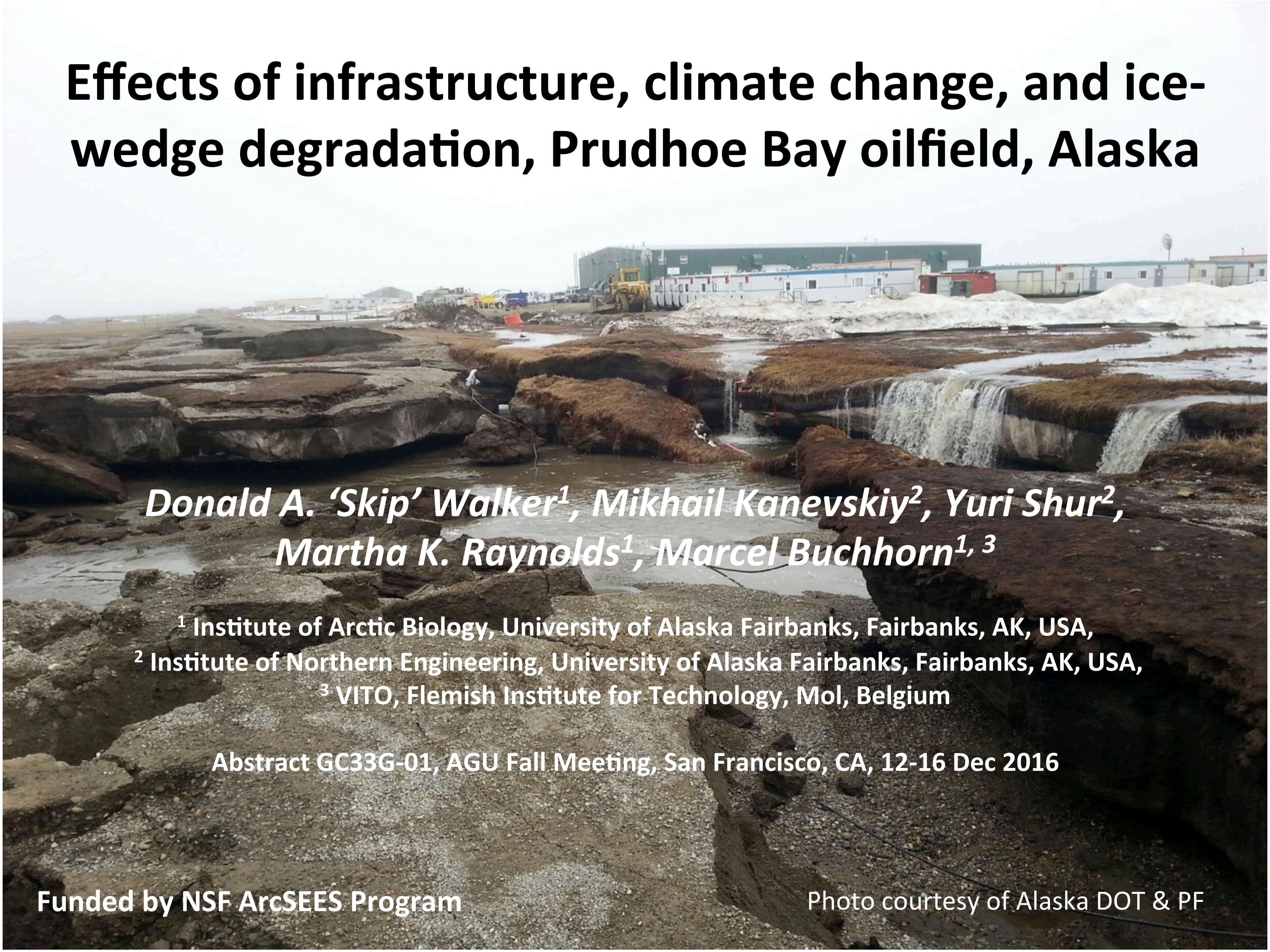
Effects of infrastructure, climate change, and ice-wedge degradation, Prudhoe Bay oilfield, Alaska



Donald A. 'Skip' Walker[1], Mikhail Kanevskiy[2], Yuri Shur[2], Martha K. Raynolds[1], Marcel Buchhorn[1, 3]

[1] Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, USA,
[2] Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, AK, USA,
[3] VITO, Flemish Institute for Technology, Mol, Belgium

Abstract GC33G-01, AGU Fall Meeting, San Francisco, CA, 12-16 Dec 2016

Funded by NSF ArcSEES Program

Photo courtesy of Alaska DOT & PF

Increased ice-wedge degradation, Prudhoe Bay, 1949-2013

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1949 (not shown) - 1985
Little change in non-roadside areas

1970-1999
Mainly roadside thermokarst changes

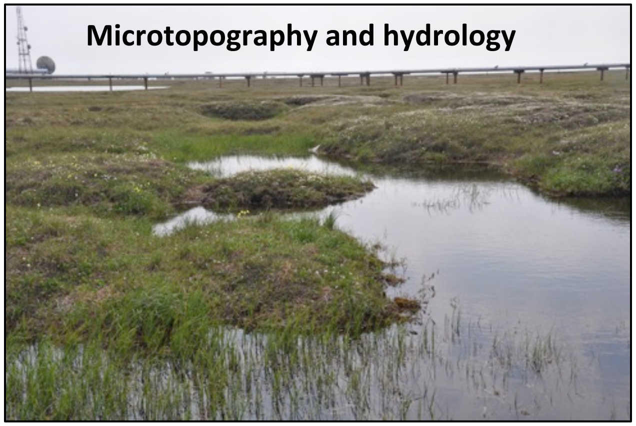
2000-2015
Widespread thermokarst in all areas near and distant from the road

Earlier publications examined the historical regional and landscape-level changes at Prudhoe Bay using the GIS databases and Landsat imagery

- Raynolds, M. K., et al. (2014). Cumulative geoecological effects of 62 years of infrastructure and climate change in ice-rich permafrost landscapes, Prudhoe Bay Oilfield, Alaska. *Global Change Biology*, *20*(4), 1211–1224.

- Raynolds, M. K., & Walker, D. A. (2016). Increased wetness confounds Landsat-derived NDVI trends in the central Alaska North Slope region, 1985–2011. *Environmental Research Letters*, *11*(8), 085004.

MAIN QUESTION FOR GROUND-LEVEL STUDIES:
What are the consequences of thermokarst to surface landforms, soils, vegetation, and permafrost?


Microtopography and hydrology


Changes to vegetation


Consequences to wildlife habitat

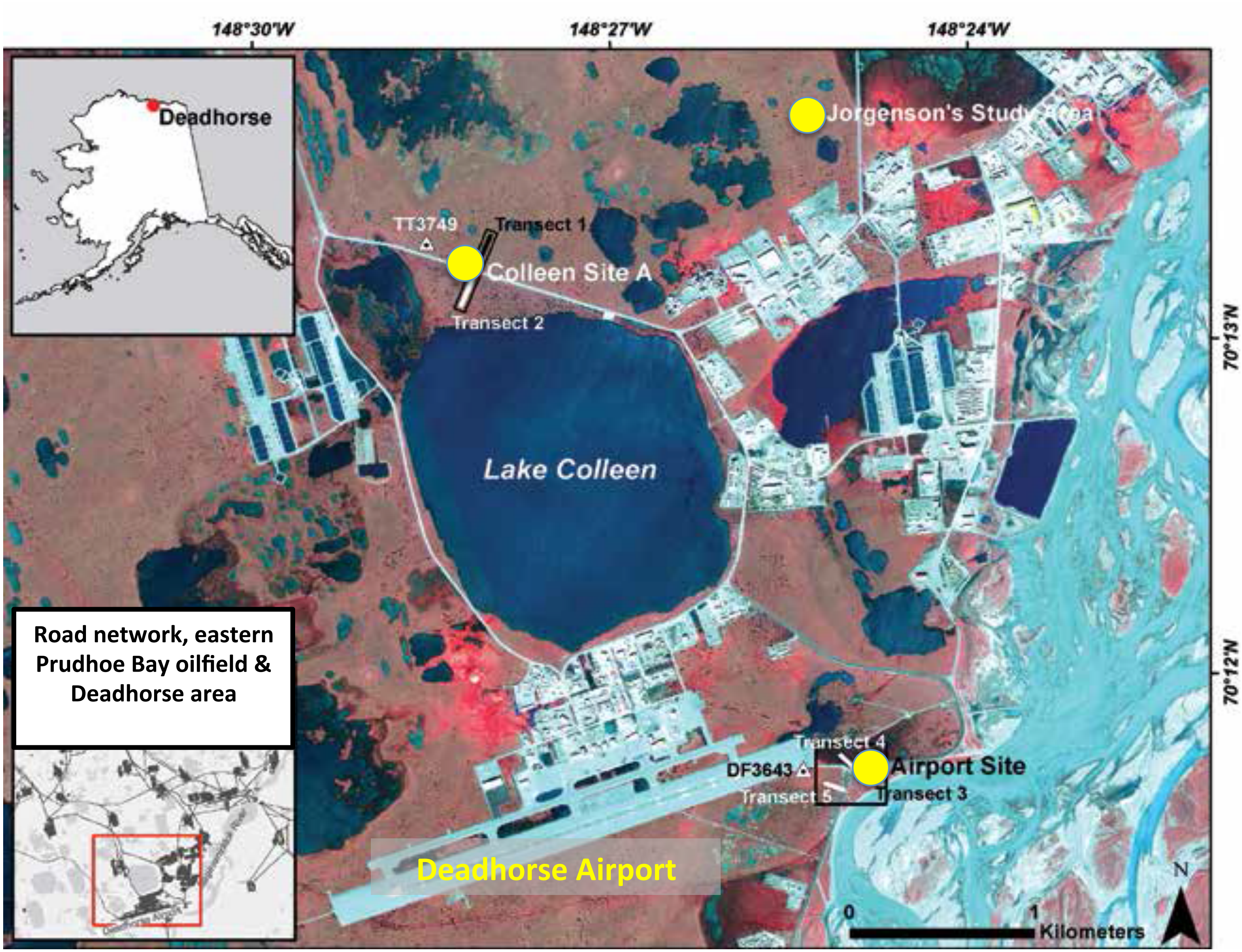

Infrastructure-related flooding

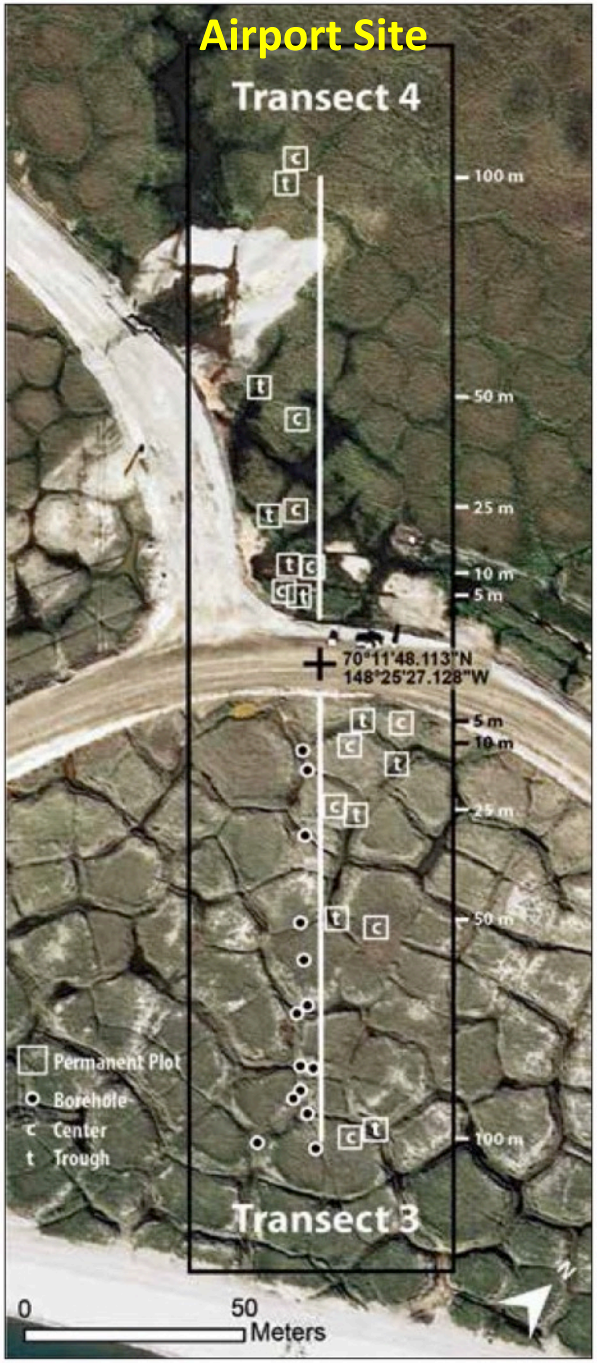

Role of road dust

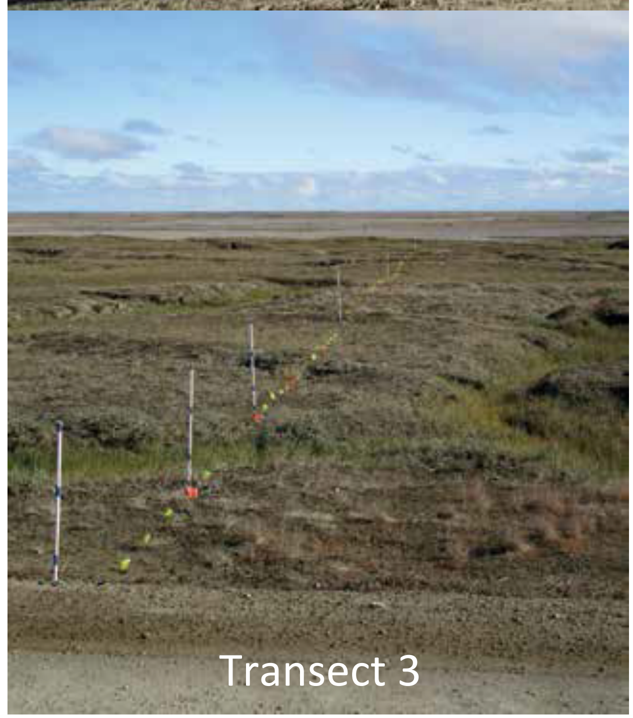

Consequences to infrastructure

1. Roadside transects
2. Vegetation and soil studies
3. Ice-wedge boreholes
4. Effects of the 2015 Sagavanirktok R. flood

Study sites: Deadhorse area, Prudhoe Bay, AK

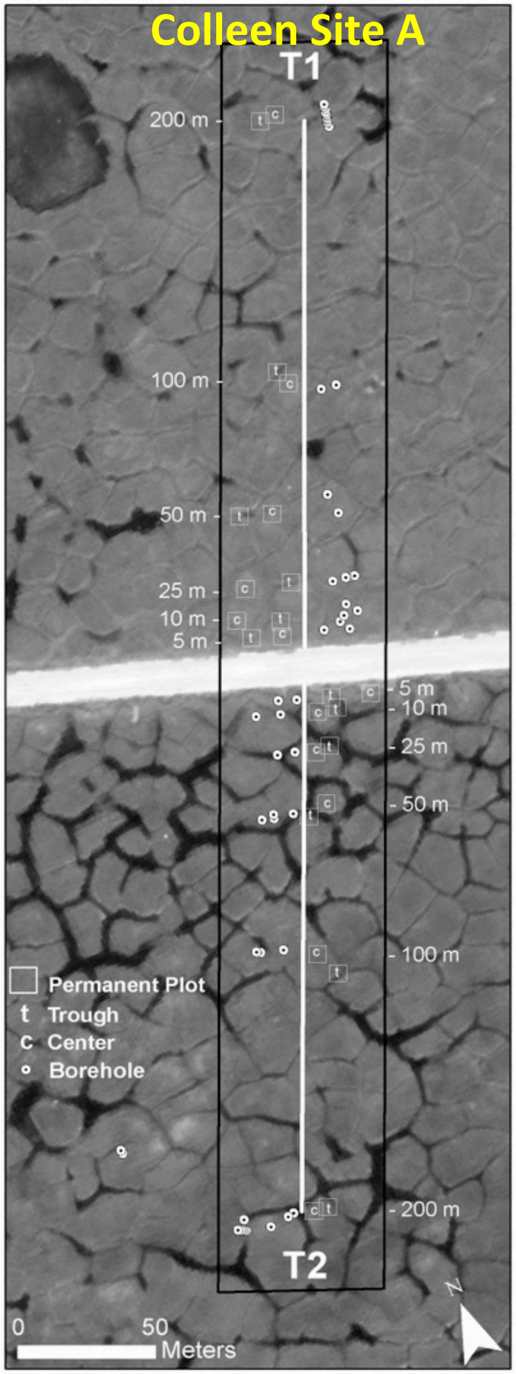






Both sites have large contrasts between the flooded and drained sides of the road.

- Much more productive, greener vegetation on the flooded side.
- Dust effects most evident on the drained side.



Transects 1 & 2, plots & boreholes

Transects:

- 1-100 m: 1-m observations
- 100-200 m: 5-m observations
- Elevation, ALT, water depth, Veg height, Veg type, Microrelief type, NDVI, LAI

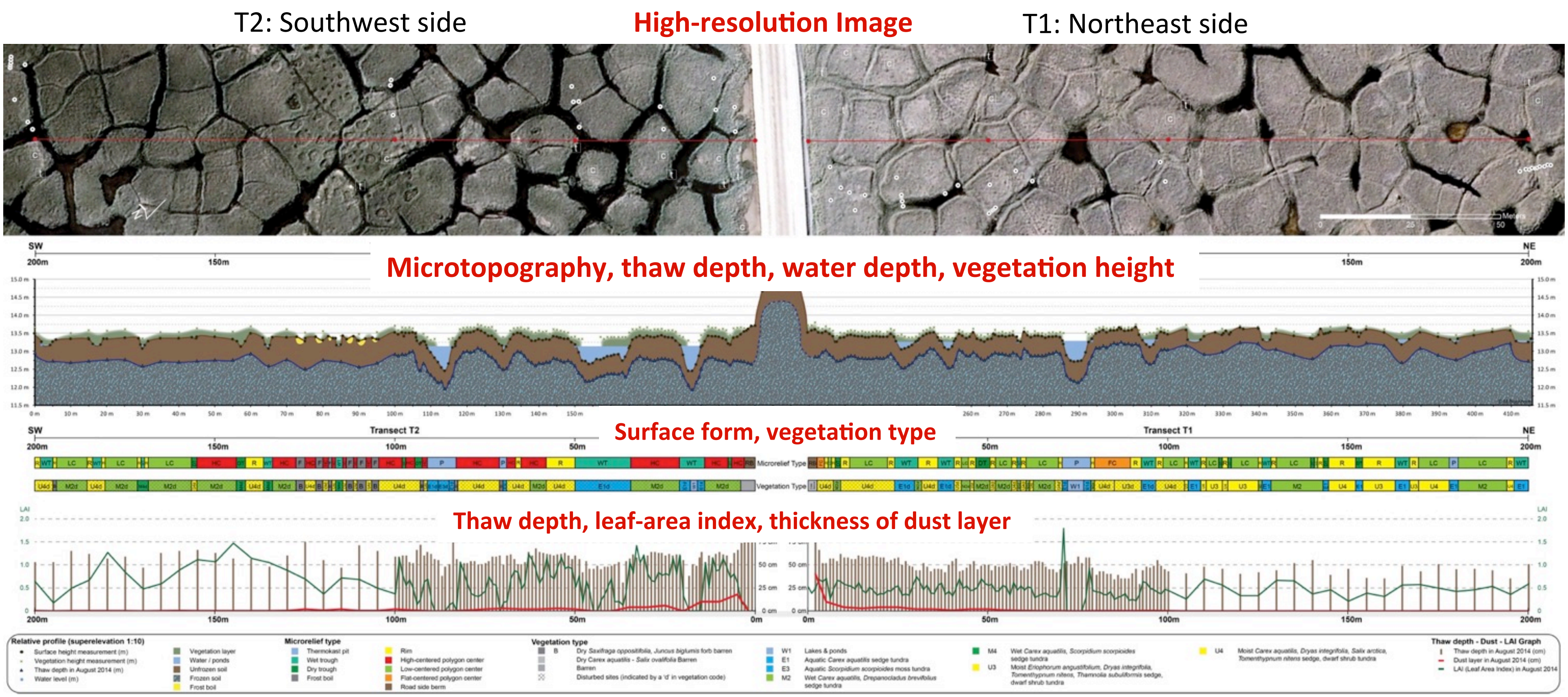
Plots:

- 5, 10, 25, 50, 100, 200 m from road
- Ice-wedge polygon troughs and centers
- Vegetation, soils, ALT, NDVI, LAI, soil and snow temperature (iButtons)

Ice-wedge boreholes:

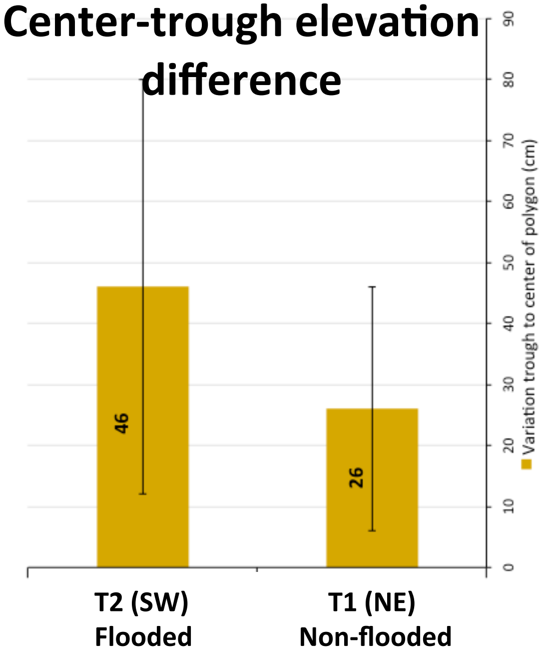
- Several holes across ice-wedge to gravel layer or ice wedge.

Transect survey

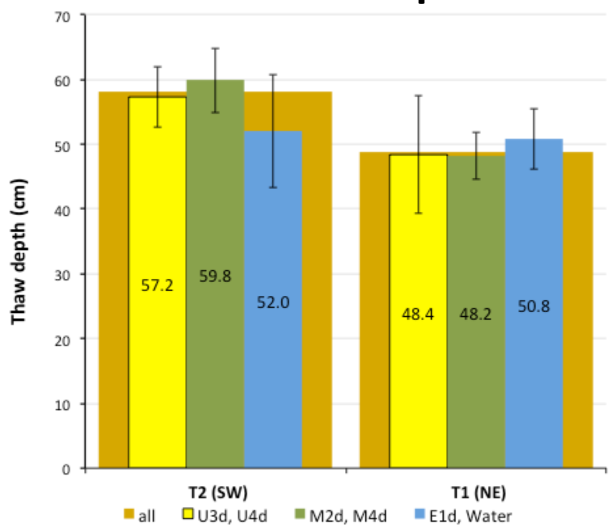


Contrasts between SW (flooded) and NE (non-flooded) sides of the road, Colleen Site A

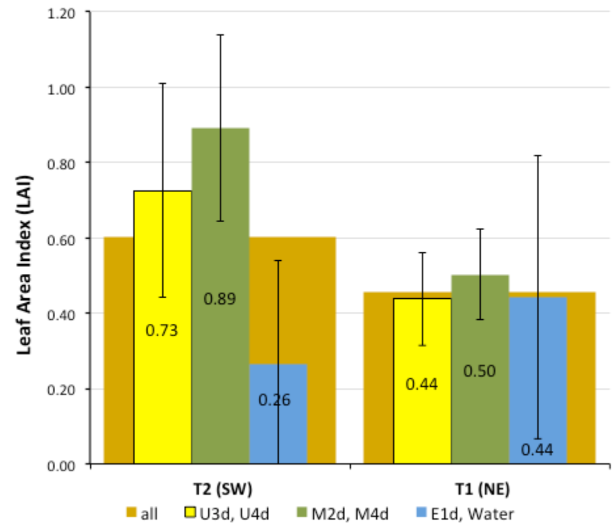
Center-trough elevation difference



Thaw depth



Leaf-Area Index



Flooded side had:

77% greater center-trough elevation difference

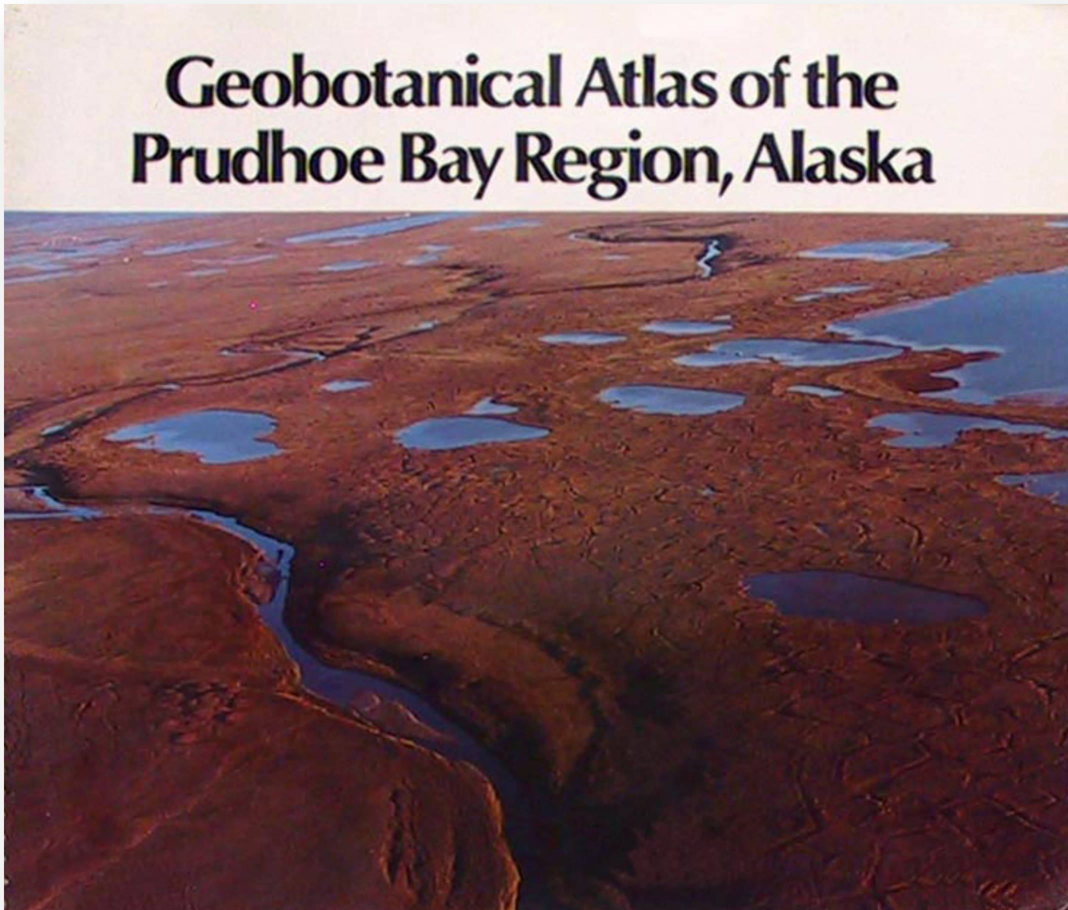
18 % deeper thaw

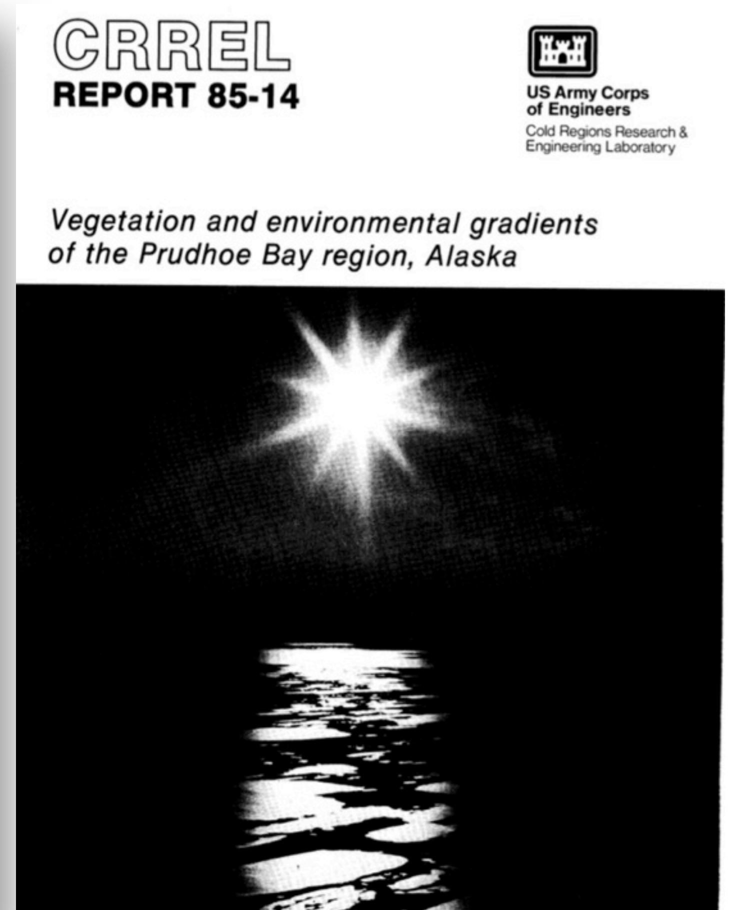
33% greater LAI

Take home message from Marcel Buchhorn

- "The striking contrasts on either side of the road are caused primarily by altered hydrology.
- Flooding on the SW side of the road caused considerable subsidence of the ice wedges, greater micro-relief contrast, conversion of low-centered polygons to high-centered polygons, water accumulation in the troughs, deeper thaw, and higher productivity.
- Dust had greater impact on the non-flooded side.
- Thermokarst has resulted in much more heterogeneous landscapes than existed in the 1970s."

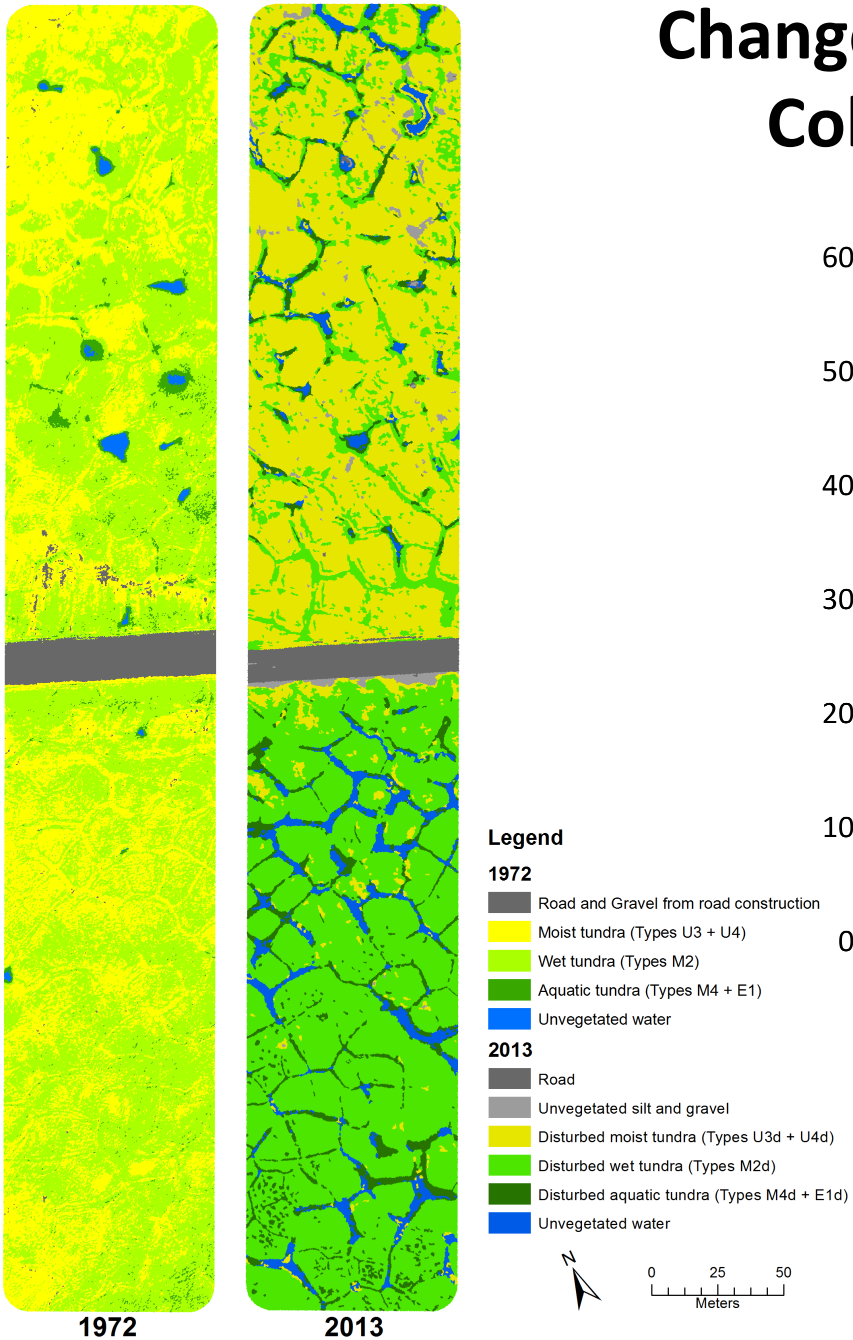
IBP studies from the 1970s provide baseline vegetation data

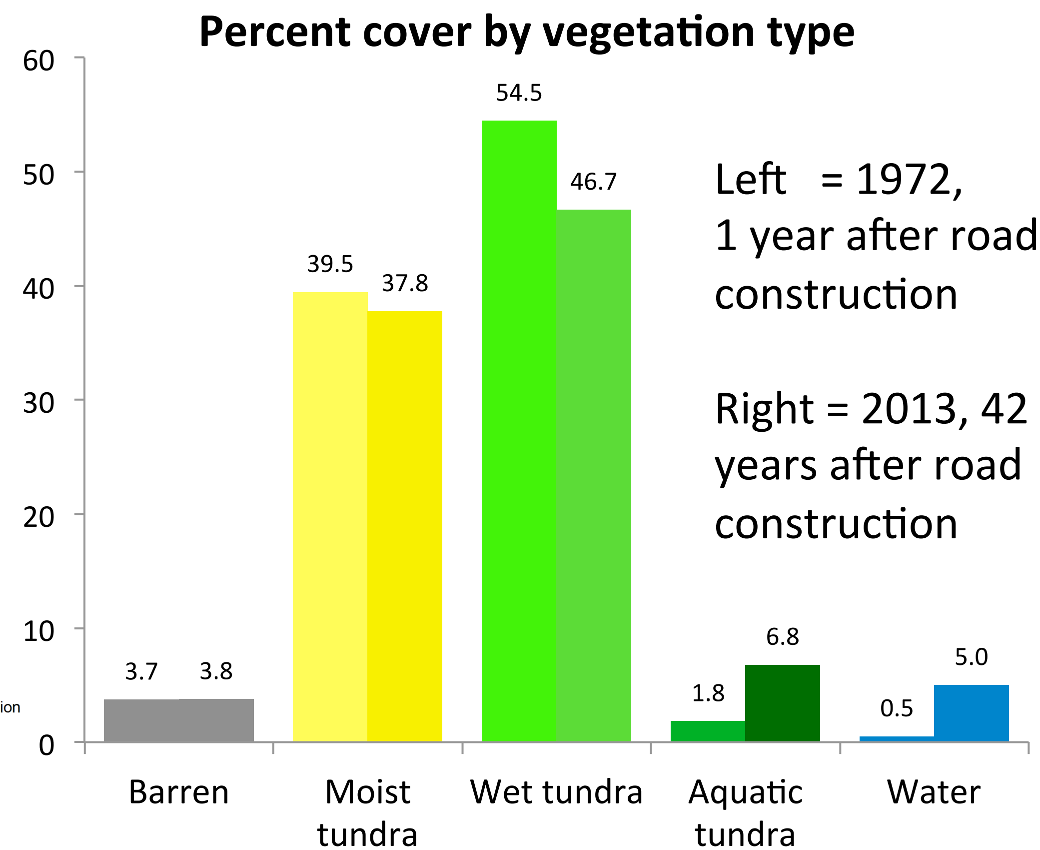




- Walker, D.A., Everett, K.R., Webber, P.J., Brown, J. 1980. *Geobotanical Atlas of the Prudhoe Bay Region*, Alaska. CRREL Report 80-14*.*
- Walker, D. A. (1985). *Vegetation and Environmental Gradients of the Prudhoe Bay Region, Alaska,* CRREL Report 85-14.

Changes in mapped vegetation at Colleen Site A (1972-2013)





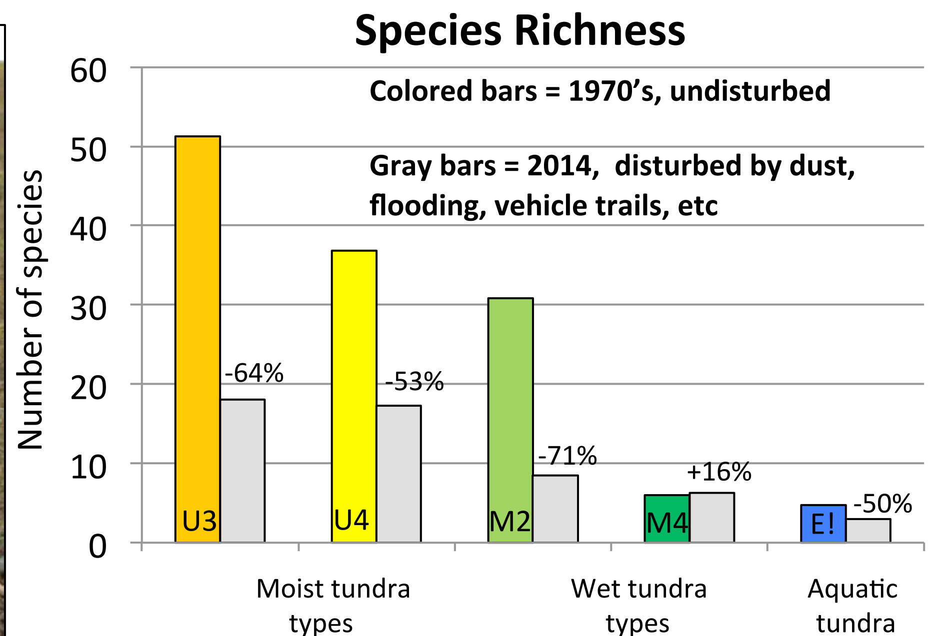
- **Reduced areas of moist tundra (-2%) and wet tundra (-8%)**
- **Increased areas of aquatic tundra (+4%) and water (+10%)**

Dust effects on soils

Soil plug from polygon center 50 m from road with new 20-cm thick mineral horizon.

>40 cm of dust adjacent to road has increased drainage and eliminated thermokarst within 5 m of the road

Vegetation composition surveys



- **Large declines in species diversity of moist and wet tundra since 1970s.**
- **Many species recorded in 1970s plots were not recorded in 2014:**
  7 Forbs, 2 Graminoids, 7 Mosses, 6 Lichens
- **Some species showed noticeable increases :**
  Salix arctica, S. lanata, Braya glabella, Eriophorum angustifolium, Carex aquatilis

Take home message from Martha Raynolds

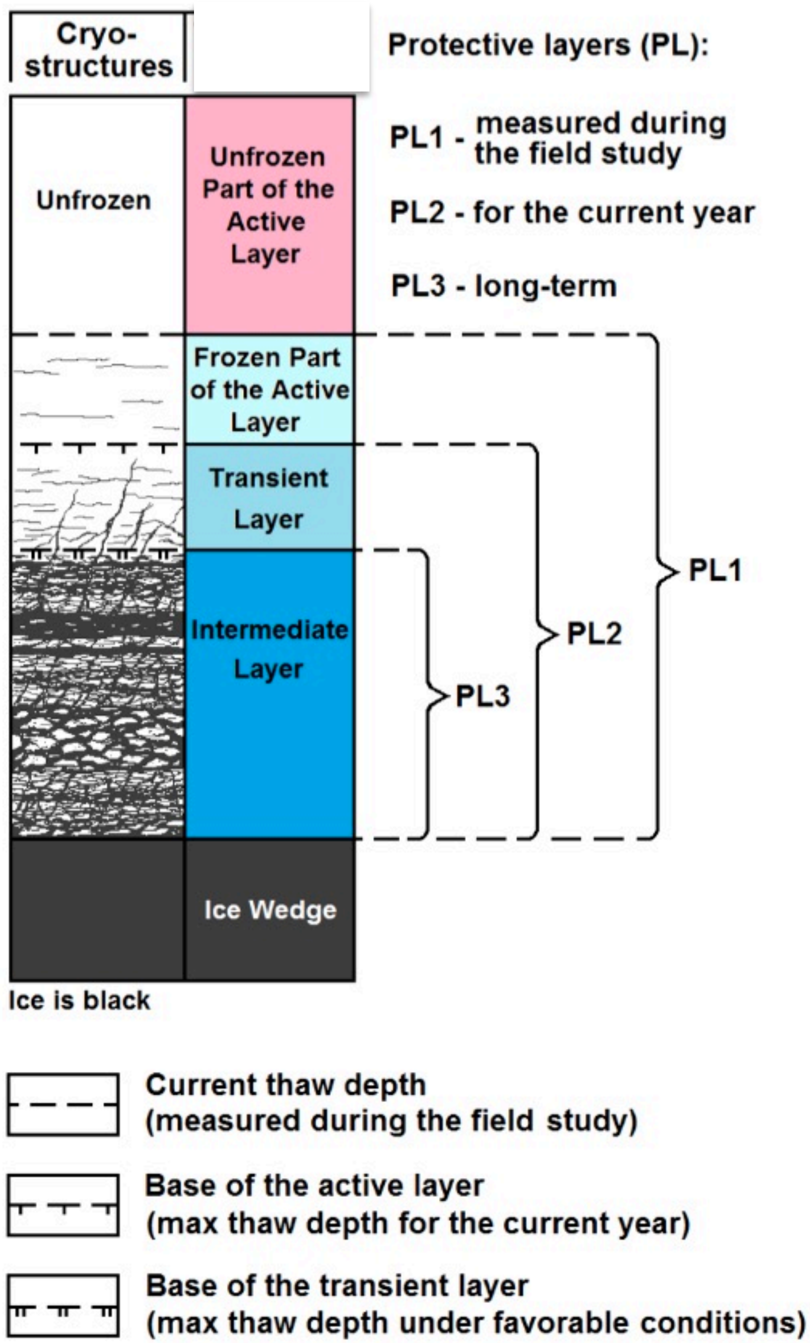
- "I was impressed with how many species had been lost from the plant communities since the 1970s.
- Dust, flooding, vehicle trails, and other disturbances have had cumulative effects on plant communities, even if the vegetation looks relatively undisturbed."

Permafrost boreholes

Ice cores from boreholes drilled in ice-wedge troughs

Intermediate layers

Intermediate layer

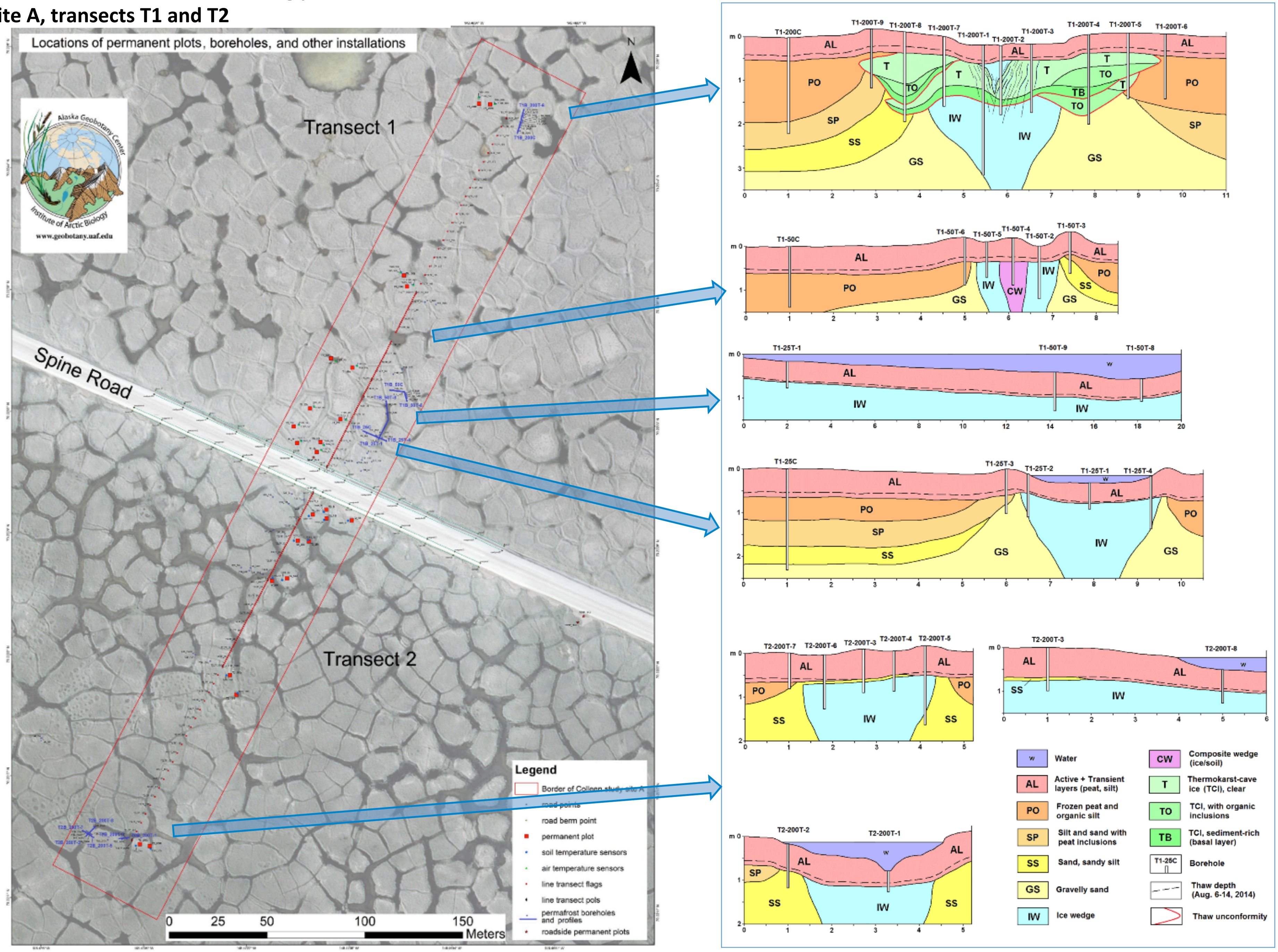


Modified from Kanevskiy et al. 2016, EICOP.

The intermediate layer

- Ice-rich and organic rich layer resistant to thaw.
- Protects the underlying ice-wedge from thaw.
- Forms when there is an aggrading permafrost table.
- If missing and summer thaw penetrates to the ice wedge, the wedge is in a degrading state.

Location of boreholes and drilling profiles, Colleen Site A, transects T1 and T2



The flooded side of the road had thicker intermediate layers and no degrading ice wedges

Transect	Inter-mediate layer (cm)	Actively degrading ice wedges***, %
T1, (NE, nonflooded)	1.2 (n=22)	9.1% (n=22)
T2 (SW, flooded	5.0 (n=13)	0% (n=13)

*** Percent of boreholes drilled between late July and mid-September, which encountered ice wedges actively degrading on the day of drilling (PL1=0).

Overall risk of ice-wedge degradation (Kanevskiy, 2016 EICOP)
Very High (PL3=0)
High (PL3=1-5)
Moderate (PL3=5-15)
Low (PL3=15-25)
Very Low (PL3>25)

Factors contributing to thicker intermediate layers on the flooded side:

- Thicker dust layers, and mineral material redistributed from the eroding polygon centers.
- Taller more productive vegetation.
- Thicker organic soil layers composed of dead sedges and aquatic mosses, reducing heat flux to the ice wedges.

Take home message from Misha Kanevskiy

- "I was surprised that ice wedges under the deep water-filled troughs were more stable at the present time than wedges not affected by flooding.
- The insulative protection provided by more plant production, thick organic layers, and accumulation of mineral material in the troughs promotes intermediate-layer formation and permafrost aggradation."

Photo: Loren Holmes / Alaska Dispatch News, May 21, 2015

Routing of flood waters to the west side of the road was caused by massive aufeis formation in the delta of the river.

- Major area of aufeis to the north blocked much of the flow of the river.
- This caused a major flow of water northward on the west side of the road,.

Photos by KTUU News, http://www.ktuu.com/news/news/deadhorse-flooding-recedes-dalton-highway-remains-closed/33191052.

Flooding at Deadhorse Airport and our Airport study site

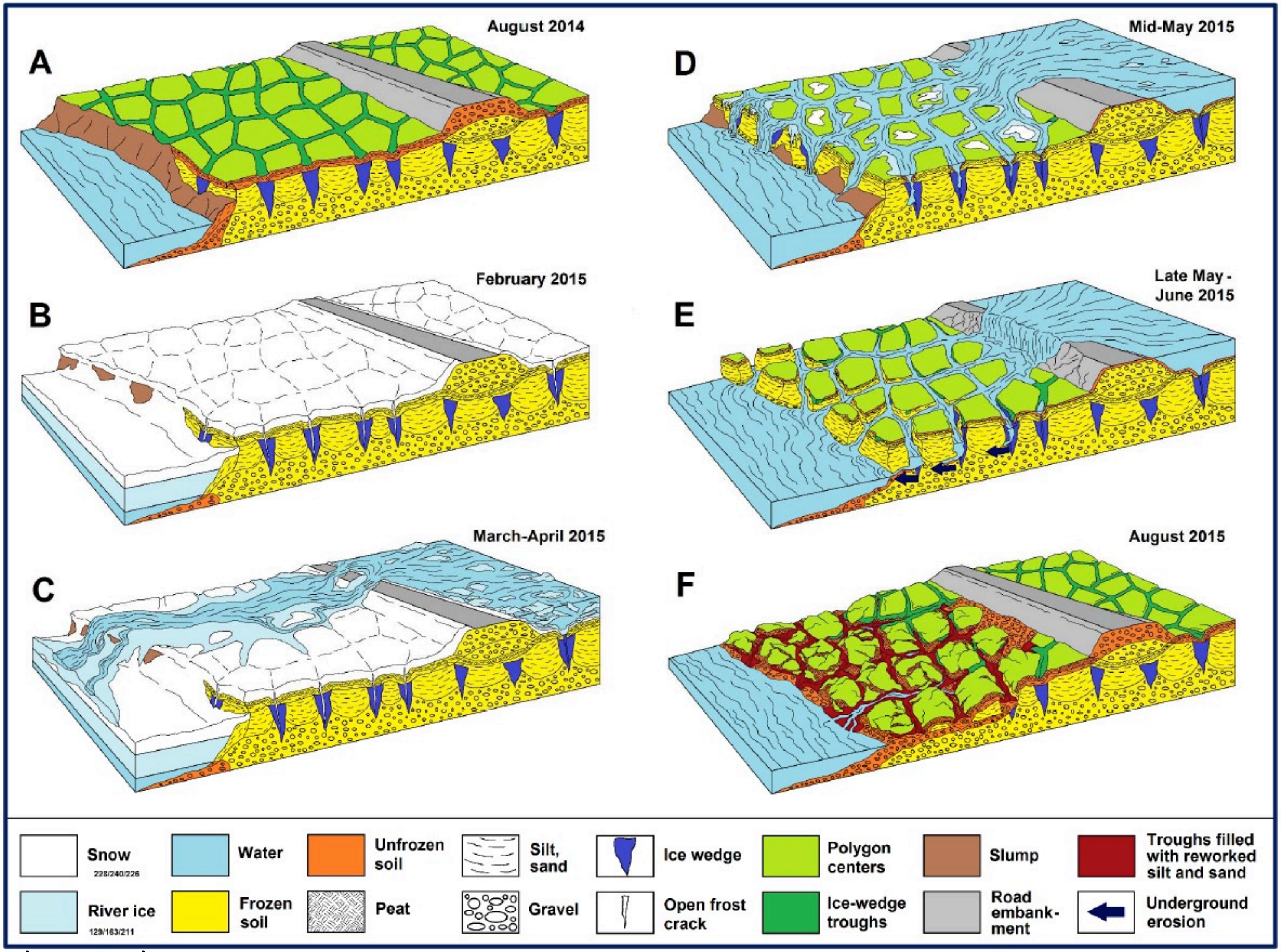
Photos: Alaska Department of Transportation and Public Facilities

Massive thermokarst occurred where high-velocity flood waters were concentrated.

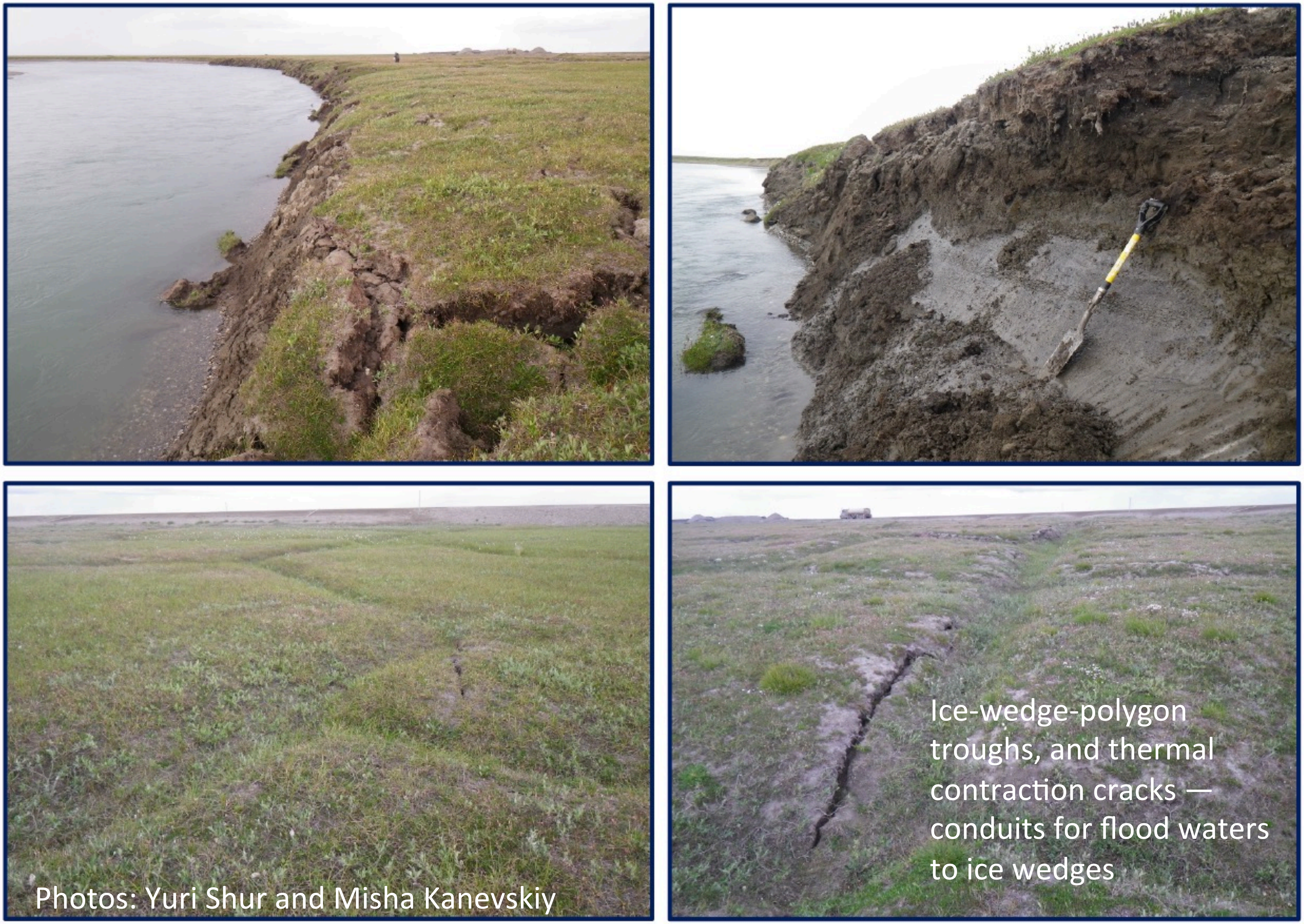
- Near the airport the road had to be breached to allow the flood waters to drain back into the main Sagavanirktok River channel.
- Massive underground ice-wedge thermokarst destroyed the Dalton Highway near the Airport.

Photos courtesy of Alaska DOT & PF

Conceptual model of underground thermokarst erosion process

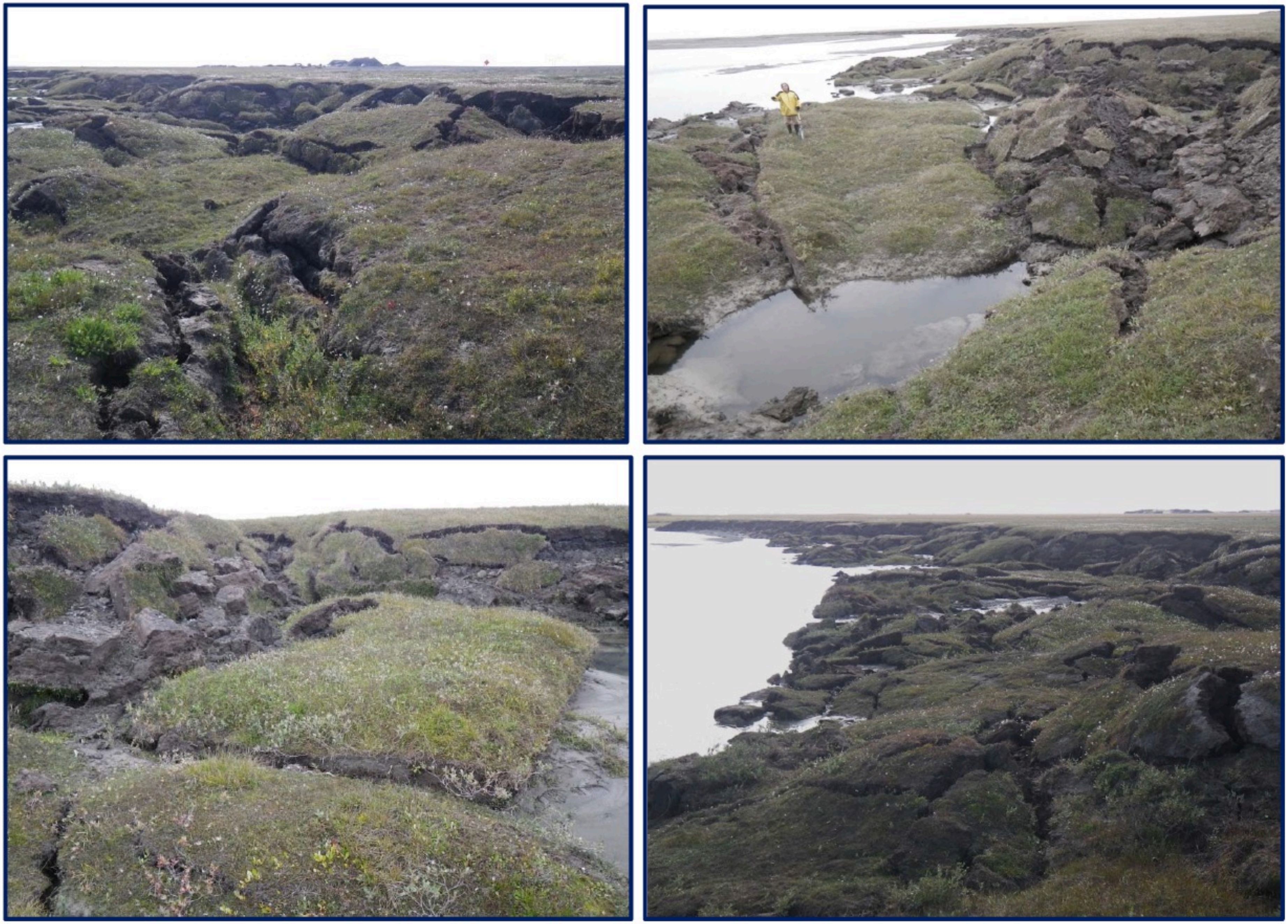


Shur et al. 2016, EICOP.



Study site SR-1, August 2012 (prior to the flooding)

Site SR-1, August 2015, after the flooding. Troughs concentrate flow and water creates funnels



Site SR-1 after the flooding and underground erosion, August 2015.

Take home message from Yuri Shur

- “The scale of the underground erosion and the forms which it left surprised me most of all.
- Also the huge icing in the Sagavanirktok River delta, which worked as a dam during spring runoff.“

Based on Shur, Y., Kanevskiy, M., Walker, D. A., Jorgenson, M. T., Buchhorn, M., & Raynolds, M. K. (2016). Permafrost-related causes and consequences of Sagavanirktok River flooding in Spring 2015, Abstract 1065. Presented at the 11th International Conference on Permafrost, Potsdam, Germany.

Conclusion

The roadside studies and the 2015 flood illustrate the complex cumulative effects caused by changes in climate, rapidly expanding infrastructure networks, altered hydrological pathways, and easily eroded massive ground ice.