

Lesson 3:

Biocomplexity of small patterned-ground features



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Overview of talk

Introduction:

- What is biocomplexity?
- What are patterned-ground features?
- Why is this an important topic?
- Conceptual models of patterned ground formation.

Overview of results from project components:

- Climate and permafrost
- Soils and biogeochemistry
- Vegetation
- Modeling
- Education



NSF-Wide Investment

Biocomplexity in the Environment

[> More NSF-Wide Investments](#)

Purpose

To understand complex environmental systems in which the dynamic behavior of living organisms is linked to the physical and chemical processes of the environment.

Background

The world faces significant scientific and societal challenges, including the prospect of rapid environmental and climatic change, and the complicated question of long-term environmental security. The integrity of ecosystems is inextricably linked to human well-being. Fundamental study of complex environmental systems is critical to developing new ways to anticipate environmental conditions and improve environmental decision-making.

Potential Impact

- A better understanding of natural processes, human behaviors and decisions in the natural world, and ways to use new technology effectively for environmental sustainability
- Improved forecasting capabilities
- Enhanced understanding of environmental decision-making
- Novel sensor systems and instrumentation
- A more comprehensive understanding of the ecology of infectious diseases
- Improved environmental education

The image above is from a numerical simulation of an idealized wind-driven ocean basin. Such computations allow a better understanding of the Earth's climate system.

Credit: Jeffrey B. Weiss,
University of Colorado at
Boulder

Goal of the Biocomplexity of Patterned-Ground Project

To better understand the complex linkages between frost heave, frost cracking, biogeochemical cycles, vegetation, disturbance, and climate across the full Arctic summer temperature gradient in order to better predict Arctic ecosystem responses to changing climate.



Biocomplexity Grid at Green Cabin, Banks Island, Canada,
2003



BECAUSE:

- The processes involved in the formation of patterned-ground landscapes are not well understood.
- The importance of patterned ground with respect to biogeochemical cycling, carbon sequestration and other ecosystem processes is poorly known.
- They are an ideal natural system to help predict the consequences of climate change of disturbed and undisturbed tundra across the full Arctic climate gradient.



Frost-heave Complexity Questions

Self organization

- How do frost-heave features self-organize themselves?
- How is vegetation involved in this process?

Complex adaptive systems

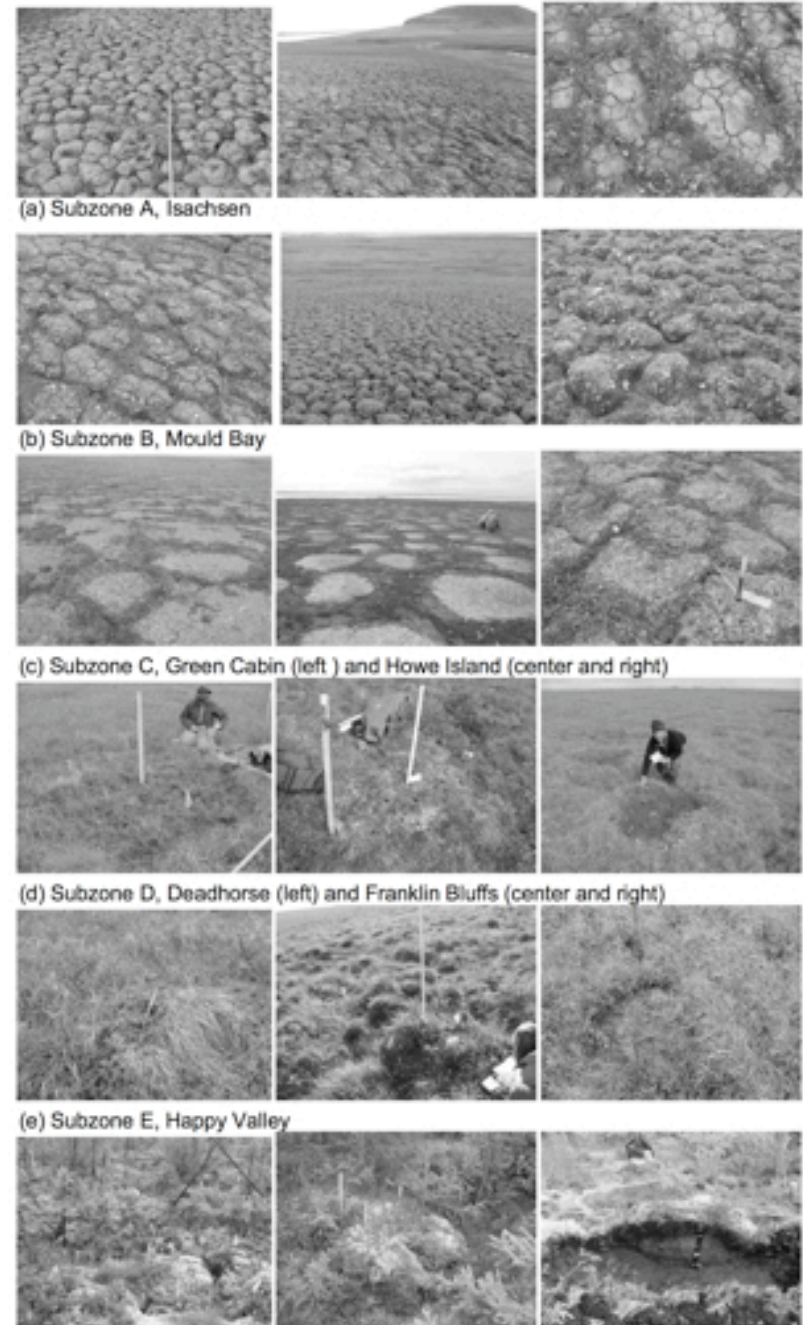
- How do frost-heave and associated ecosystems change along the arctic climate gradient?
- How does the vegetation affect the microclimate, ground ice, disturbance, and soils of frost-heave features along the Arctic climate gradient?

Scaling issues

- What are the emergent properties of frost-heave systems at different scales?
- How do frost-heave features affect trace gas fluxes, hydrological systems, and patterns of wildlife at large spatial scales?

Variety of frost-boil and earth hummock forms along the Arctic climate gradient

- Subzone A and B: Mainly small polygons with vegetation concentrated in the cracks.
- Subzone C: Larger polygons, and frost-boils (nonsorted circles) with vegetation in the cracks and margins of circles and mostly barren frost boils.
- Subzone D: Partially vegetated circles with well-vegetated inter-circle areas with thick moss mats.
- Subzone E: Mainly small circles and earth hummocks thickly covered in vegetation.



Some forms caused by differential frost heave

- Frost-heave non-sorted circles
- Earth hummocks



Non-sorted circles, Franklin Bluffs, AK, Subzone D.



Non-sorted circles, Howe Island, AK, Subzone E.



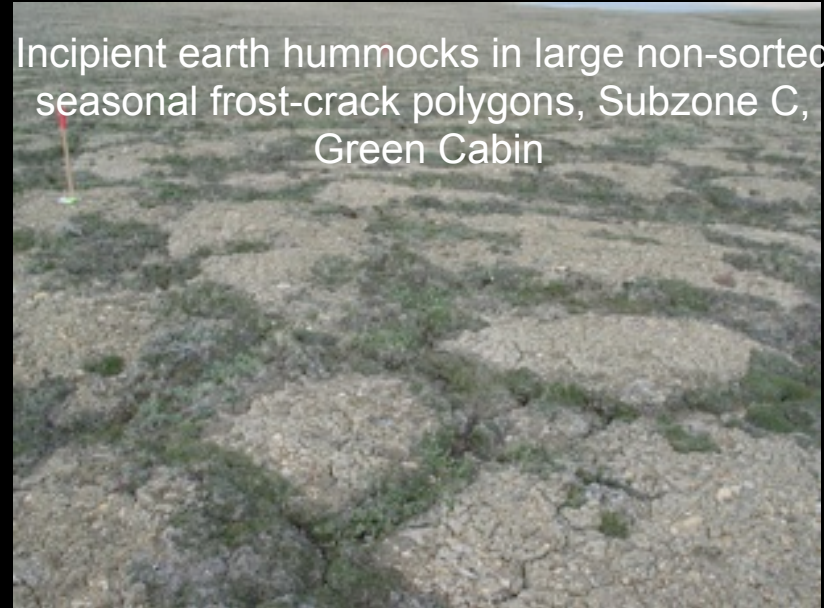
Earth hummock, Inuvik, NWT, Canada,, Northern Boreal Forest.
Photos: D.A. Walker

Earth hummocks caused by differential frost heave

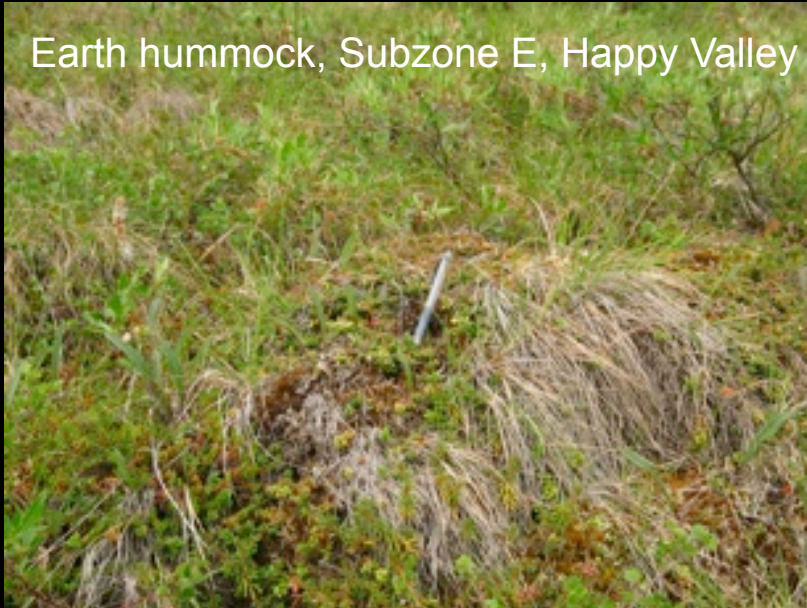
Earth hummocks, Subzone B, Mould Bay



Incipient earth hummocks in large non-sorted seasonal frost-crack polygons, Subzone C, Green Cabin



Earth hummock, Subzone E, Happy Valley



Earth hummocks, northern boreal forest, Inuvik, NWT





Non-sorted stripes, Subzone C, Green Cabin.



Large non-sorted circles in wet soils, Green Cabin.

Complexities caused by slope, soil moisture and rocky soils

- Stripes on slopes
- Very large non-sorted circles in wet sites.
- Sorted circles in rocky soils.



Sorted Circles at Mould Bay, Canada, Elevation Belt A. Photos: D.A. Walker

Contraction Cracking



*Mould Bay, Prince Patrick Island,
Elevation, Belt A.*



*Contraction cracks in a drained lake basin,
Prudhoe Bay, Alaska, Subzone D.*



*Green Cabin, Banks Island,
Bioclimate Subzone C.*



*Howe Island, northern Alaska,
southern Bioclimate Subzone C.*

- Small non-sorted polygons (Washburn 1980).
- Occur on most sandy to clayey soils in the High Arctic (Subzones A, B, C).
- Seasonal frost cracking (Washburn 1980).
- Can be confused with desiccation cracking.

Photos: D.A. Walker

Modification of small polygons to form turf hummocks

- Erosion and eolian deposition modify the basic forms resulting in turf hummocks (Broll and Tarnocai 2003).



Turf hummocks on slopes with *Dryas integrifolia* and *Cassiope tetragona*, Green Cabin.
Photo: D.A. Walker

In the High Arctic, small contraction-crack polygons are the dominant patterned-ground features.



Isachsen, Ellef Ringnes I.



Mould Bay, Prince Patrick I.



Howe Island, northern Alaska

- Small non-sorted polygons (Washburn 1980).
- Occur on soils of all textures in the High Arctic.
- May be caused by either desiccation cracking or seasonal frost cracking (Washburn 1980).

Photos: D.A. Walker

Desiccation cracking vs. seasonal frost cracking



Desiccation cracks.
Mould Bay.



Desiccation cracks.
Dinosaur Provincial Park, Alberta.



Green Cabin, small non-sorted polygons



Green Cabin, polygon removed from soil.

Desiccation cracking:

- Washburn (1980) and Tricart (1967) attributed most fine-scale (<1 -m diameter polygons) to desiccation cracking.

Seasonal frost cracking:

- Ubiquitous on most High Arctic surfaces.
- All soil textures.
- Deeper cracking.
- Experiments and models are needed to determine conditions for seasonal frost cracking.

Frost cracking occurs at many scales



Permafrost crack nonsorted polygons, Kuparuk R., Alaska



Small seasonal frost-crack non-sorted polygons, Green Cabin.



Frost cracking within small polygons, Mould Bay.



Frost cracking within *Dryas* hummock, Green Cabin.

Role of soil texture



Rocky soils: sorted circles and polygons,
Mould Bay, Prince Patrick I.



Sandy soils: no circles nor hummocks
Atkasuk, AK



Silty soils: sorted circles without earth hummocks
Prudhoe Bay, AK



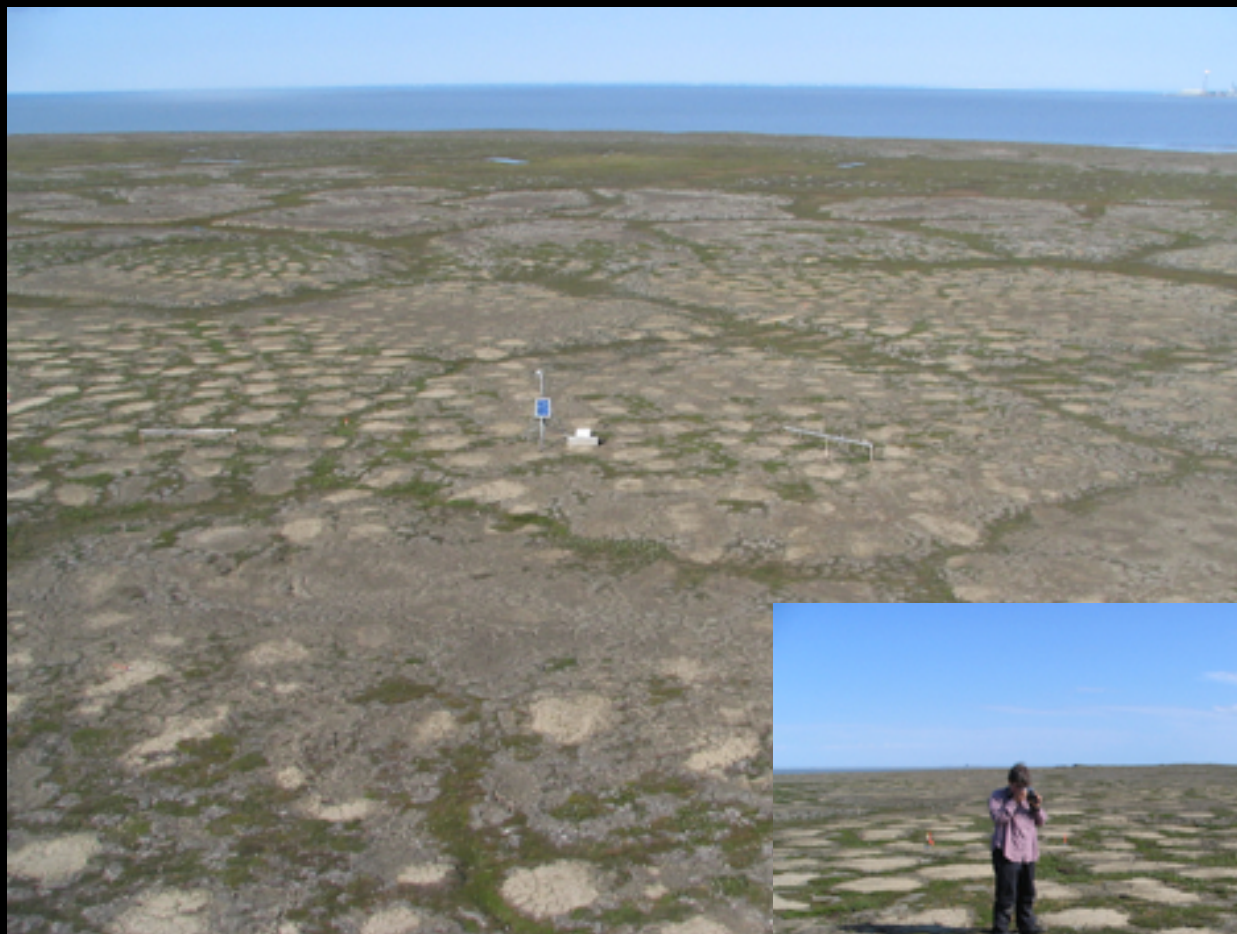
Clayey soils: earth hummocks,
Inuvik, NWT

Variety of forms on different substrates



**Stoney substrates:
Mould Bay, Prince Patrick I.**

Variety of forms on different substrates



**Saline sandy loam substrate:
Howe Island, Alaska**



Variety of forms on different substrates



**Mesic loamy substrates:
Southern Yamal Peninsula
(above), Kurishka, Kolyma R.
(right)**

In general:

- **Circular forms are caused by differential heave resulting in circles and earth hummocks.**
- **Polygonal forms are caused by cracking (thermal or desiccation):**
 - **Large polygons (thermal contraction cracking penetrates deep into the permafrost)**
 - **Small non-sorted polygons (contraction cracking confined to zone of seasonal thaw)**
- **Both differential heave and cracking can occur at a variety of scales forming complex landscape patterns.**
- **The forms can be modified by soil texture and a wide variety of processes including sorting (sorted forms), erosion and eolian deposition (turf hummocks, high-centered polygons), down-slope soil movement (stripes and lobes).**

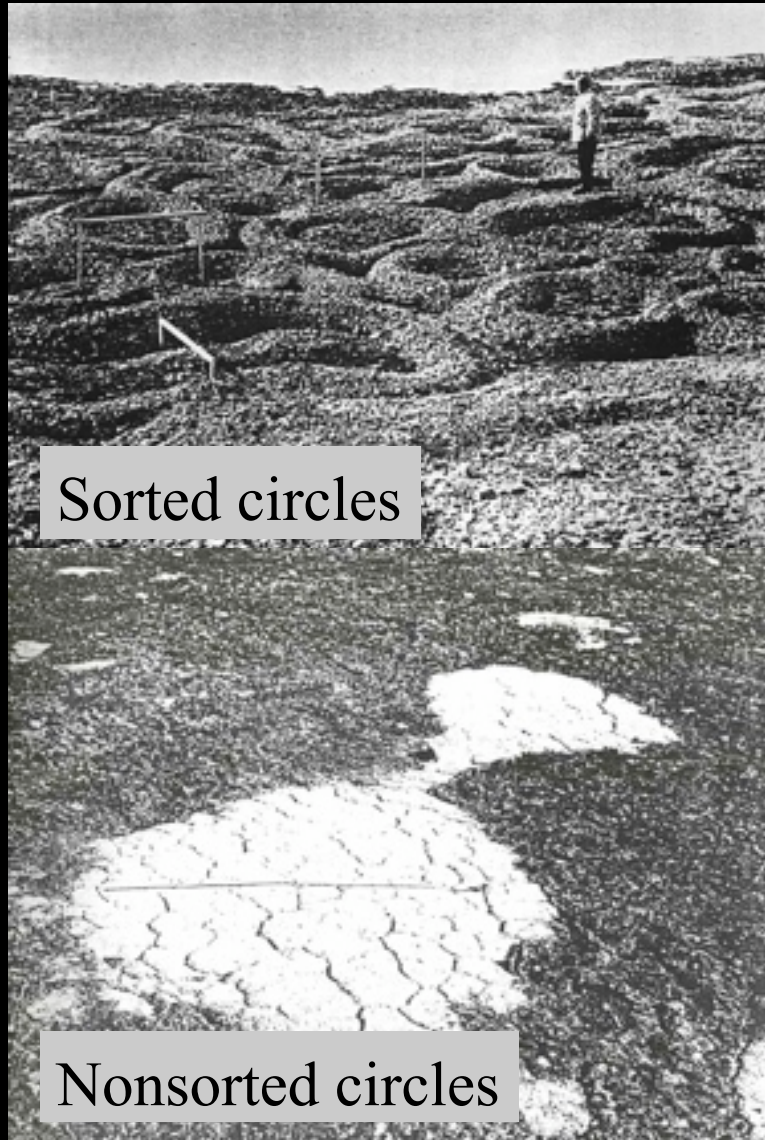
Project initially focused on “frost boils”



Subzone C, Howe Island, AK.
Photo; D.A. Walker

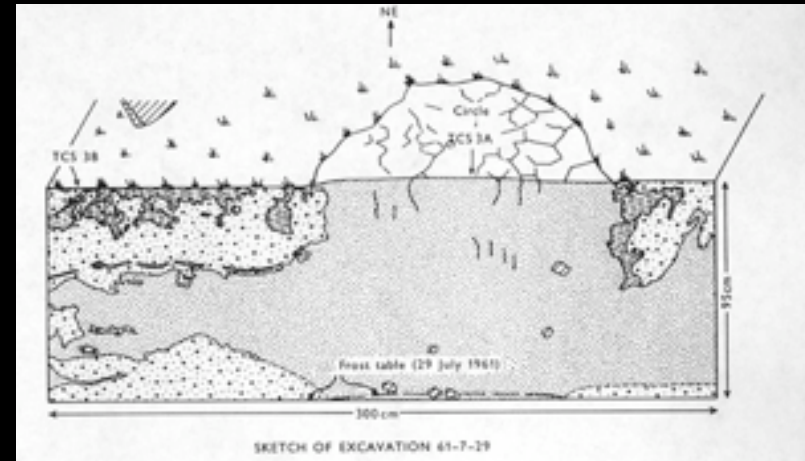
- **Caused principally by differential frost heave (Peterson and Krantz 2003).**
- **Also called:**
 - Non-sorted circles (Washburn 1980)
 - ‘Frost medallions’ (Russian term),
 - ‘Mud boil’ (Zoltai and Tarnocai 1981)
 - ‘Frost boi’ (van Everdingen 1998)
 - ‘Frost scar’ (Everett 1966)
 - ‘Spotted tundra’ (pyatnistye tundry, (Dostoyalov and Kudravstev 1967).

What are non-sorted circles?



Sorted circles

Nonsorted circles



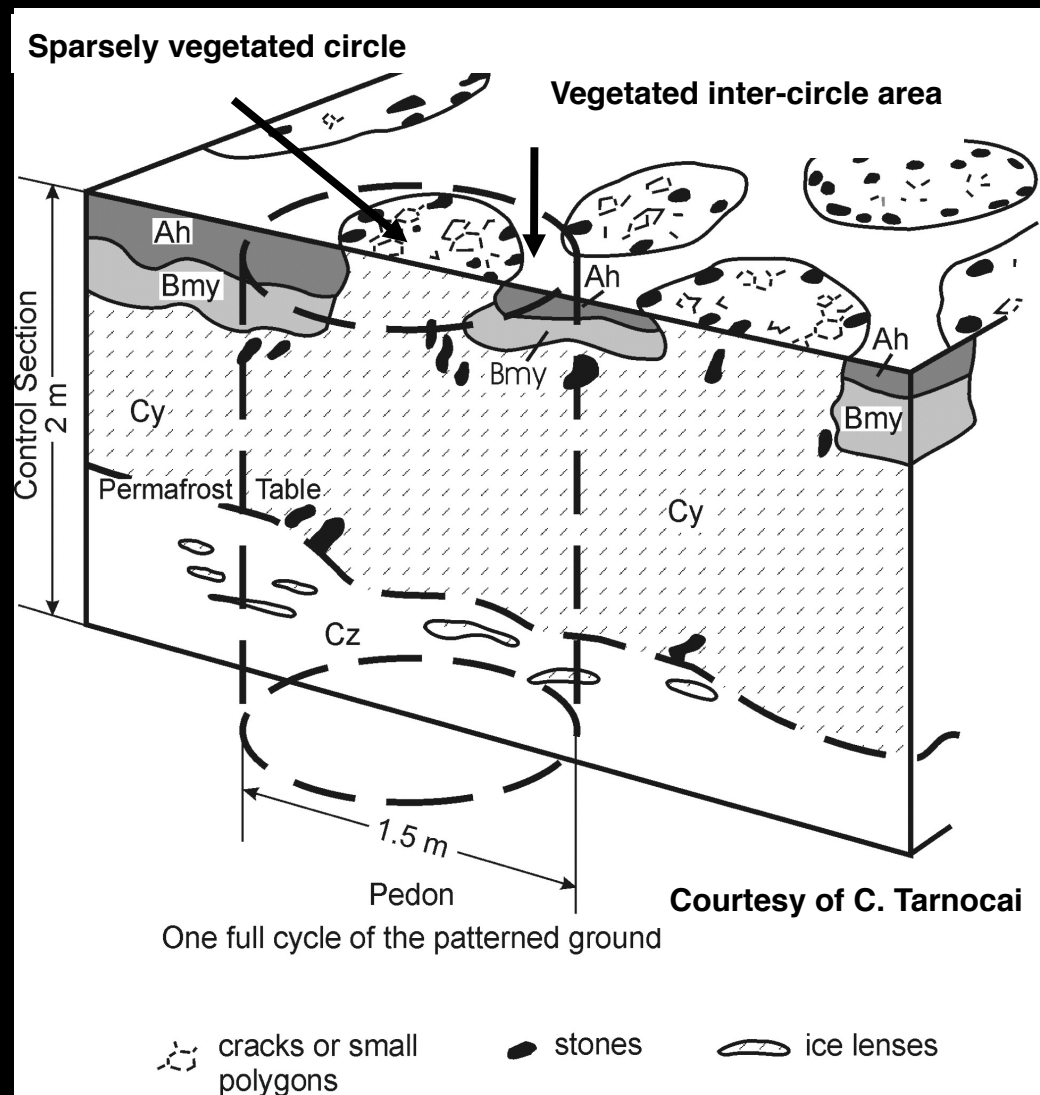
= Frost boil: “a patterned ground form that is equidimensional in several directions with a dominantly circular outline which lacks a border of stones...”

van Everdingen 1998

- Frost “boil” is a misnomer because no “boiling” is involved.
- Closest term in Russian is Piyatnoe medalion - “frost medallion”
- Moroznoe kepenie - frost churning due to needle-ice formation.
- Pyatneestaya tundra: “spotted tundra” in Russian

Figures from Washburn 1980

The non-sorted circle system



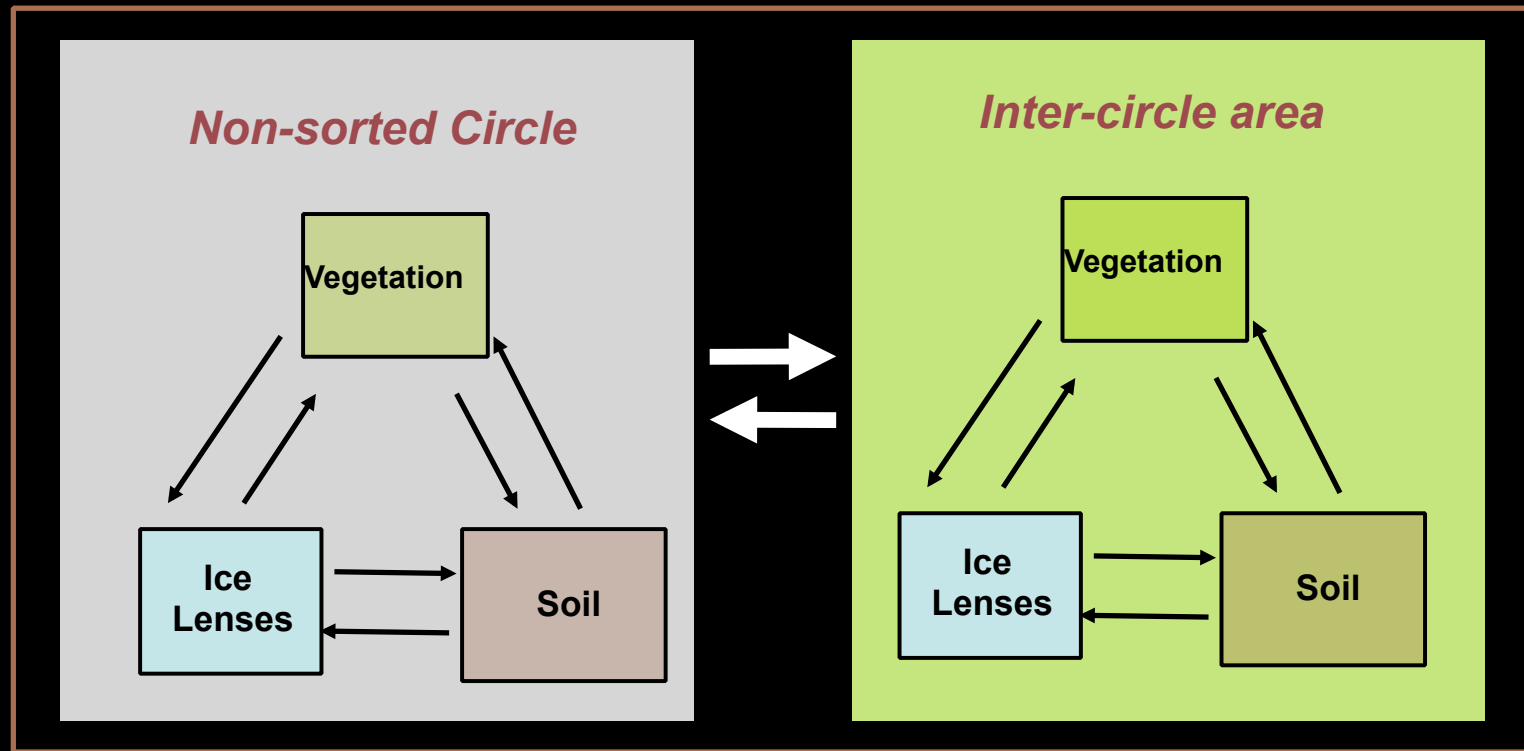
Central Questions



- How do biological and physical processes interact to form small patterned ground ecosystems?
- How do these systems change across the Arctic climate gradient?

Howe Island, AK.
Photo: D.A. Walker

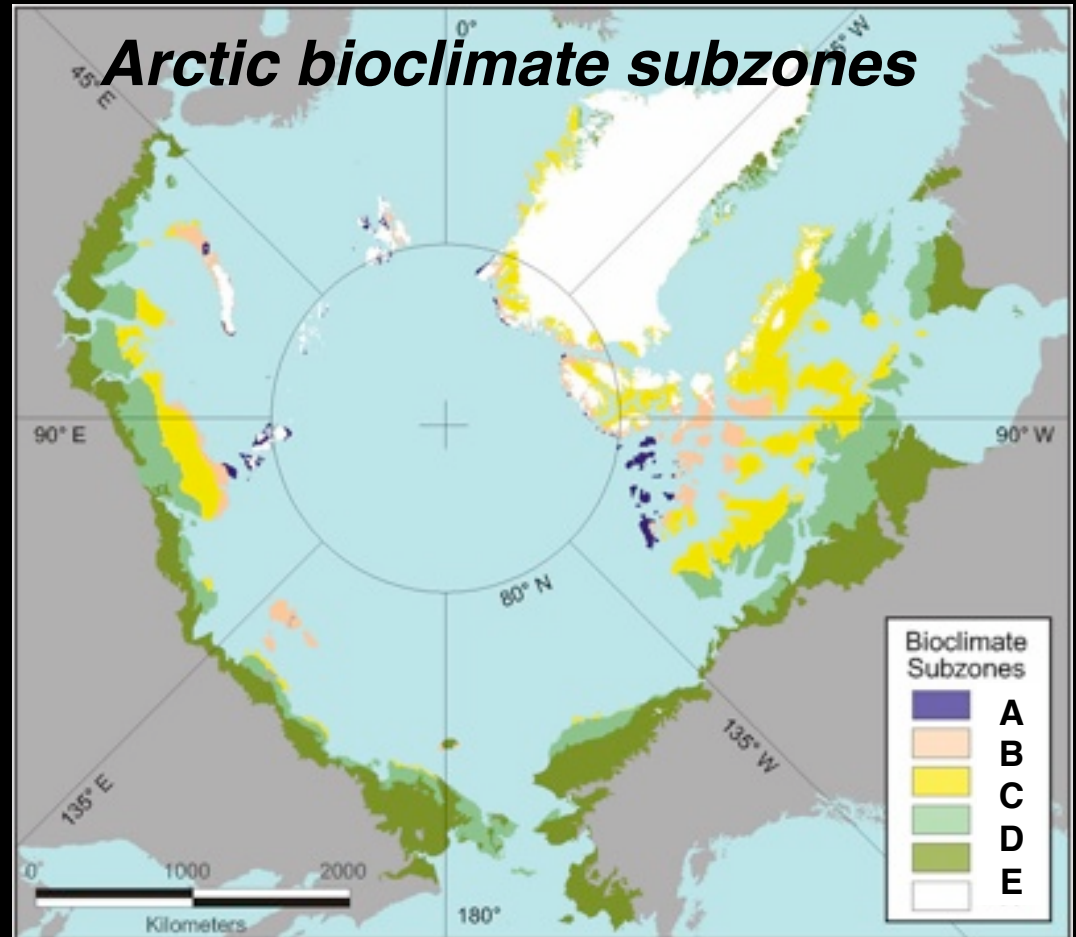
Conceptual model of the non-sorted circle system



The white arrows indicate interactions and feedbacks between **elements** (frost boils and inter frost boils), and black arrows between **components** of each element (ice lenses, soils, and vegetation).

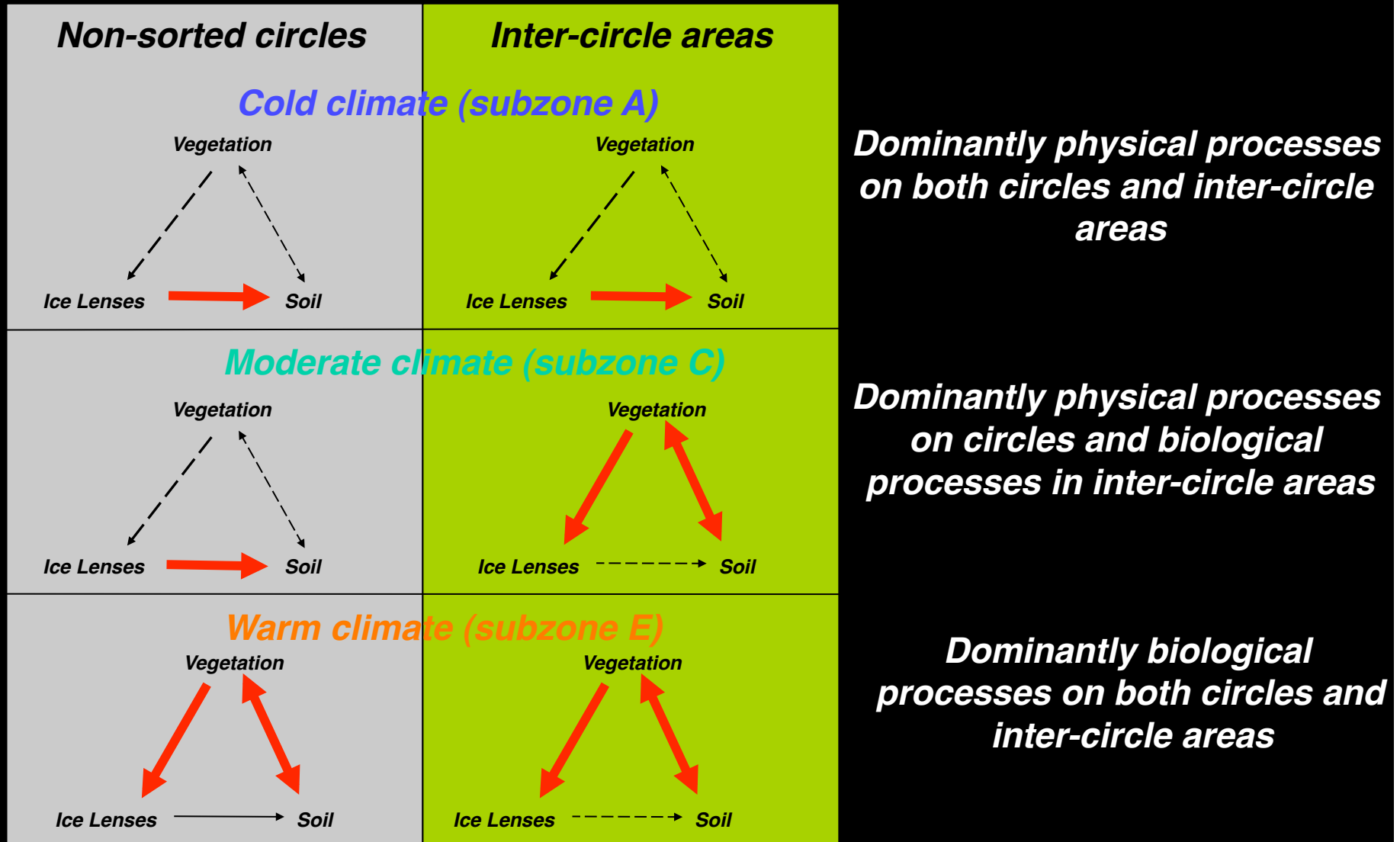
Examination of frost heave features across the Arctic bioclimate gradient

<i>Sub-zone</i>	<i>Mean July temperature (°C)</i>	<i>Dominant plant growth forms</i>
A	2-3	Cushion forbs, mosses, lichens
B	3-5	Prostrate dwarf shrubs
C	5-7	Hemi-prostrate dwarf shrub, sedges
D	7-9	Erect dwarf shrubs, sedges mosses
E	9-12	Low shrubs, tussock sedges, mosses



From the *Circumpolar Arctic Vegetation Map*, 2003.

Dominant drivers of patterned-ground formation across the Arctic bioclimate gradient



Dominantly biological processes on both circles and inter-circle areas

Expeditions and Timeline:

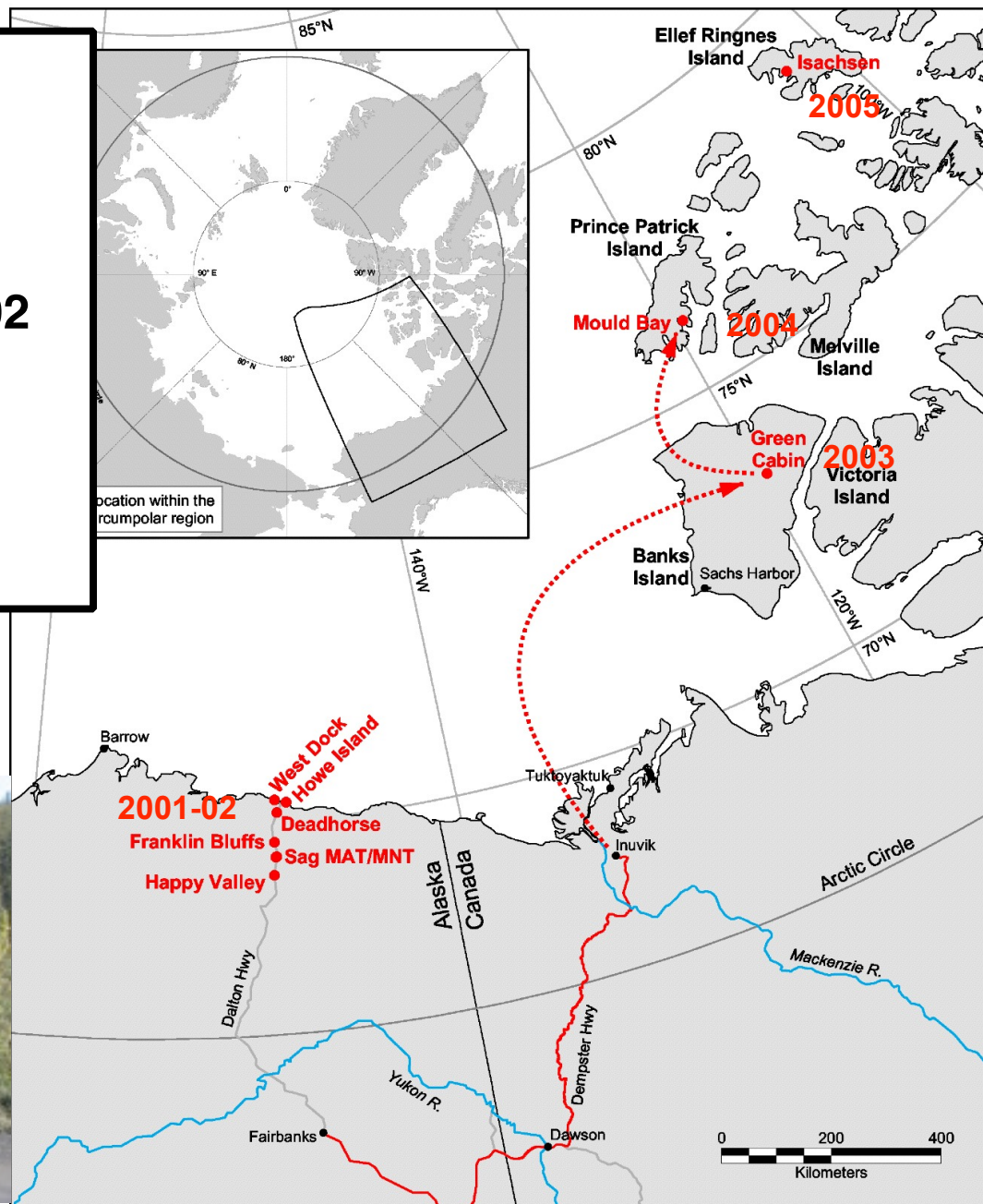
Dalton Highway: 2001-2002

Green Cabin: 2003

Mould Bay: 2004

Isachsen: 2005

Synthesis: 2006-2008





Ken Borak air
support in the
Canadian Arctic

**Low point of the
6-year project**



Stuck in the mud!!





Field Camp at Green Cabin, Banks Island

Project components

- **Climate and permafrost:** Vladimir Romanovsky, Ronnie Daanen, Yuri Shur
- **Soils and biogeochemistry:** Chien-Lu Ping, Gary Michaelson, Howie Epstein, Alexia Kelley
- **Vegetation:** Skip Walker, Anja Kade, Patrick Kuss, Martha Raynolds, Corinne Vonlanthen
- **Modeling:** Ronnie Daanen, Howie Epstein, Bill Krantz, Dmitri Nikolsky , Rorik Peterson, Vladimir Romanovsky
- **Education:** Bill Gould, Grizelle Gonzalez
- **Coordination and management:** Skip Walker

Climate and permafrost component



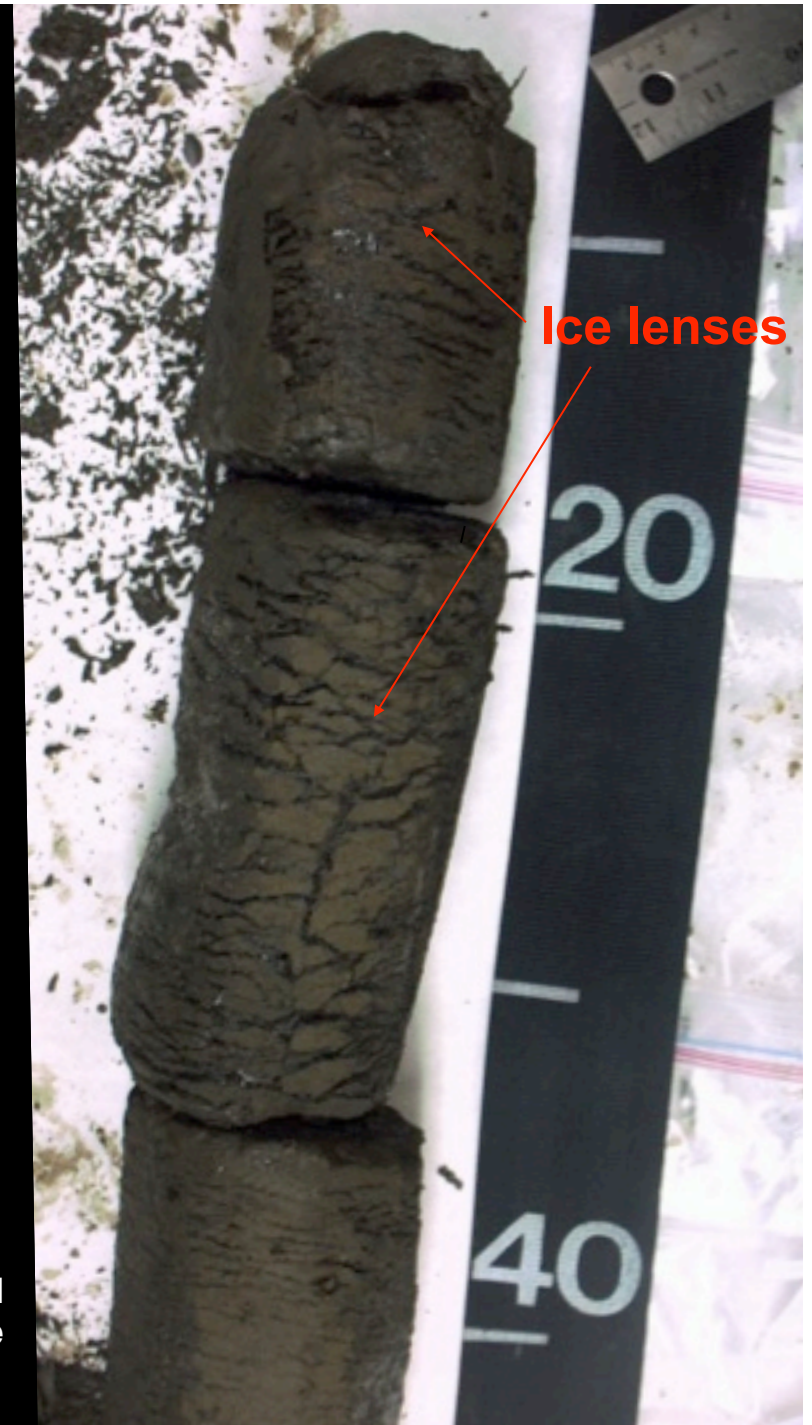
Vlad Romanovsky



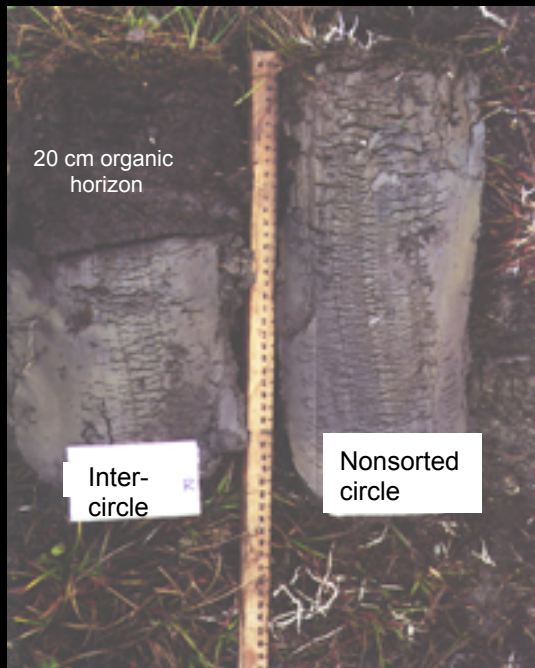
The ice-lens part of the nonsorted-circle system

- Ice lenses drive frost heave.
- Numerous closely spaced lenses form as the soil freezes downward from the surface.
- The increased volume of the water causes heave.
- Heave also is caused by formation of ice at the bottom of the active layer as the soil freezes upward.

Frozen soil core from a frost boil
Photo Julia Boike



These processes are described in three models of differential frost heave (Peterson and Krantz 2003, Daanen et al. 2008, Nickolsky et al. 2008).

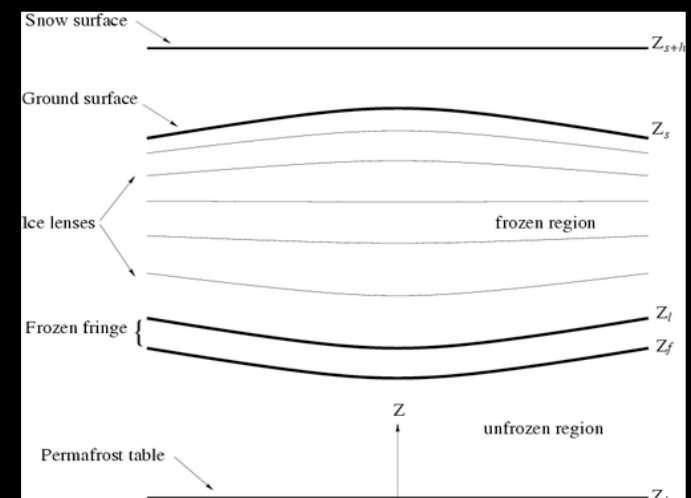


Lenticular voids in soil in summer created by ice lenses.

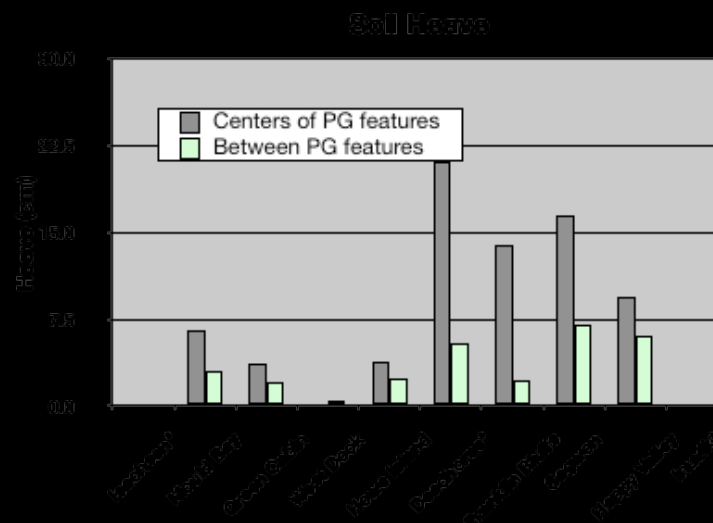
Briefly:

- Heat preferentially escapes from the surface at high points of small irregularities in the surface.
- These high points self-organize into patterns controlled by mechanical properties of the soil (e.g., texture) and active layer thickness.
- These high points are sites of increased heat and water flux, ice-lens development, and more heave. Water is pulled to the site of freezing by cryostatic suction.

Schematic of soil undergoing top-down freezing. Ice lenses exist in the frozen region and permafrost underlies the active layer.



Frost heave measurements

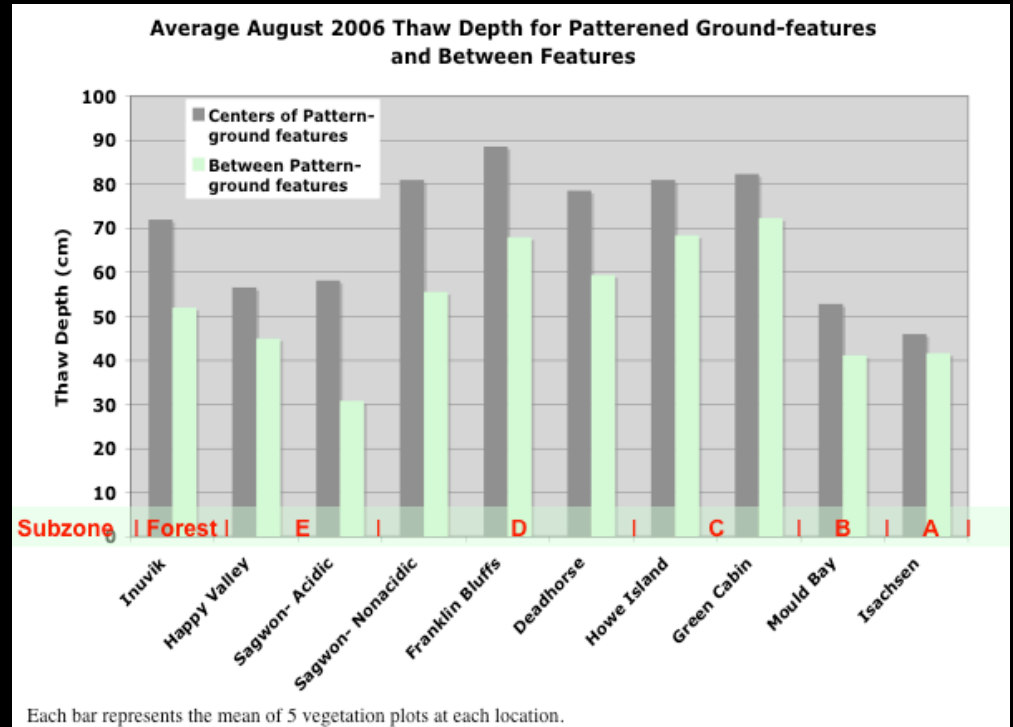


- Differential heave is the greatest in subzone D, where centers are unvegetated but areas between features are well-vegetated.
- Heave greatest in northern Alaska on silty soils

Active Layer depth



Thaw probe and prober.



Soils component



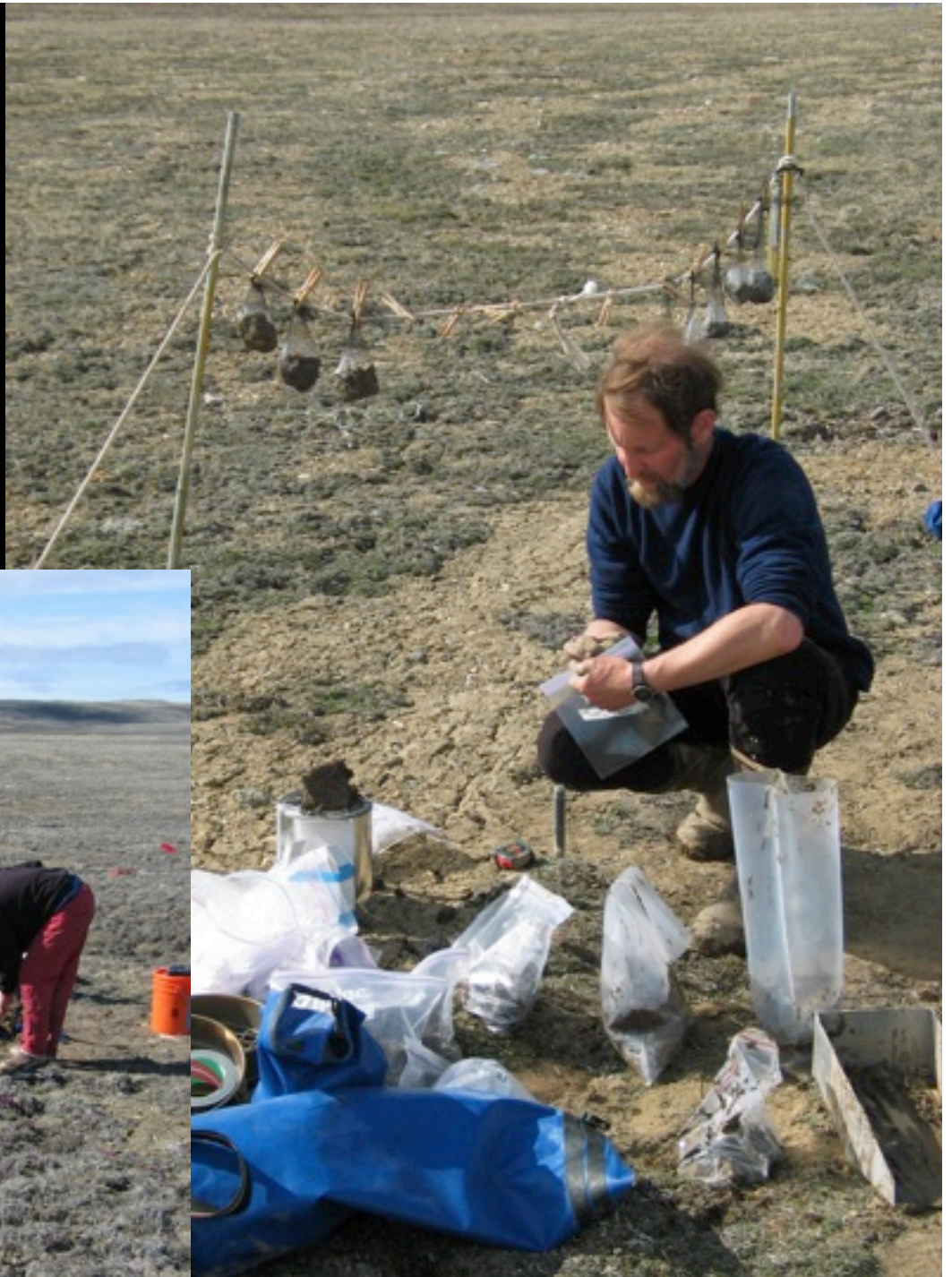


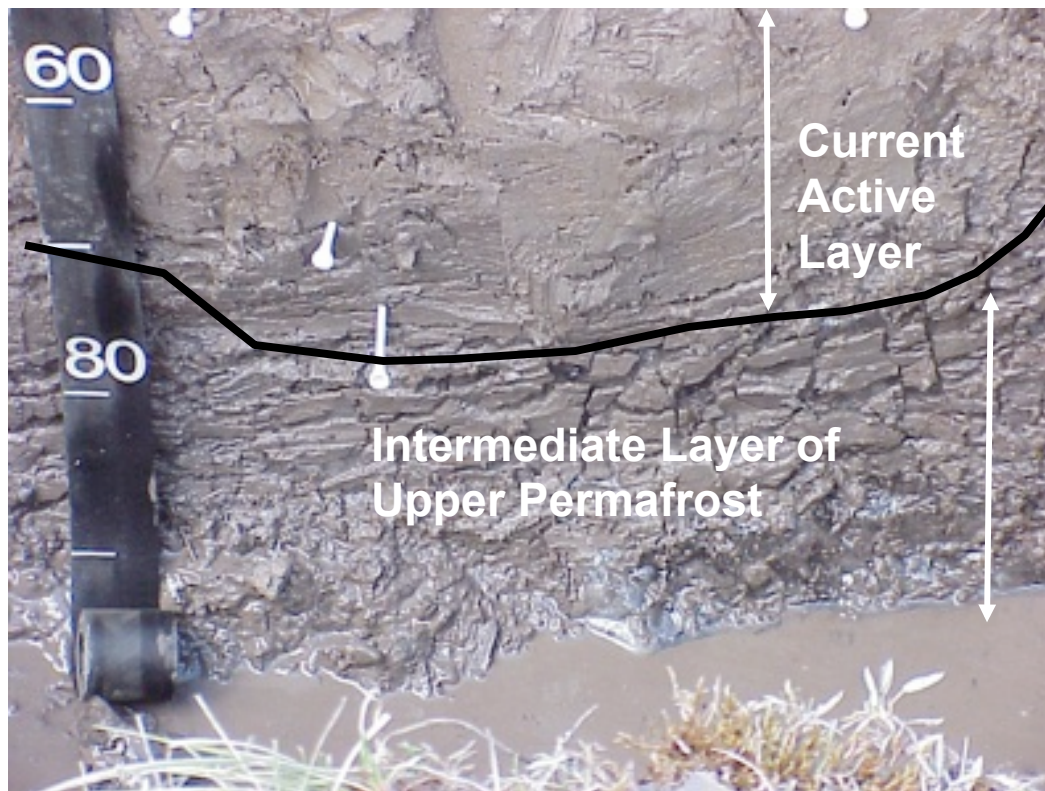
Chien-Lu Ping and Gary Michaelson

Charles Tarnocai

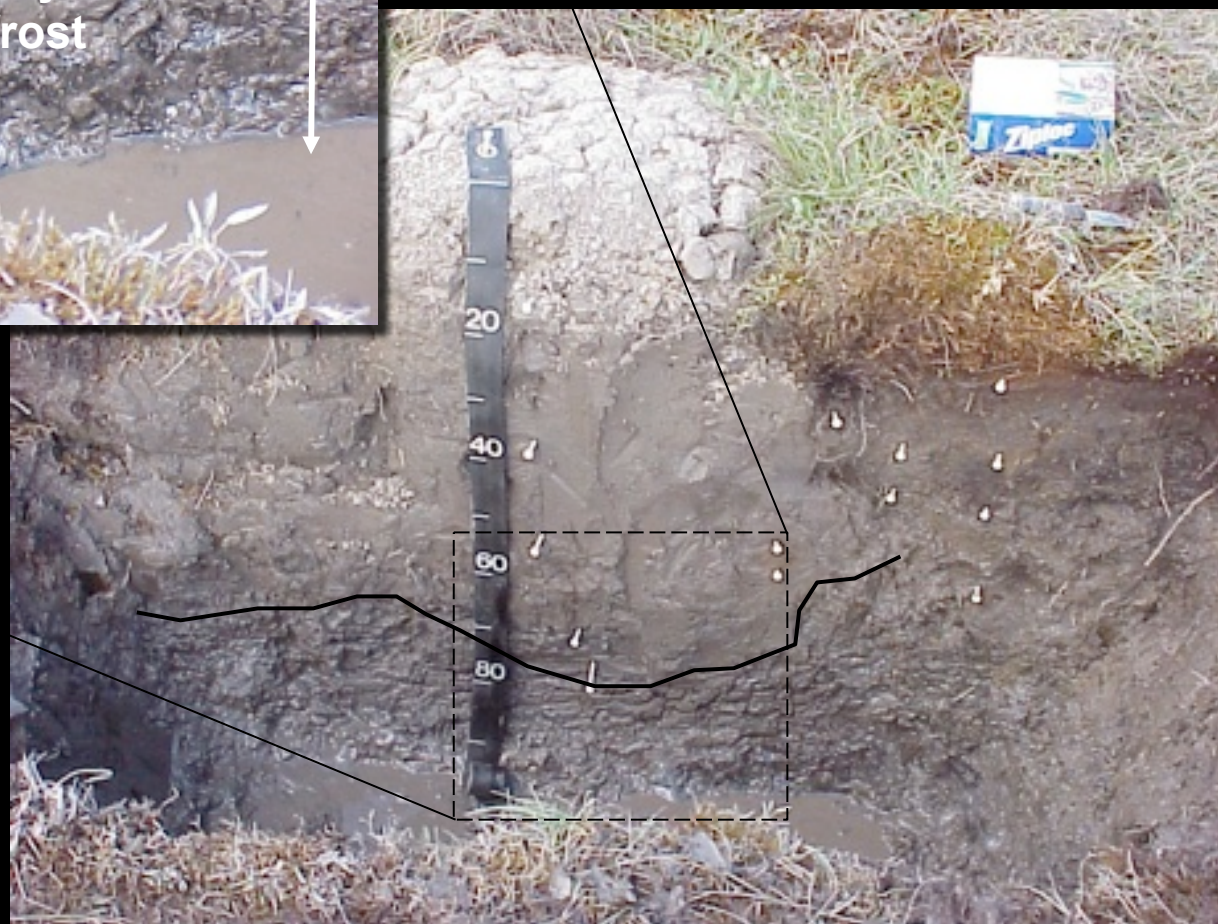
Complete characterization of soils

- Large soil pits across full patterned ground cycle.
- Lots of student help.



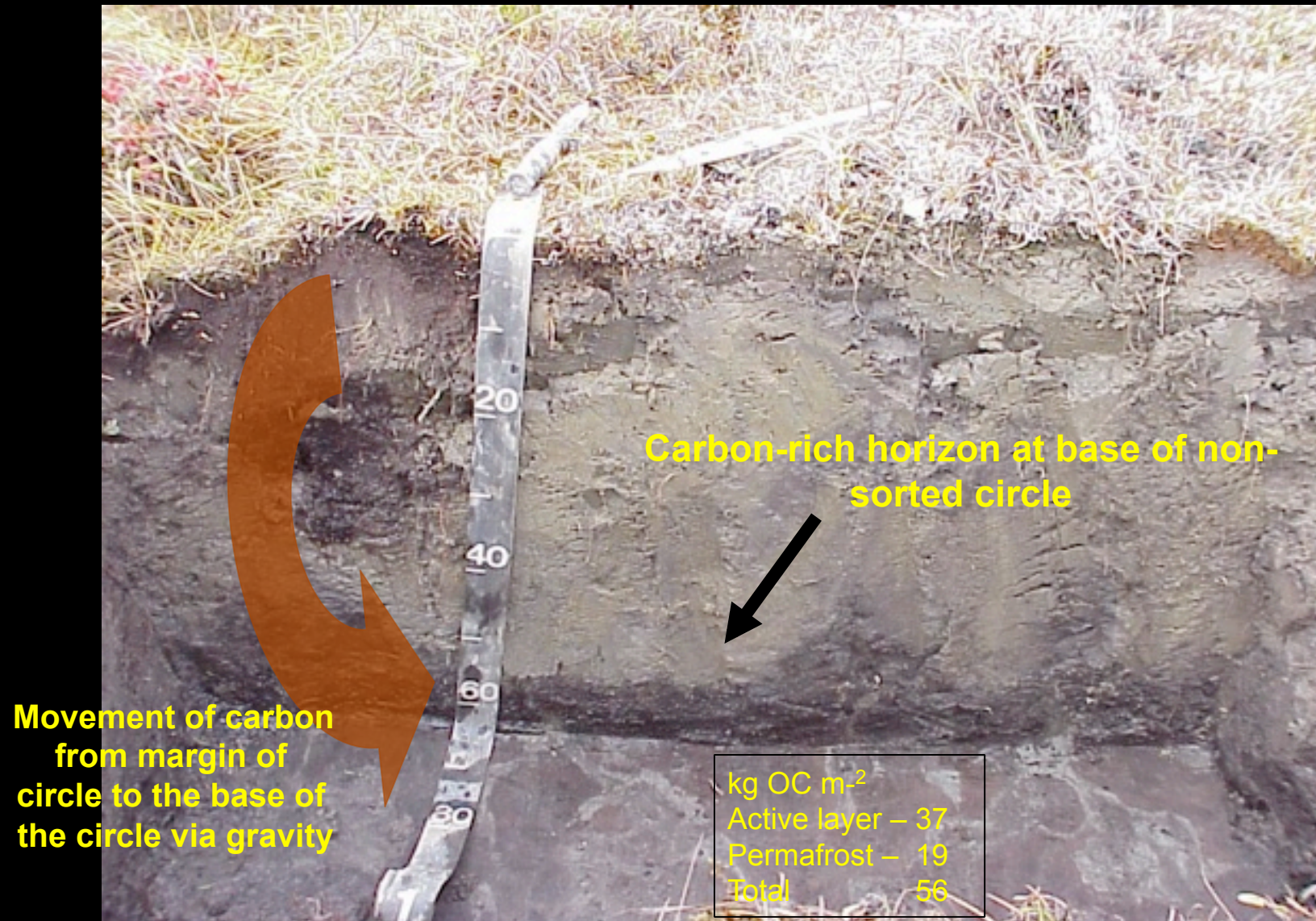


Buried carbon in the intermediate layer of permafrost table



Courtesy of Gary Michaelson

Sequestered carbon beneath frost boils



Carbon is concentrated in the cracks between small polygons.



Nonsorted circles, Ostrov Belyy, Russia.



After removal of top 10 cm of soil.

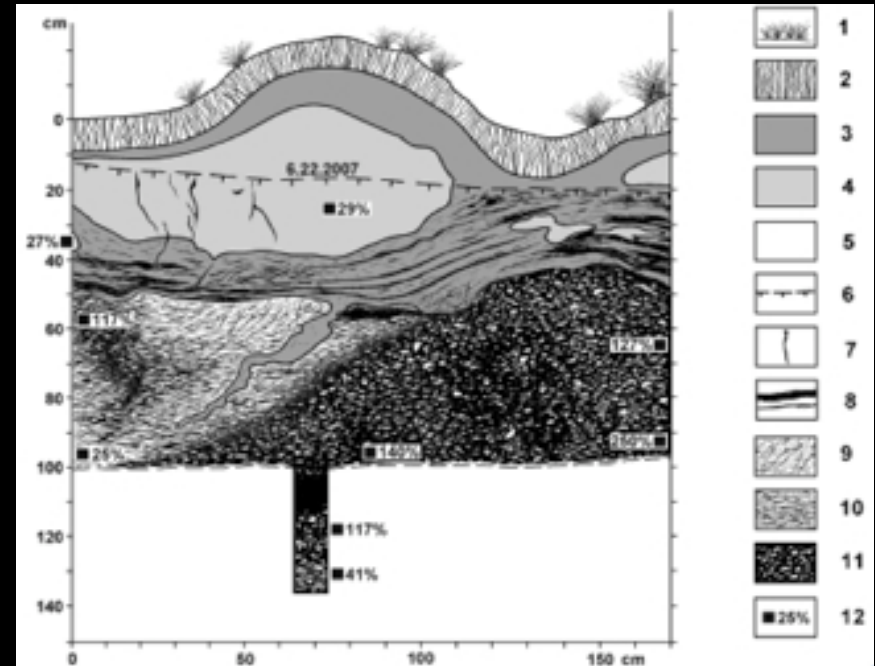
Circles are situated in the centers of 60-90-cm diameter nonsorted polygons with cracks.

Movement of organic material along thermal cracks to the base of the active layer.



Photos: Left and center: Laborovaya, Russia; right: Mould Bay, Canada

Large amounts of carbon are sequestered at the top of the permafrost table in the intermediate layer.



Major questions:

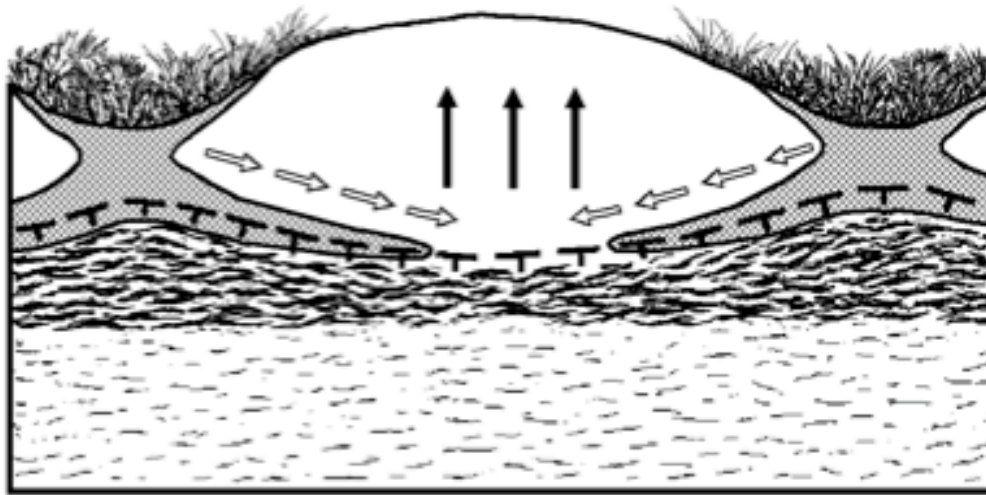
How old is the carbon?

How stable is the carbon?

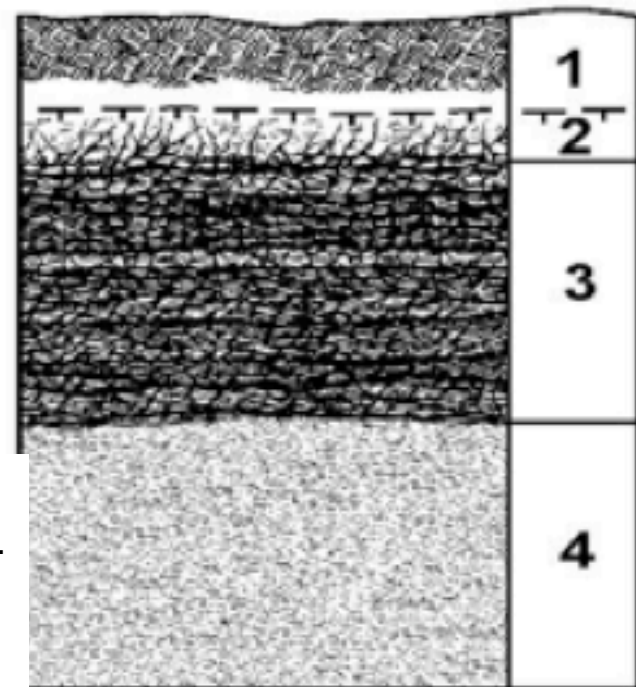
Is it susceptible to decomposition if the active layer becomes deeper?

Courtesy of Misha Kenevskiy & Yuri Shur

Structure of active layer and top permafrost layers beneath a nonsorted circle.



- 1 – Active layer (zone of annually thawed soil).
 - 2 – Transient layer (frozen in some summers and thawed in).
 - 3 – Intermediate layer).
 - 4 – Original permafrost.
- Arrows denote hypothesized movement of organic material.





**Ice-rich intermediate
layer in the upper
permafrost**

**Courtesy of Yuri Shur and
Misha Kanevsky**

Needle-ice (Pipkrakes)

Soil surface is lifted
by ice crystals
during diurnal
freeze-thaw cycles.



Photos: Outcalt 1971; Davies 2001

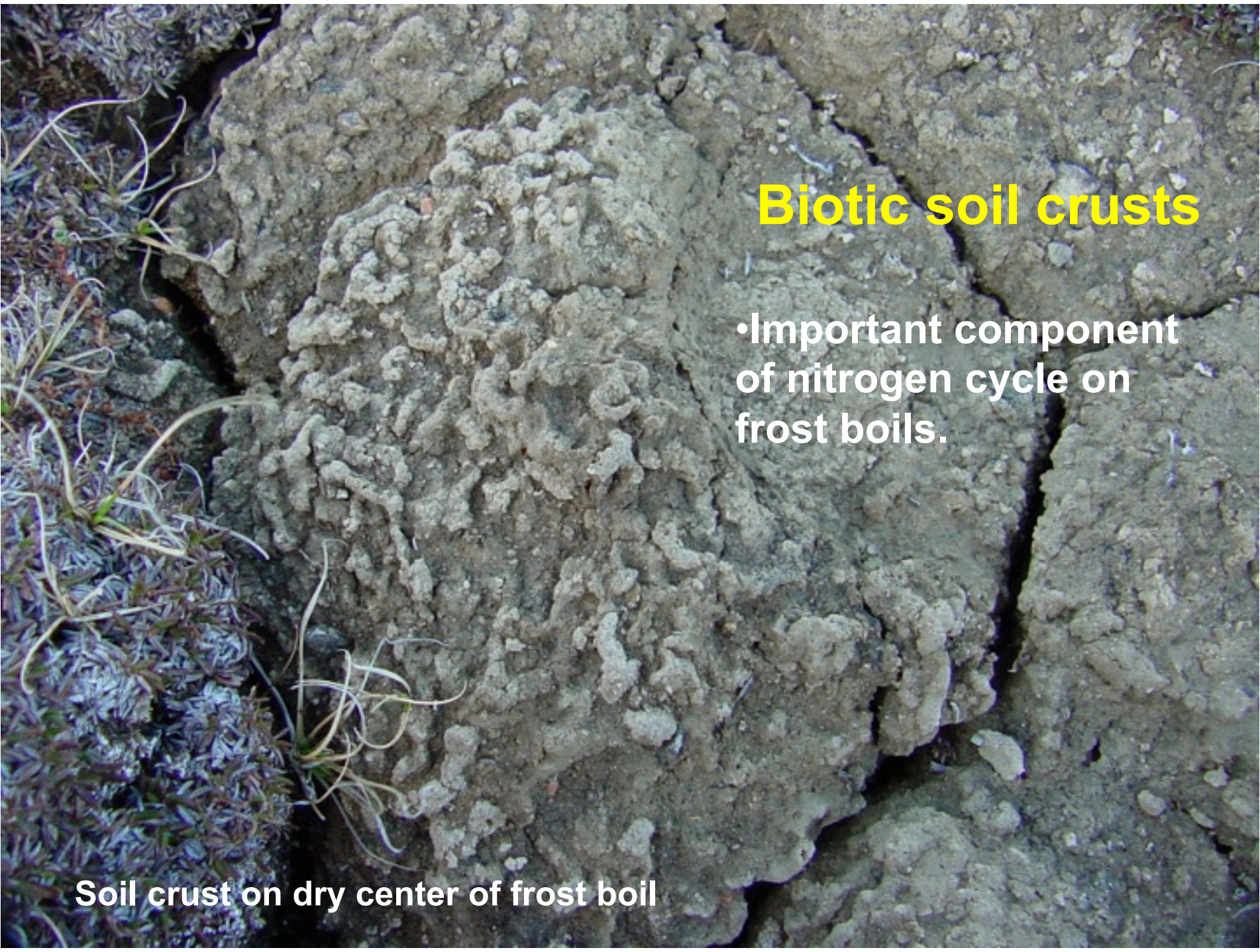
Needle-ice consequences



Cottage-cheese soil



Braya bartlettiana and root

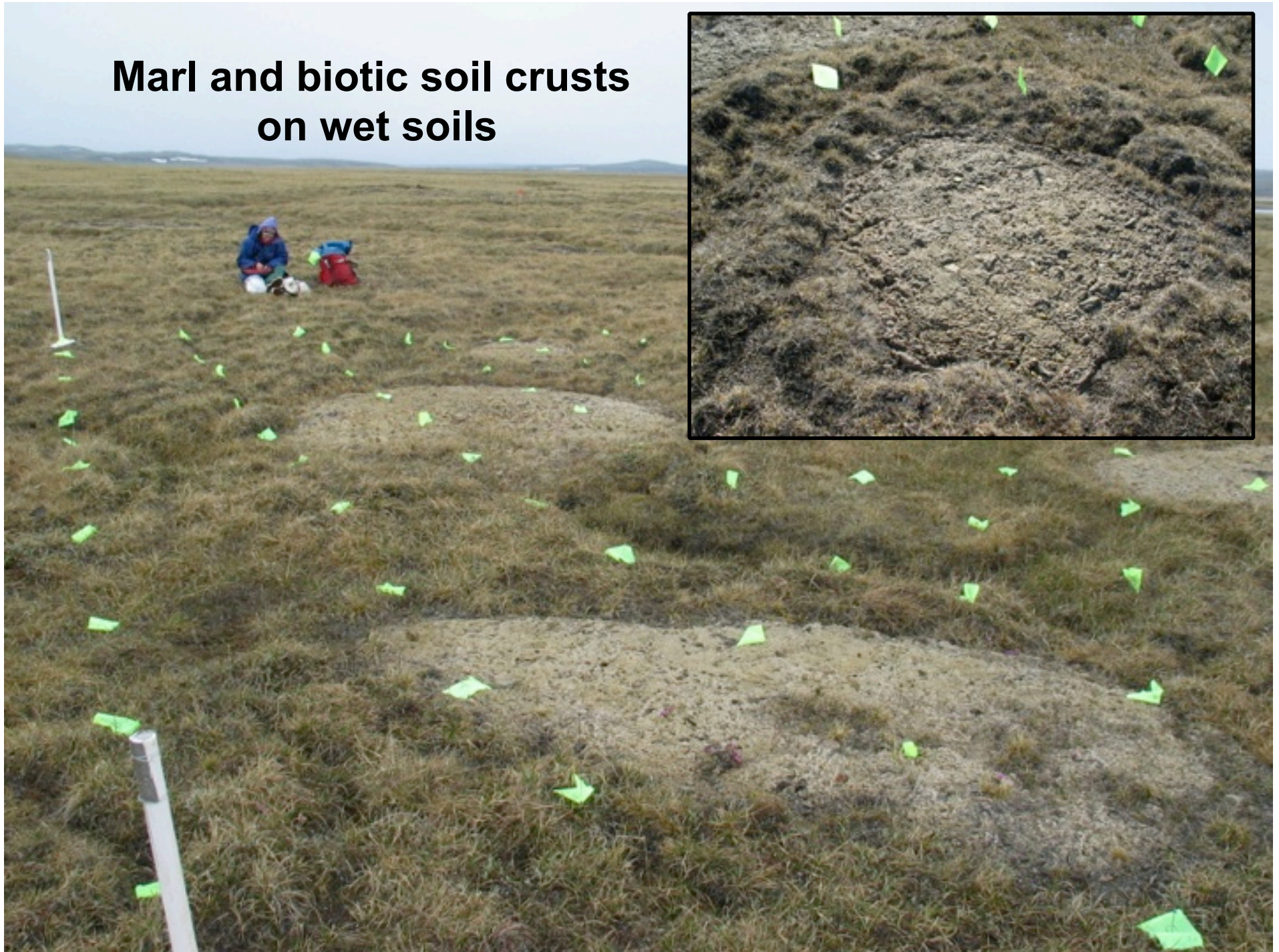


Biotic soil crusts

- Important component of nitrogen cycle on frost boils.

Soil crust on dry center of frost boil

Marl and biotic soil crusts on wet soils



**Marl with interior lining
of algae and fungal
hyphae**



Nitrogen Mineralization studies

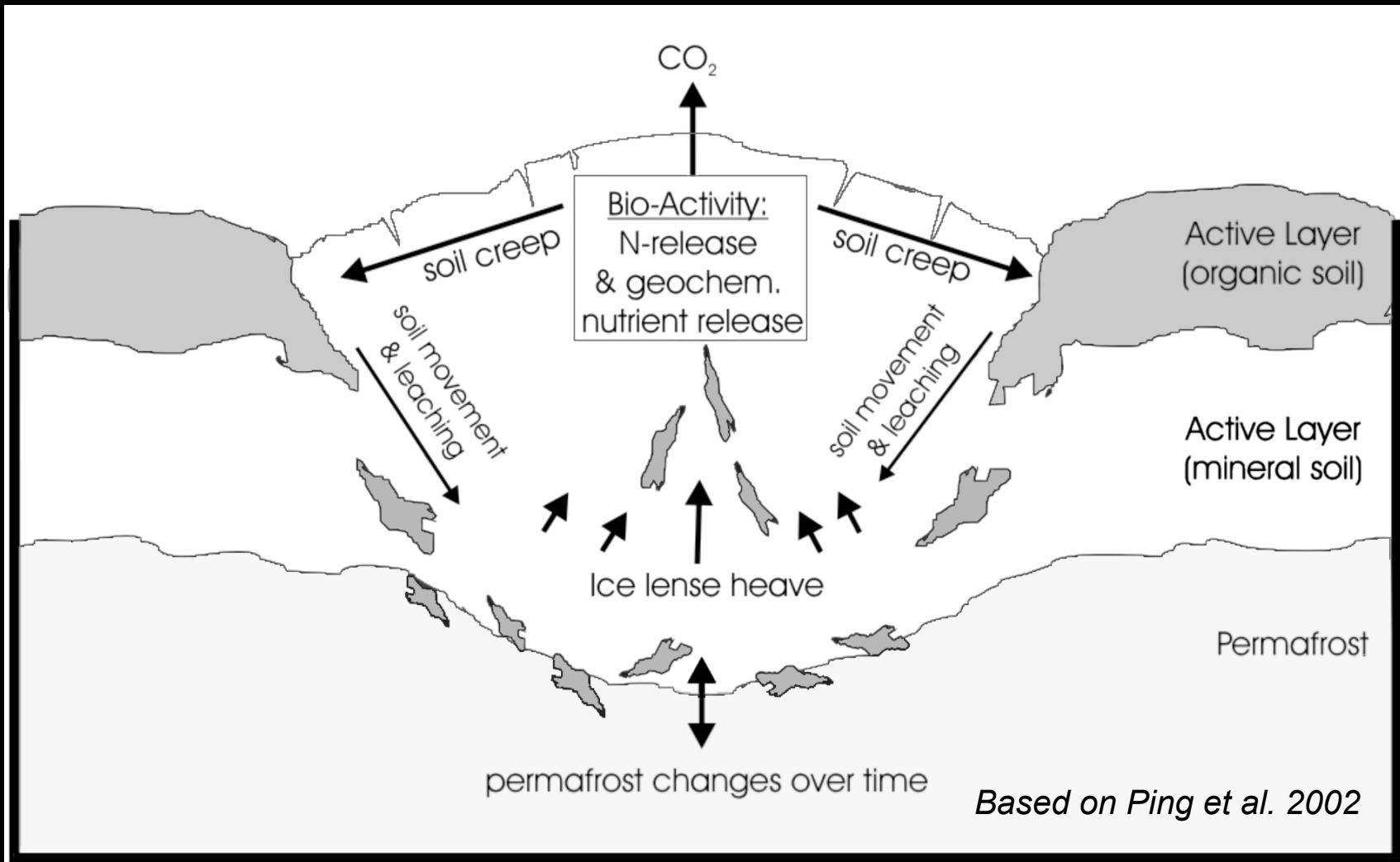


Alexia Kelley

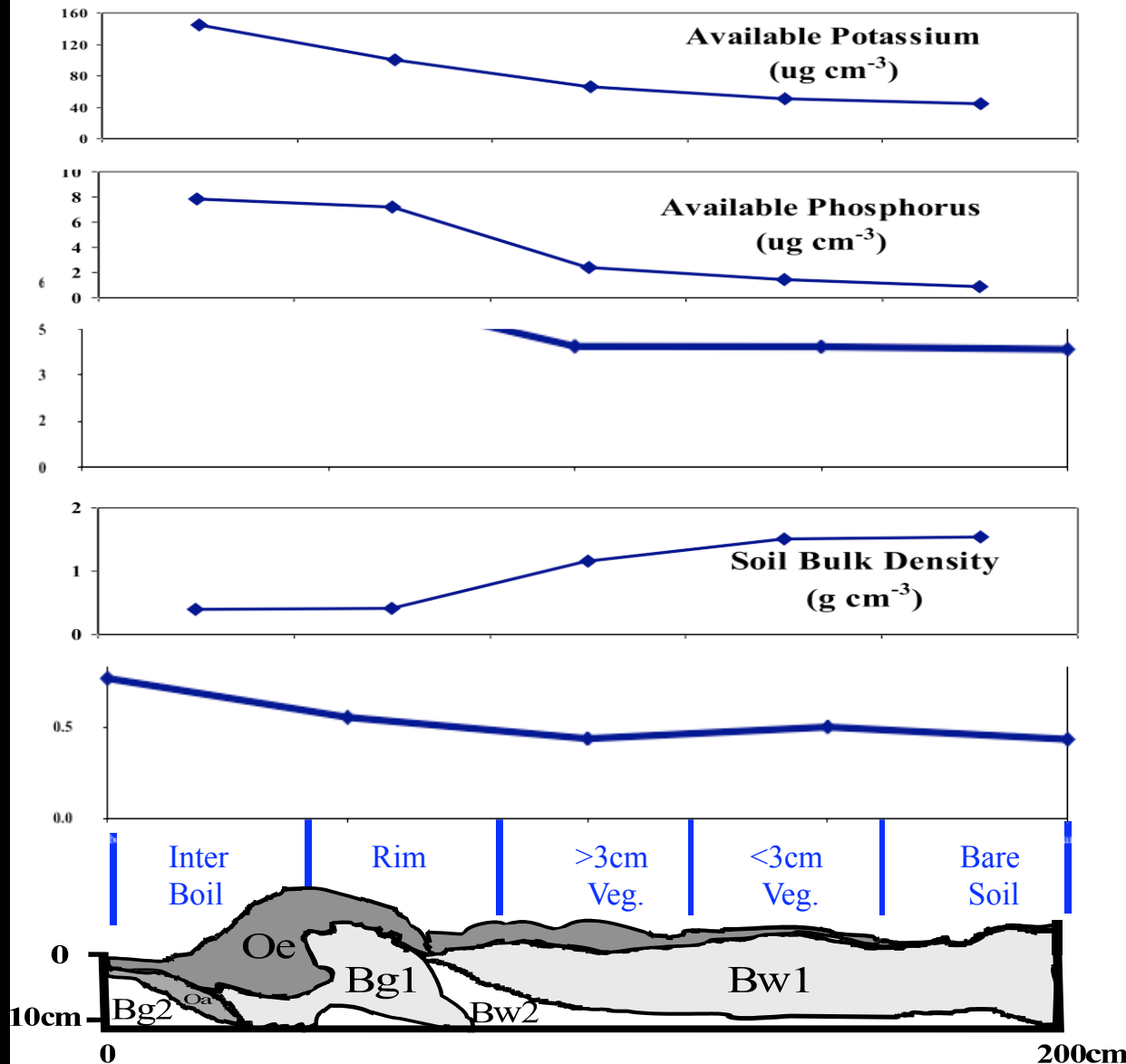


Howie Epstein

Biogeochemical cycling and carbon sequestration within frost heave features



Spatial variation in soil properties across a non-sorted circle



Michaelson, G.J., Ping, C.L., Epstein, H., et al. 2008. Soils and frost boil ecosystems across the North American Arctic Transect. *Journal of Geophysical Research - Biogeosciences*. 113:1-11.

Ping, C.L., Michaelson, G.J., Kimble, J.M., et al. 2008. Cryogenesis and soil formation along a bioclimate gradient in Arctic North America. *Journal of Geophysical Research - Biogeosciences*. 113:G03S12.

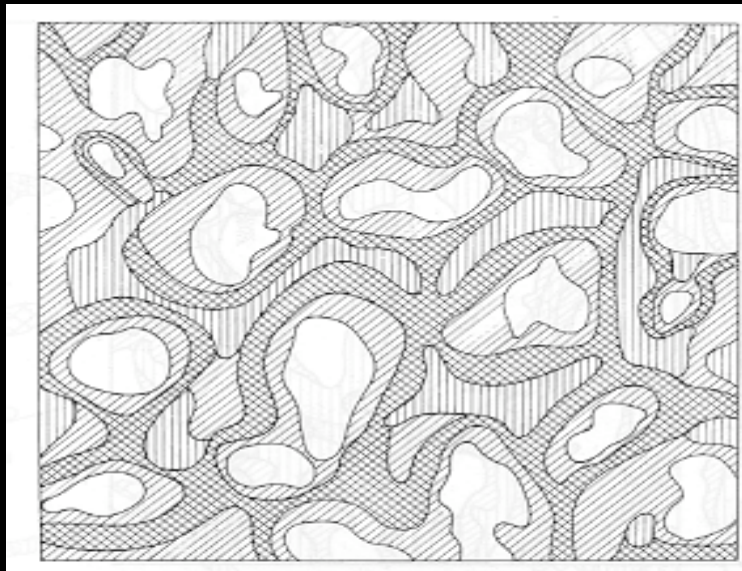
Vegetation component



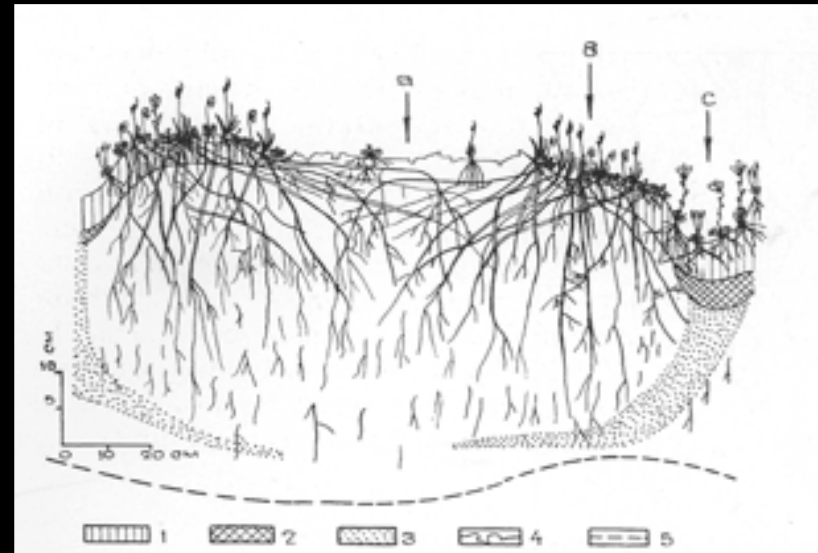
The added roles of vegetation

Plant cover:

- Insulates the surface decreasing the heat flux and summer soil temperatures.
- stabilizes cryoturbation and limits needle-ice formation.
- Promotes nitrogen and carbon inputs to the soil.



N. Matveyeva - Map and drawing of frost boil vegetation on the Taimyr Peninsula, Russia.



Bill Steere collecting *Bryum wrightii* on a frost boil at Prudhoe Bay, July, 1971.

Approach: Measurements along the NAAT

Measurements

- 21 Grids and maps
 - Active layer
 - Vegetation
 - Snow
- Climate /permafrost
 - Met station
 - Soil temperatures
 - Frost heave
- Soils
 - Characterization
 - Nitrogen mineralization
 - Decomposition
- Remote sensing
 - NDVI
 - Biomass

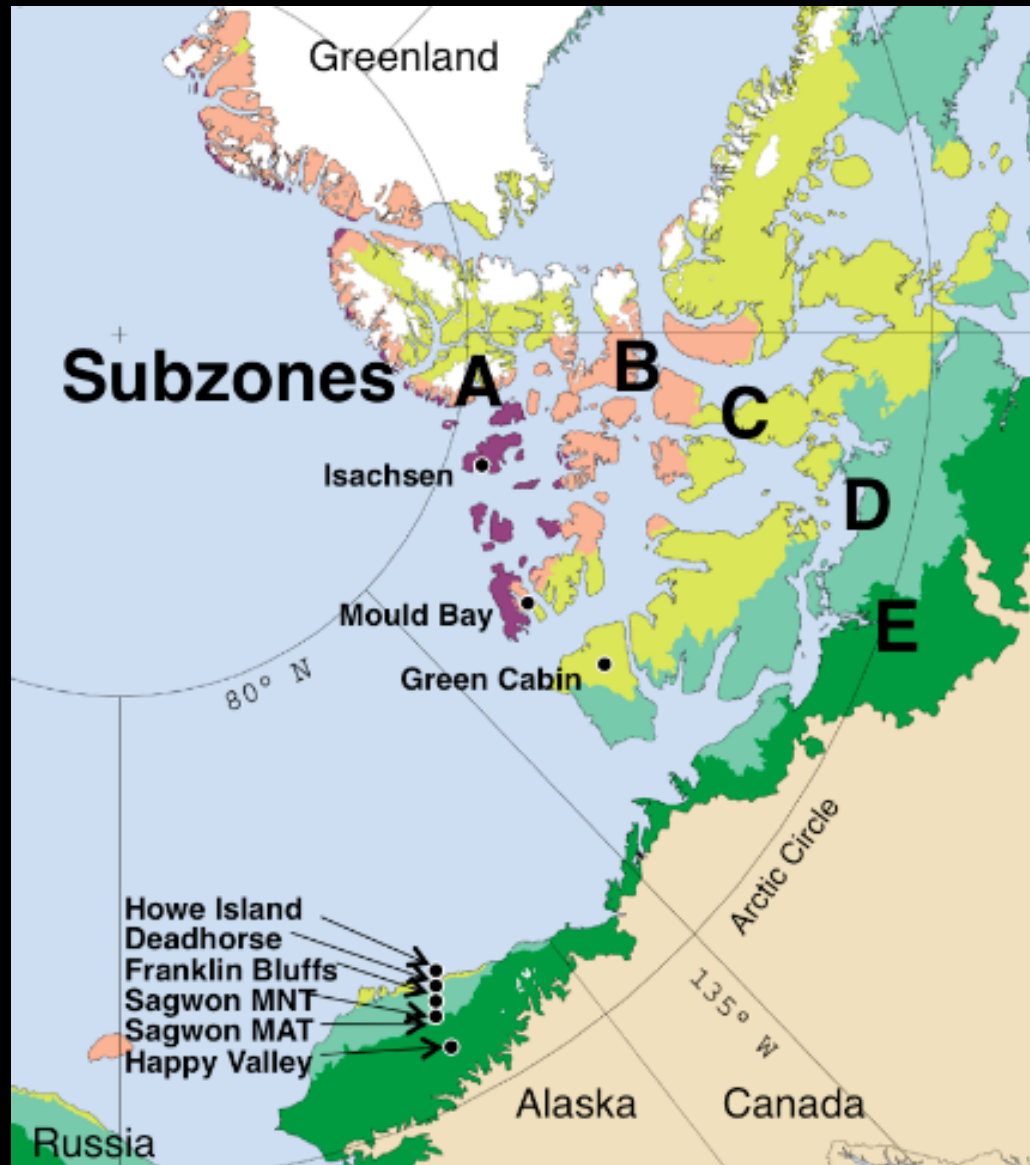


10 x 10 m grid at Isachsen

North American Arctic Transect

Arctic Bioclimate Subzones

Sub-zone	MJT (°C)	SWI (°C mo)
A	<3	<6
B	3-5	6-9
C	5-7	9-12
D	7-9	12-20
E	9-12	20-35
Forest	>12	>35



Subzone A:

Satellite Bay, Canada – 1

Isachsen, Canada - 3 planned

Subzone B:

Mould Bay, Canada - 2

Subzone C:

Howe Island, Alaska – 1

West Dock, Alaska – 1

Green Cabin, Canada - 3

Biocomplexity grids

Subzone D:

Deadhorse, Alaska - 1

Franklin Bluffs, Alaska - 3

Sagwon MNT, Alaska- 2

Ambarchik, Russian - 1

Subzone E:

Sagwon MAT, Alaska - 1

Happy Valley, Alaska - 3

Kurishka, Russia - 1

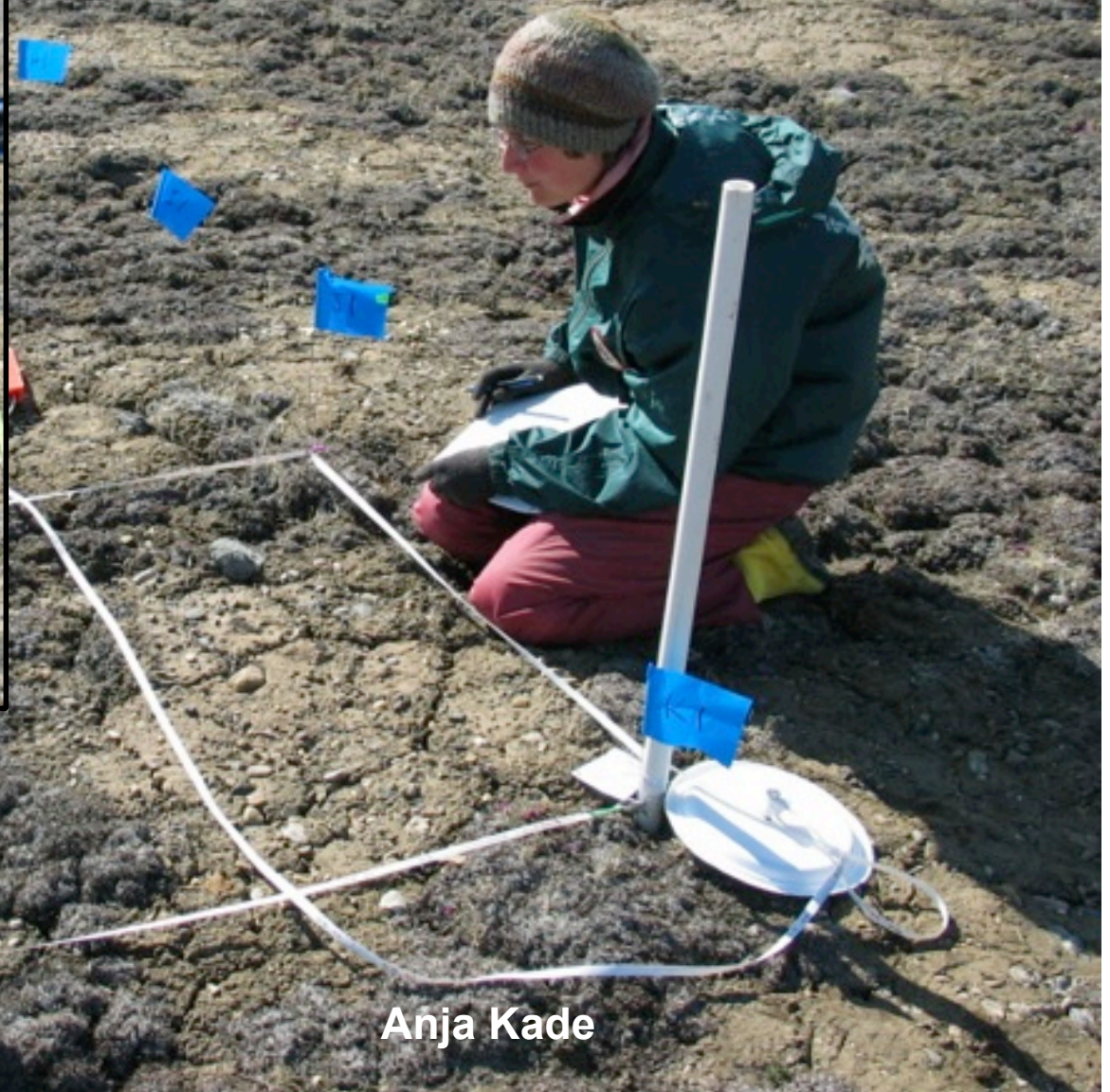
TOTAL 20 + (3 planned) = 23



Happy Valley Grid

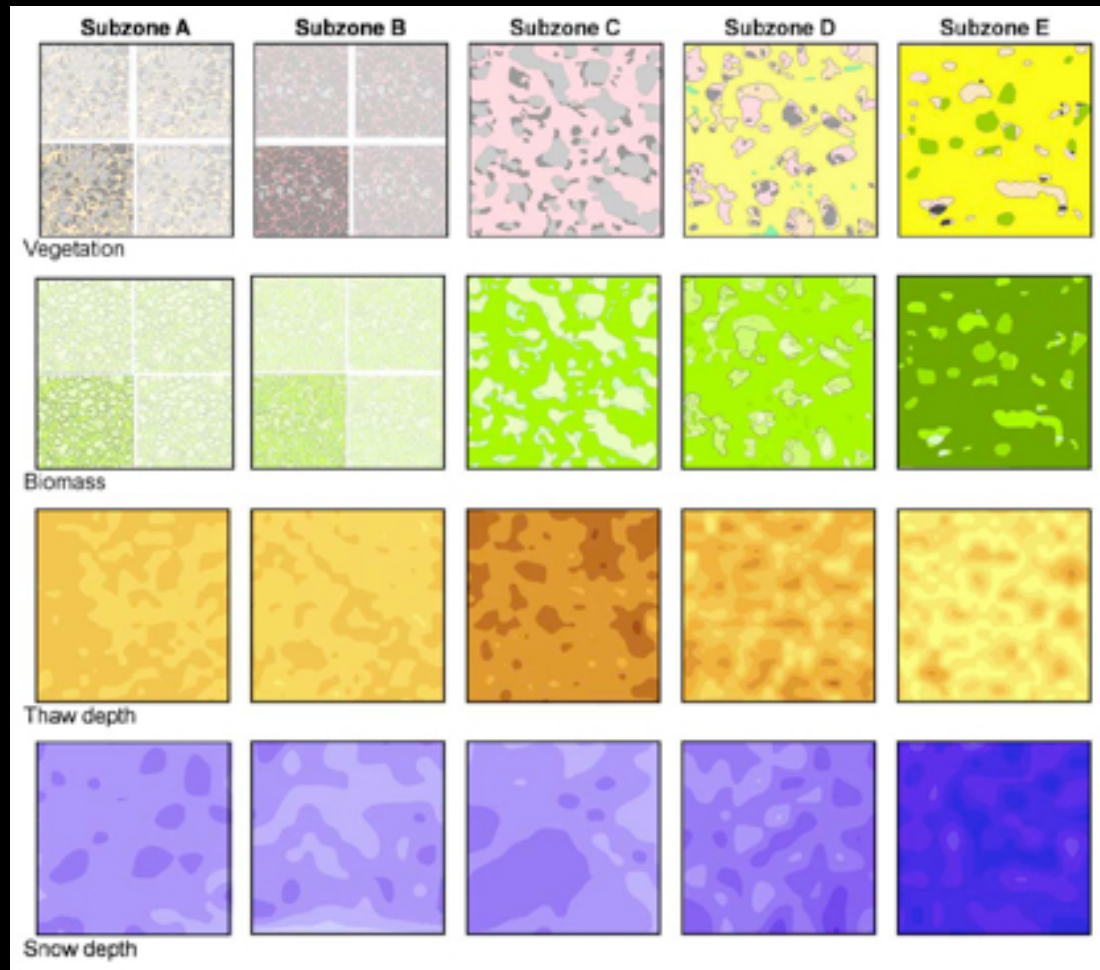
Vegetation mapping and analysis of of active-layer/heave/vegetation relationships

Martha Raynolds



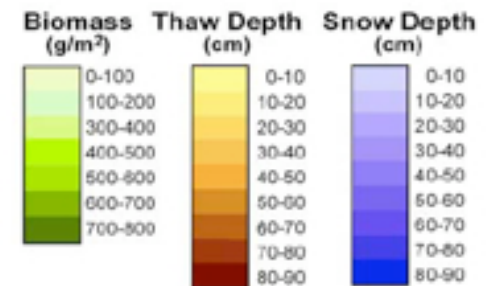
Anja Kade

Small landscape maps along climate gradient: 10 x 10 grids



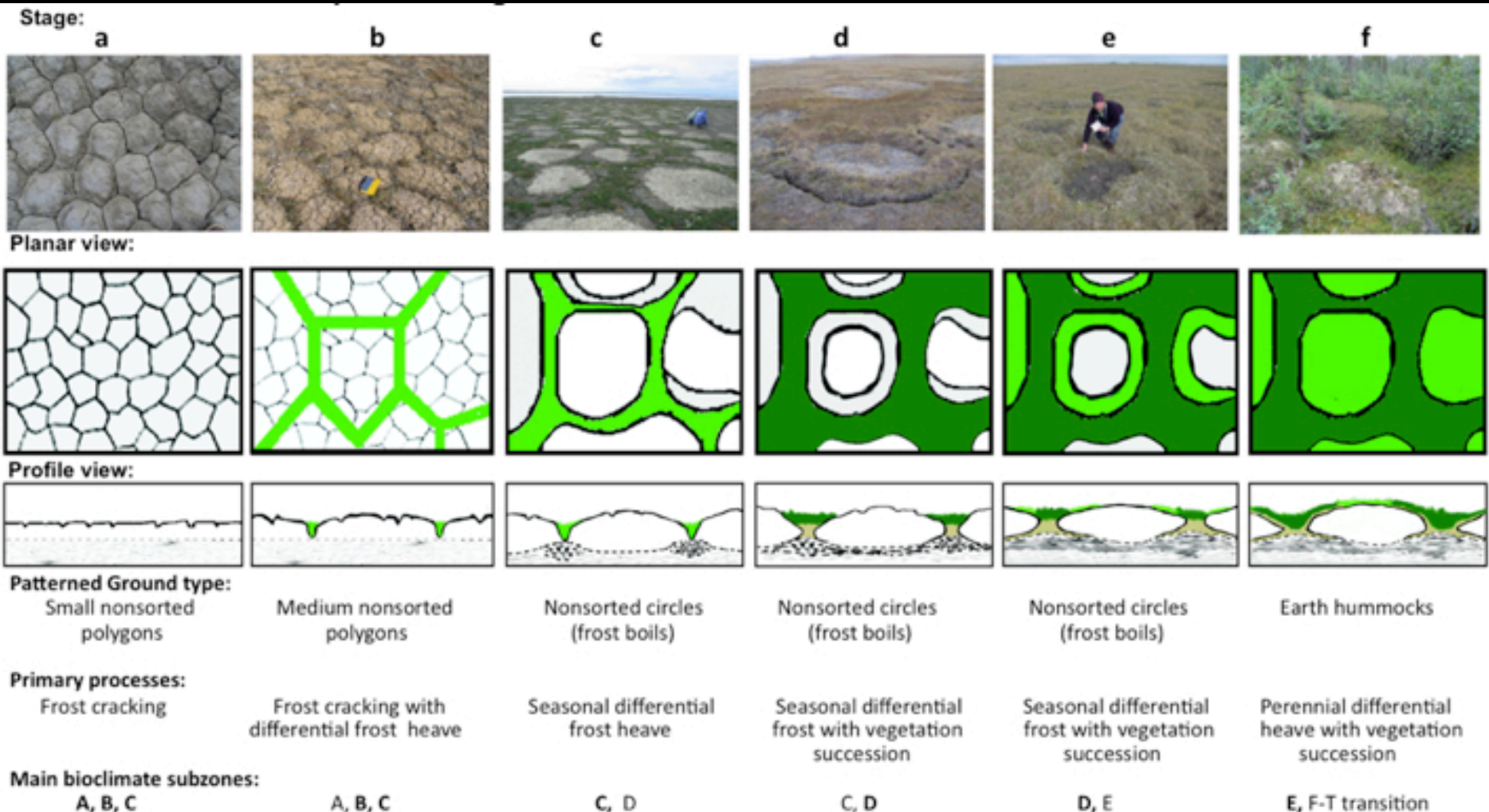
Vegetation of 10 x 10 m grids

- B1a - Bare Ground
- B1b - Lichen, forb barren
- B1c - Liverwort, moss barren
- G1 - Rushgrass, forb, cryptogam tundra
- G2 - Graminoid, prostrate dwarf-shrub, forb tundra
- G3 - Nontussock sedge, dwarf-shrub, moss tundra
- G4 - Tussock-sedge, dwarf-shrub, moss tundra
- P1a - Prostrate dwarf-shrub, herb, lichen tundra
- P1b - Prostrate dwarf-shrub, lichen, moss tundra
- S1 - Erect dwarf-shrub tundra
- W2 - Sedge, moss, dwarf-shrub wetland
- Water



Raynolds, M.K., Walker, D.A., Munger, C.A., et al. 2008. A map analysis of patterned-ground along a North American Arctic Transect. *Journal of Geophysical Research - Biogeosciences*. 113:1-18

Trends in patterned-ground morphology and vegetation on zonal sites across the Arctic bioclimate gradient



Subzone A



Isachsen, Ellef Ringnes Island, mean July temperature = 3 °C, SWI = 4 °C mo

Subzone C



Howe Island, Ak and Green Cabin, Banks Island, MJT, 8 °C, SWI = 16 °C mo

Subzone E



Tuktuyaktuk, NWT, Happy Valley, AK, MJT = 12 °C, SWI = 30 °C mo

Classification of patterned-ground vegetation along the NAAT

Phytocoenologia	35 (4)	761–820	Berlin–Stuttgart, December 13, 2005
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Plant communities and soils in cryoturbated tundra along a bioclimate gradient in the Low Arctic, Alaska

by Anja KADE, Donald A. WALKER and Martha K. RAYNOLDS, Fairbanks,
Alaska

with 24 figures, 12 tables and 1 appendix

Abstract. Nonsorted circles and earth hummocks are important landscape components of the arctic tundra. Here we describe the vegetation on these frost-heave features at seven study sites along a N-S transect from the Arctic Ocean to the Arctic Foothills, Alaska. We established 117 relevés in frost-heave features and surrounding tundra and classified the vegetation according to the Braun-Blanquet sorted-table method. We used Detrended Correspondence Analysis to analyze relationships between vegetation and environmental variables. We identified nine communities: *Braya purpurascens-Puccinellia angustata* community (dry nonsorted circles, subzone C); *Dryas integrifolia-Saxifraga arctica* community (dry tundra, subzone C); *Salix rotundifoliae-Carex tetracontophylla* community (moist coastal tundra, subzone C); *Junco biglumis-Dryas octopetala* community (moist nonsorted circles, subzone D); *Dryas octopetala-Dryas octopetala* community (moist tundra, subzone D); *Scorpidium scorpioides-Carex tetracontophylla* community (wet tundra, subzone D); *Cladonia-Vaccinium vitis-idaea* community (dry nonsorted circles and earth hummocks, subzone E); *Sparganium angustifolium* community (moist tundra, subzone E); and *Anthelia juratzkana-Junco biglumis* community (wet nonsorted circles, subzone E).

The DCA ordination displayed the vegetation types with respect to complex environmental gradients. The first axis of the ordination corresponds to a bioclimate/pH gradient, and the second axis corresponds to a disturbance/soil moisture gradient. Frost-heave features are dominated by lichens, whereas the adjacent tundra supports more dwarf shrubs, graminoids and mosses. Frost-heave features have greater thaw depths, more bare ground, thinner organic horizons and lower soil moisture than the surrounding tundra. The morphology of frost-heave features changes along the climatic gradient, with large, barren nonsorted circles dominating the northern sites and vegetated, less active earth hummocks dotting the southern sites. Thawing of permafrost and a possible shift in plant community composition due to global warming could lead to a decline in frost-heave features and result in the loss of landscape heterogeneity.

Keywords: biocomplexity, Braun-Blanquet classification, Detrended Correspondence Analysis, earth hummocks, frost heave, nonsorted circles.

1 Introduction

The vegetation and soil patterns in many arctic tundra regions are influenced by the distribution of frost-heave features such as nonsorted circles and earth hummocks (WASHBURN 1980). Nonsorted circles and earth hummocks form

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Patterned-Ground Plant Communities along a bioclimate gradient in the High Arctic, Canada

by Corinne M. VORLANTH, Donald A. WALKER, Martha K. RAYNOLD, Anna KACE, Patrick KUSS (Fairbanks, Alaska, USA), Fred J. A. GANDEL (Münster, Germany), and Nadezhda V. MATVEYCHIK (St. Petersburg, Russia)

with 16 figures, 14 tables and 1 appendix.

[illegible]

linguist classification, Nonmetric Multidimensional Scaling, north American, 1990s.

such as circles, or products of third-ground review (1980). The book is written by LISA B. STENOBERG who is a biologist who affects numerous and processes investigations many of them (1980), will or Peterson et al. relationships (e.g., address the "Western 1964, MCTA 1987, MCTA 1989, MCTA 1990, MCTA 1991, MCTA 1992, MCTA 1993, MCTA 1994, MCTA 1995, MCTA 1996, MCTA 1997, MCTA 1998, MCTA 1999, MCTA 2000, MCTA 2001, MCTA 2002, MCTA 2003, MCTA 2004, MCTA 2005, MCTA 2006, MCTA 2007, MCTA 2008, MCTA 2009, MCTA 2010, MCTA 2011, MCTA 2012, MCTA 2013, MCTA 2014, MCTA 2015, MCTA 2016, MCTA 2017, MCTA 2018, MCTA 2019, MCTA 2020, MCTA 2021, MCTA 2022, MCTA 2023, MCTA 2024, MCTA 2025, MCTA 2026, MCTA 2027, MCTA 2028, MCTA 2029, MCTA 2030, MCTA 2031, MCTA 2032, MCTA 2033, MCTA 2034, MCTA 2035, MCTA 2036, MCTA 2037, MCTA 2038, MCTA 2039, MCTA 2040, MCTA 2041, MCTA 2042, MCTA 2043, MCTA 2044, MCTA 2045, MCTA 2046, MCTA 2047, MCTA 2048, MCTA 2049, MCTA 2050, MCTA 2051, MCTA 2052, MCTA 2053, MCTA 2054, MCTA 2055, MCTA 2056, MCTA 2057, MCTA 2058, MCTA 2059, MCTA 2060, MCTA 2061, MCTA 2062, MCTA 2063, MCTA 2064, MCTA 2065, MCTA 2066, MCTA 2067, MCTA 2068, MCTA 2069, MCTA 2070, MCTA 2071, MCTA 2072, MCTA 2073, MCTA 2074, MCTA 2075, MCTA 2076, MCTA 2077, MCTA 2078, MCTA 2079, MCTA 2080, MCTA 2081, MCTA 2082, MCTA 2083, MCTA 2084, MCTA 2085, MCTA 2086, MCTA 2087, MCTA 2088, MCTA 2089, MCTA 2090, MCTA 2091, MCTA 2092, MCTA 2093, MCTA 2094, MCTA 2095, MCTA 2096, MCTA 2097, MCTA 2098, MCTA 2099, MCTA 2100, MCTA 2101, MCTA 2102, MCTA 2103, MCTA 2104, MCTA 2105, MCTA 2106, MCTA 2107, MCTA 2108, MCTA 2109, MCTA 2110, MCTA 2111, MCTA 2112, MCTA 2113, MCTA 2114, MCTA 2115, MCTA 2116, MCTA 2117, MCTA 2118, MCTA 2119, MCTA 2120, MCTA 2121, MCTA 2122, MCTA 2123, MCTA 2124, MCTA 2125, MCTA 2126, MCTA 2127, MCTA 2128, MCTA 2129, MCTA 2130, MCTA 2131, MCTA 2132, MCTA 2133, MCTA 2134, MCTA 2135, MCTA 2136, MCTA 2137, MCTA 2138, MCTA 2139, MCTA 2140, MCTA 2141, MCTA 2142, MCTA 2143, MCTA 2144, MCTA 2145, MCTA 2146, MCTA 2147, MCTA 2148, MCTA 2149, MCTA 2150, MCTA 2151, MCTA 2152, MCTA 2153, MCTA 2154, MCTA 2155, MCTA 2156, MCTA 2157, MCTA 2158, MCTA 2159, MCTA 2160, MCTA 2161, MCTA 2162, MCTA 2163, MCTA 2164, MCTA 2165, MCTA 2166, MCTA 2167, MCTA 2168, MCTA 2169, MCTA 2170, MCTA 2171, MCTA 2172, MCTA 2173, MCTA 2174, MCTA 2175, MCTA 2176, MCTA 2177, MCTA 2178, MCTA 2179, MCTA 2180, MCTA 2181, MCTA 2182, MCTA 2183, MCTA 2184, MCTA 2185, MCTA 2186, MCTA 2187, MCTA 2188, MCTA 2189, MCTA 2190, MCTA 2191, MCTA 2192, MCTA 2193, MCTA 2194, MCTA 2195, MCTA 2196, MCTA 2197, MCTA 2198, MCTA 2199, MCTA 2200, MCTA 2201, MCTA 2202, MCTA 2203, MCTA 2204, MCTA 2205, MCTA 2206, MCTA 2207, MCTA 2208, MCTA 2209, MCTA 2210, MCTA 2211, MCTA 2212, MCTA 2213, MCTA 2214, MCTA 2215, MCTA 2216, MCTA 2217, MCTA 2218, MCTA 2219, MCTA 2220, MCTA 2221, MCTA 2222, MCTA 2223, MCTA 2224, MCTA 2225, MCTA 2226, MCTA 2227, MCTA 2228, MCTA 2229, MCTA 2230, MCTA 2231, MCTA 2232, MCTA 2233, MCTA 2234, MCTA 2235, MCTA 2236, MCTA 2237, MCTA 2238, MCTA 2239, MCTA 2240, MCTA 2241, MCTA 2242, MCTA 2243, MCTA 2244, 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MCTA 2427, MCTA 2428, MCTA 2429, MCTA 2430, MCTA 2431, MCTA 2432, MCTA 2433, MCTA 2434, MCT

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Plant species and cover information for each plant community

Table 4. Community table of the *Braya purpurascens*-*Puccinellia angustata* community.

	typicum					<i>Mycobilimbia lobulata</i> var.				
Relevé No.	113	114	110	24	21	25	26	115	111	23
Altitude (m.a.s.l.)	4	6	6	12	15	10	13	6	5	7
Number of vascular taxa	3	2	2	3	2	10	9	9	11	3
Number of nonvascular taxa	2	2	1	2	0	17	18	17	16	10
Total number of taxa	5	4	3	5	2	27	27	26	27	13
Ch/D: Community										
<i>Braya glabella</i> ssp. <i>purpurascens</i>	1	+	+	1	+	+	1	1	+	+
<i>Puccinellia angustata</i>	+	+	+	1	+	+	+	1	+	+
<i>Polyblastia sendneri</i>	+	+	+	.	.	1	2	2	1	2
D: <i>Mycobilimbia lobulata</i> var.										
<i>Mycobilimbia lobulata</i>	+	+	.	.	.	3	3	3	3	4
<i>Lecanora epiphyron</i>	.	.	.	.	.	1	1	1	2	+
<i>Salix ovalifolia</i>	.	.	.	.	.	1	+	+	+	+
<i>Fulgensia bracteata</i>	.	.	.	r	.	+	+	+	+	+
<i>Distichium inclinatum</i>	.	.	.	.	.	+	1	1	1	.
<i>Chrysanthemum integrifolium</i>	.	.	.	.	.	+	+	+	+	.
<i>Collema</i> sp.	.	.	.	.	.	+	+	+	+	.
<i>Polyblastia bryophila</i>	.	.	.	.	.	2	2	1	.	+
<i>Hennediella heimii</i> var. <i>arctica</i>	.	.	.	.	.	1	1	1	.	+
<i>Cnidium procerrimum</i>	.	.	.	.	.	+	+	.	+	.
<i>Thamnotia subuliformis</i>	.	.	.	.	.	+	r	.	+	.
<i>Orthothecium varia</i>	.	.	.	.	.	+	.	+	+	.
<i>Bryum</i> sp.	.	.	.	.	.	.	+	+	+	.
<i>Cerastium beeringianum</i>	.	.	.	.	.	.	+	+	r	.
<i>Tortula ruralis</i>	.	.	.	r	.	.	+	+	.	+
<i>Draba cinerea</i>	.	.	.	.	.	r	+	.	.	.
<i>Potentilla uniflora</i>	.	.	.	.	.	+	.	+	.	.
<i>Encalypta alpina</i>	.	.	.	.	.	.	+	.	1	.
<i>Megaspora verrucosa</i>	.	.	.	.	.	.	+	.	+	.
<i>Pertusaria dactylina</i>	.	.	.	.	.	+	.	.	+	.
<i>Cirriphyllum cirrosum</i>	.	.	.	.	.	+	.	.	.	+
<i>Pedicularis capitata</i>	.	.	.	.	.	r	r	.	.	.
<i>Cephalozella arctica</i>	.	.	.	.	.	+	.	+	.	.
<i>Lophozia collaris</i>	.	.	.	.	.	+	.	.	+	.
<i>Artemisia campestris</i> ssp. <i>borealis</i> var. <i>borealis</i>	.	.	.	.	.	r	.	.	r	.
<i>Campylopus stellatum</i>	.	.	.	.	.	.	+	+	.	.
<i>Draba</i> sp.	.	.	.	.	.	.	.	+	+	.
<i>Bryoerythrophyllum recurvirostre</i>	.	.	.	.	.	.	.	+	+	.
<i>Encalypta</i> sp.	.	.	.	.	.	.	.	+	.	1
Others										
<i>Androsace chamaejasme</i>	+	.	.	.	.	r	.	.	+	.
<i>Cochlearia groenlandica</i>	.	.	.	+	.	+	.	+	.	.

Single occurrences: *Amblystegium serpens* (rel. 25: +), *Rinodina rosida* (25: +), *Salix arctica* (26: +), *Alcina brevirostris* (26: +), *Encalypta raptocarpa* (26: +), *Arctagrostis latifolia* (26: r), *Ochrolechia frigida* (26: r), *Juncus biglum* is (115: +), *Didymodon rigidulus* var. *icm adophilus* (115: +), *Distichum flexicaule* (115: +), *Dryas integrifolia* (111: +), *Polygonum viviparum* (111: +), *Saxifraga oppositifolia* (111: +), *Didymodon* sp. (111: +), *Distichum capillaceum* (23: +).

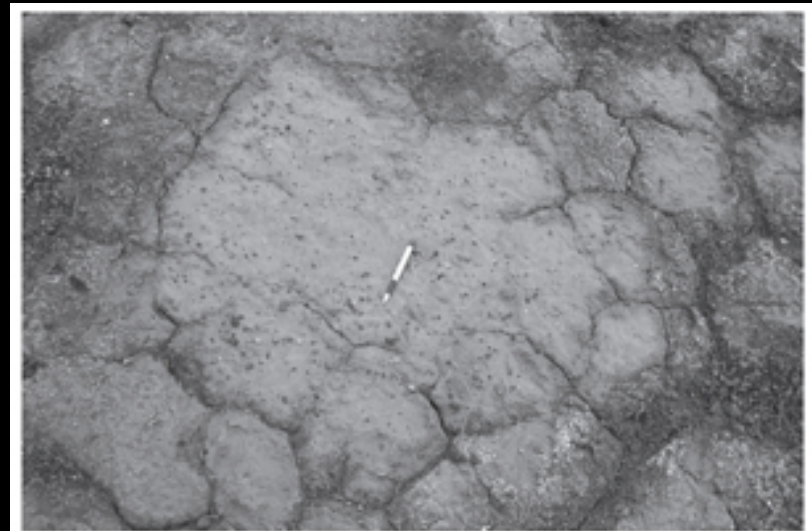


Fig. 6. *Braya purpurascens*-*Puccinellia angustata* community, with the typicum variant occurring on the dry nonacidic nonsorted circles and the *Mycobilimbia lobulata* variant occurring on the small polygons surrounding the central bare area. Subzone C, Howe Island, Alaska.

Classification according to Braun-Blanquet approach

Kade et al. 2005, Plant communities and soils in cryoturbated tundra along a bioclimate gradient in the Low Arctic, Alaska. *Phytocoenologia*, 35: 761-820.

Frost-boil plant communities, soil and site information

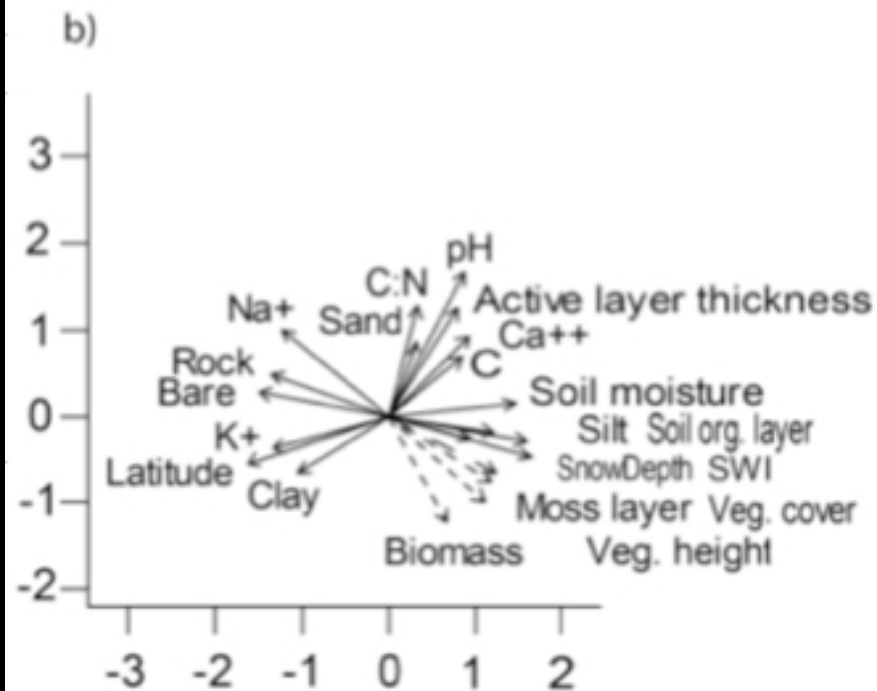
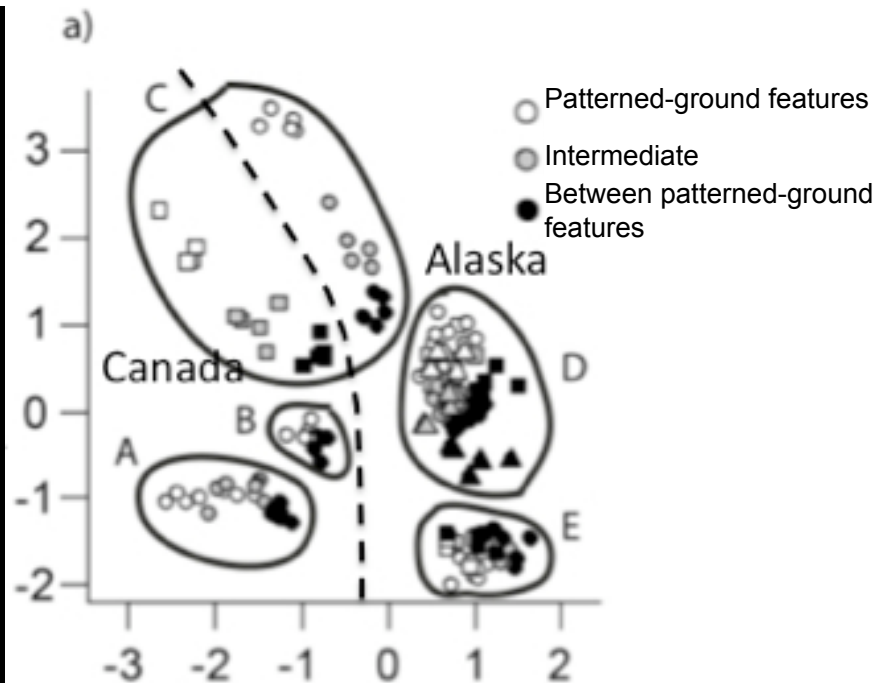
Table 3. Class, order, alliance and association or community names and habitats of the cryoturbated tundra in the Alaskan Low Arctic.

Undescribed unit
Braya purpurascens-Puccinellia angustata comm.
Nonsorted circles and small polygons; dry nonacidic tundra; subzone C
C. Carici rupestris-Kobresietea bellardii Ohba 1974
O. Kobresio-Dryadetalia (Br.-Bl 1948) Ohba 1974
A. Dryadion integrifoliae Ohba ex Daniëls 1982
Dryas integrifolia-Salix arctica comm.
Stable, dry nonacidic tundra; subzone C
Junco biglumis-Dryadetum integrifoliae ass. nov.
Nonsorted circles; moist nonacidic tundra; subzone D
Dryado integrifoliae-Caricetum bigelowii Walker et al. 1994
Stable, moist nonacidic tundra; subzone D
C. Scheuchzerio-Caricetea nigrae (Nordh. 1936) Tx. 1937
O. Scheuchzerietalia palustris Nordh. 1936
A. Caricion lasiocarpae Vanden Berghen ap. Lebrun et al. 1949
Salici rotundifoliae-Caricetum aquatilis ass. nov.
Stable, moist nonacidic coastal tundra; subzone C
Scorpidium scorpioides-Carex aquatilis comm.
Stable, wet nonacidic tundra; subzone D
C. Loiseleurio-Vaccinietea Egger 1952
O. Rhododendro-Vaccinietalia Br.-Bl ap. Br.-Bl & Jenny 1926
(A. Loiseleurio-Diapension (Br.-Bl Et al. 1939) Daniëls 1982?)
Cladino-Vaccinietum vitis-idaeae ass. nov.
Nonsorted circles and earth hummocks; moist acidic tundra; subzone E
Sphagno-Eriophoretum vaginati Walker et al. 1994
Stable, moist acidic tundra; subzone E
C. Salicetea herbaceae Br.-Bl 1947
O. Salicetalia herbaceae Br.-Bl 1926
A. Saxifrago-Ranunculon nivalis Nordh. 1943 emend. Dierß. 1984
Anthelia juratzkana-Juncus biglumis comm.
Nonsorted circles; moist acidic tundra; subzone E

Table 1. Environmental variables and soil physical and chemical properties for the plant associations and communities of the cryoturbated tundra. Mean with standard error in parentheses.

	Braya purpurascens-Puccinellia angustata comm.	Dryas integrifolia-Salix arctica comm.	Salici rotundifoliae-Caricetum aquatilis ass.	Junco biglumis-Dryadetum integrifoliae ass.	Dryado integrifoliae-Caricetum bigelowii ass.	Scorpidium scorpioides-Carex aquatilis comm.	Cladino-Vaccinietum vitis-idaeae ass.	Sphagno-Eriophoretum vaginati ass.	Anthelia juratzkana-Juncus biglumis comm.
Thaw depth (cm)	79.4 (1.1)	65.0 (1.4)	28.0 (0.3)	88.1 (1.4)	64.9 (1.9)	70.0 (1.8)	60.3 (0.9)	33.6 (1.6)	59.8 (1.9)
Snow depth (cm)	8.1 (2.0)	13.3 (2.7)	19.2 (2.6)	27.0 (1.9)	39.8 (2.5)	58.6 (7.4)	39.7 (4.6)	60.1 (4.4)	63.2 (0.9)
O-horizon depth (cm)	0.0 (0.0)	0.4 (0.2)	26.8 (1.2)	0.2 (0.1)	15.3 (1.5)	25.4 (0.9)	6.4 (1.6)	11.9 (1.0)	0.0 (0.0)
Bare soil (%)	55.0 (11.8)	0.0 (0.3)	0.1 (0.1)	26.3 (4.8)	0.3 (0.2)	2.4 (1.1)	0.0 (0.0)	0.0 (0.0)	10.6 (4.2)
Soil moisture (vol-%)	28.3 (2.9)	37.3 (2.6)	47.1 (0.4)	39.2 (0.9)	45.2 (2.5)	49.0 (1.9)	35.8 (1.6)	44.1 (1.3)	41.8 (3.3)
Bulk density (g/cm ³)	1.11 (0.04)	0.79 (0.03)	0.82 (0.02)	1.35 (0.04)	1.23 (0.07)	1.34 (0.04)	0.95 (0.05)	1.07 (0.04)	1.13 (0.04)
Sand content (%)	52.1 (3.3)	65.3 (2.3)	36.8 (1.6)	44.9 (2.7)	45.3 (3.3)	43.3 (2.7)	29.8 (1.4)	33.4 (1.9)	28.6 (1.9)
Silt content (%)	31.8 (2.3)	30.1 (2.6)	45.7 (2.0)	34.9 (2.6)	40.8 (3.0)	46.6 (5.8)	44.4 (1.1)	44.9 (1.1)	43.6 (1.5)
Clay content (%)	16.1 (3.9)	4.6 (0.8)	17.5 (2.2)	20.2 (0.6)	13.9 (1.2)	10.1 (3.2)	25.8 (0.8)	21.7 (1.8)	27.8 (1.8)
Soil pH	8.3 (0.1)	7.9 (0.1)	6.5 (0.1)	8.1 (0.1)	7.9 (0.1)	7.7 (0.1)	5.0 (0.1)	5.3 (0.1)	5.2 (0.1)
Total C (%)	4.77 (0.31)	6.30 (0.24)	5.34 (0.11)	5.1 (0.21)	5.78 (0.26)	5.42 (0.83)	3.73 (0.39)	3.46 (0.28)	2.68 (0.55)
Total N (%)	0.11 (0.01)	0.18 (0.03)	0.19 (0.02)	0.18 (0.01)	0.29 (0.03)	0.26 (0.05)	0.21 (0.02)	0.21 (0.02)	0.15 (0.04)
Available Ca ²⁺ (me/100g)	39.8 (1.4)	48.3 (1.8)	22.0 (0.8)	67.3 (6.7)	53.2 (2.7)	40.6 (8.3)	5.4 (0.9)	9.2 (0.5)	6.0 (0.9)
Available Mg ²⁺ (me/100g)	2.35 (0.12)	1.78 (0.15)	1.14 (0.08)	1.7 (0.18)	1.86 (0.21)	1.20 (0.12)	0.76 (0.10)	1.59 (0.07)	1.07 (0.11)
Available K ⁺ (me/100g)	0.18 (0.01)	0.14 (0.02)	0.11 (0.01)	0.12 (0.01)	0.18 (0.02)	0.18 (0.02)	0.10 (0.01)	0.07 (0.01)	0.08 (0.01)
Available Na ⁺ (me/100g)	3.18 (0.61)	0.32 (0.14)	1.42 (0.10)	0.05 (0.01)	0.06 (0.01)	0.06 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)

Kade et al. 2005, Plant communities and soils in cryoturbated tundra along a bioclimate gradient in the Low Arctic, Alaska. Phytocoenologia, 35: 761-820.



Ordination of zonal patterned ground vegetation: controlling environmental gradients

- NMDS ordination.
- Clear gradient of vegetation response to cryoturbation within each subzone and clear floristic separation between subzones.
- But no clear overall controlling factors for the whole data set.
- Floristic separation between Alaska and Canada portions of the gradient due to different floristic provinces, and substrate differences.

Walker, D.A., Kuss, P., et al., 2011 (in revision), Vegetation and patterned-ground relationships along the Arctic bioclimate gradient in North America Applied Vegetation Science.

Biomass for each relevé was used to develop landscape-level biomass for each grid.

Table 4. Aboveground Plant Biomass Sampled Along a North American Arctic Transect^a

Grid	Biomass of Individual Vegetation Types, kg/100 m ²											
	Grid Biomass, kg/100 m ²	B1a	B1b	B1c	G1	G2	G3	G4	P1a	P1b	S1	W2
is-d	1.25	0	0.9		36.9							
is-z	17.13	0	3.9		36.9							
is-m	23.17	1.9	16.6		36.8							
mb-d	9.17	0.7	10.7						22.5			
mb-z	14.99	0	5.8			31.2						
gc-d	14.25	0.4	6.6						46.8			
gc-z	30.28	0.4	6.6						46.8			
gc-m	27.08	0.1	6.6				41.2					29.1
hi-z	33.33	0.2	0.2						80.9			
wd-z	61.82						61.8					
dh-z	33.17		9.5				41.6		18.5	18.5		41.6
fb-d	48.96		4.8				62.8		36.2			
fb-z	43.40		4.8				48.3		36.2	36.3		42.1
fb-w	40.39		11.5				48.3		36.3			42.1
sn-z1	44.19		3.7				60.9		41.1	41.1		
sn-z2	56.30		3.7				60.9			41.1		60.9
sa-z	75.10			10.0				75.8		48.1	73.4	
hv-d	73.54			10.0				75.6		48.1	61.1	
hv-z	72.08			10.0				75.6		48.1	61.1	
hv-m	73.44			10.0				75.6		48.1	61.1	

^aGrid biomass for 10 × 10-m grids (kg/100 m²) are based on relevé biomass of vegetation types multiplied by proportion of vegetation types within each grid (see Figure 7), and biomass density (kg/100 m²) of individual vegetation types on each grid. See Figure 5 and Table 3 for description of vegetation type codes.

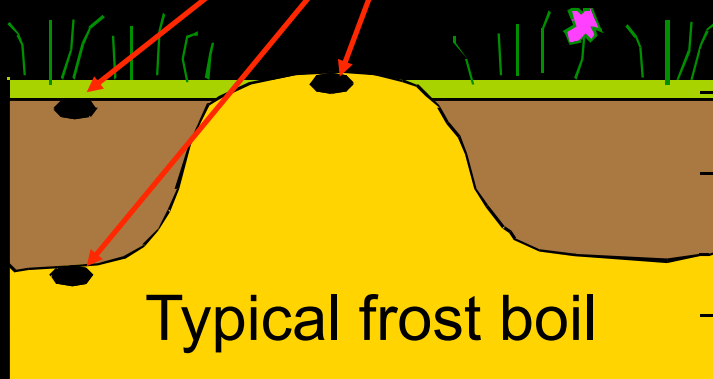
To examine the insulative effect of vegetation: *n*-factor was determined for each vegetation type.



i-button data loggers

Loggers:

1. base of live vegetation
2. base of organic horizons
3. center of circle



Typical frost boil

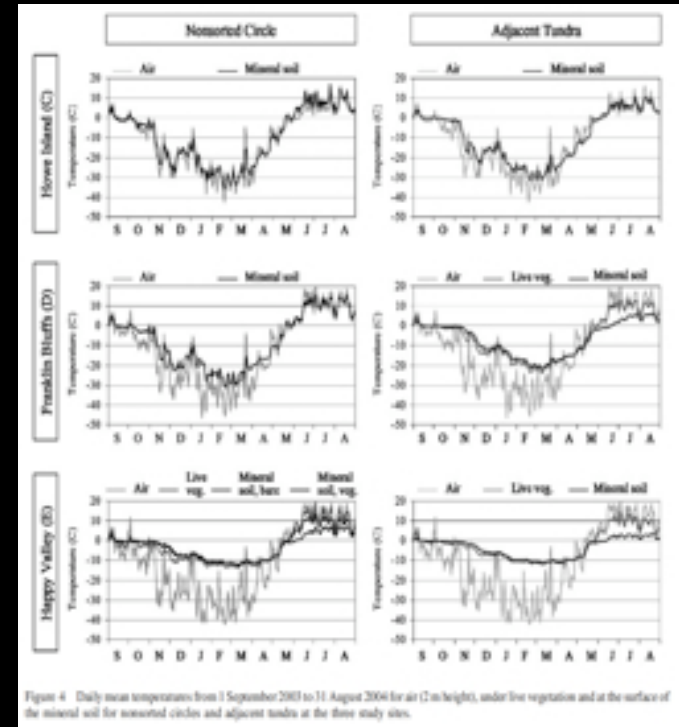


Figure 4 Daily mean temperatures from 1 September 2003 to 11 August 2006 for air (2 m height), under live vegetation and at the surface of the mineral soil for nonsorted circles and adjacent tundra at the three study sites.

Kade, A., Romanovsky, V.E., and Walker, D.A., 2006, The N-factor of nonsorted circles along a climate gradient in Arctic Alaska: Permafrost and Periglacial Processes, v. 17, p. 279-289.

n-factors for patterned- ground features along the NAAT

n-factor:

–Ratio of the degree-day total at the soil surface to the degree-day total of the air.

– Summer n factor uses thawing-degree days.

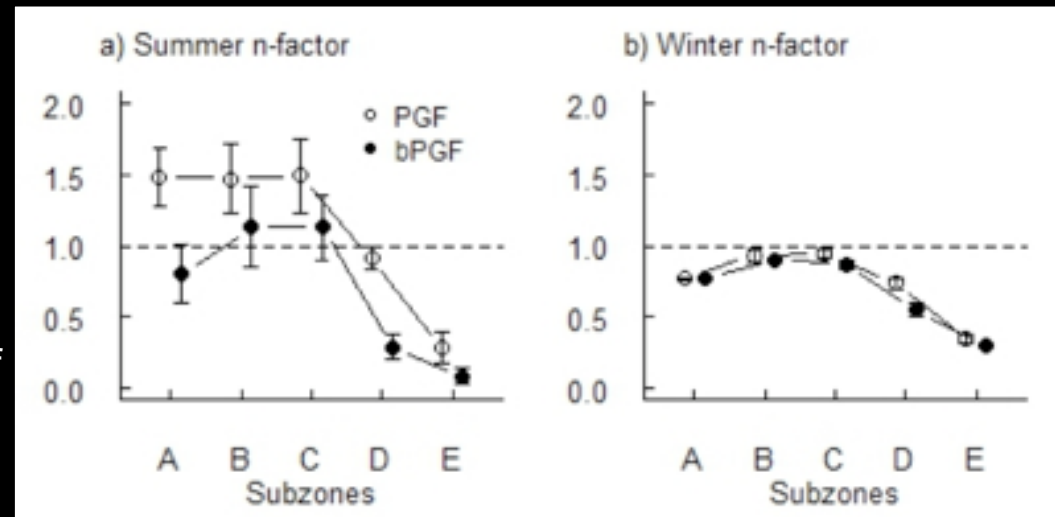
– Winter n factor uses freezing-degree days.

High Arctic: Mineral soil temperature warmer than air temperature because of radiative warming of the soil surface.

Low Arctic: Interboil mineral-soil temperatures are colder than air temperatures because of insulation of vegetation and organic soil.

Winter: Soil temperatures much warmer than air temperature, particularly in Low Arctic because of snow insulation.

$$n = \text{DDT}_{\text{soil}} / \text{DDT}_{\text{air}}$$



Walker, D.A., Kuss, P., et al., 2011 (in revision), Vegetation and patterned-ground relationships along the Arctic bioclimate gradient in North America Applied Vegetation Science.

Experimental alteration of vegetation canopy to examine effects of vegetation on active layer and frost heave

Ph.D. project of Anja Kade



Control



Vegetation Removal



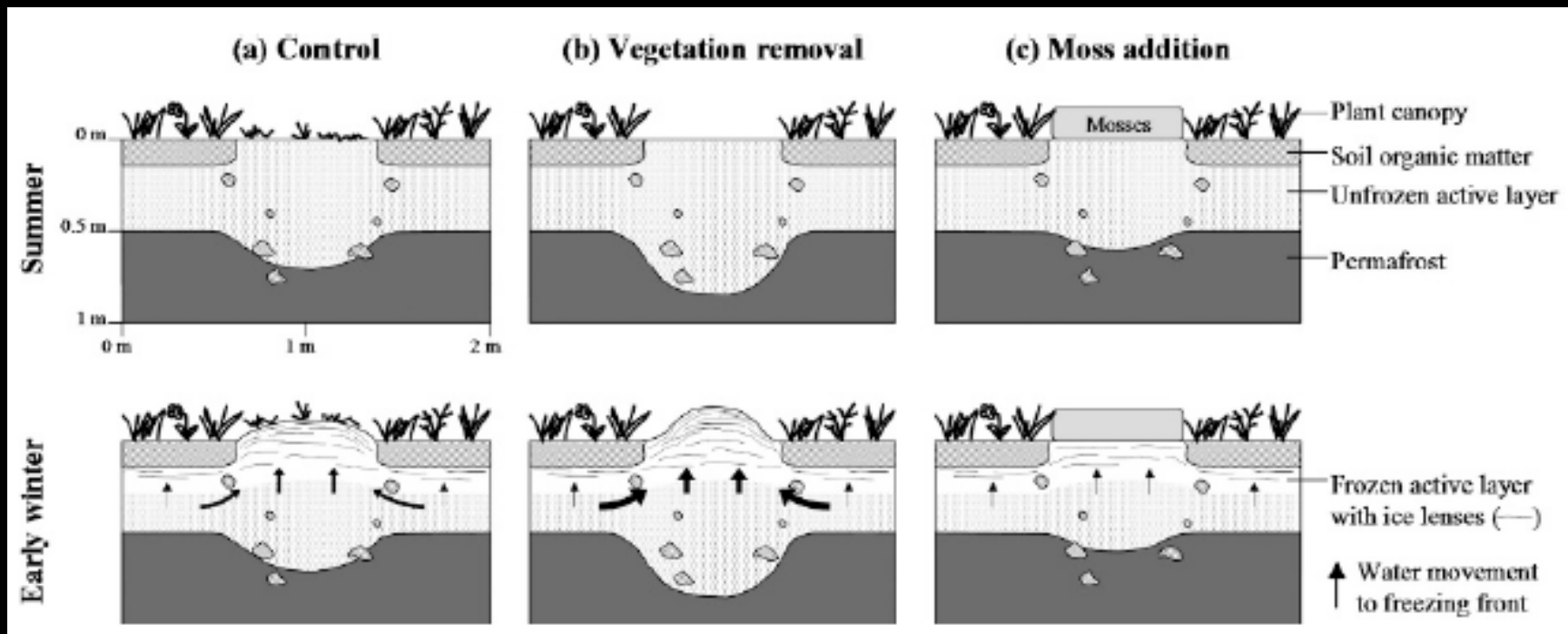
Graminoid Transplants



Moss Carpet Transplants

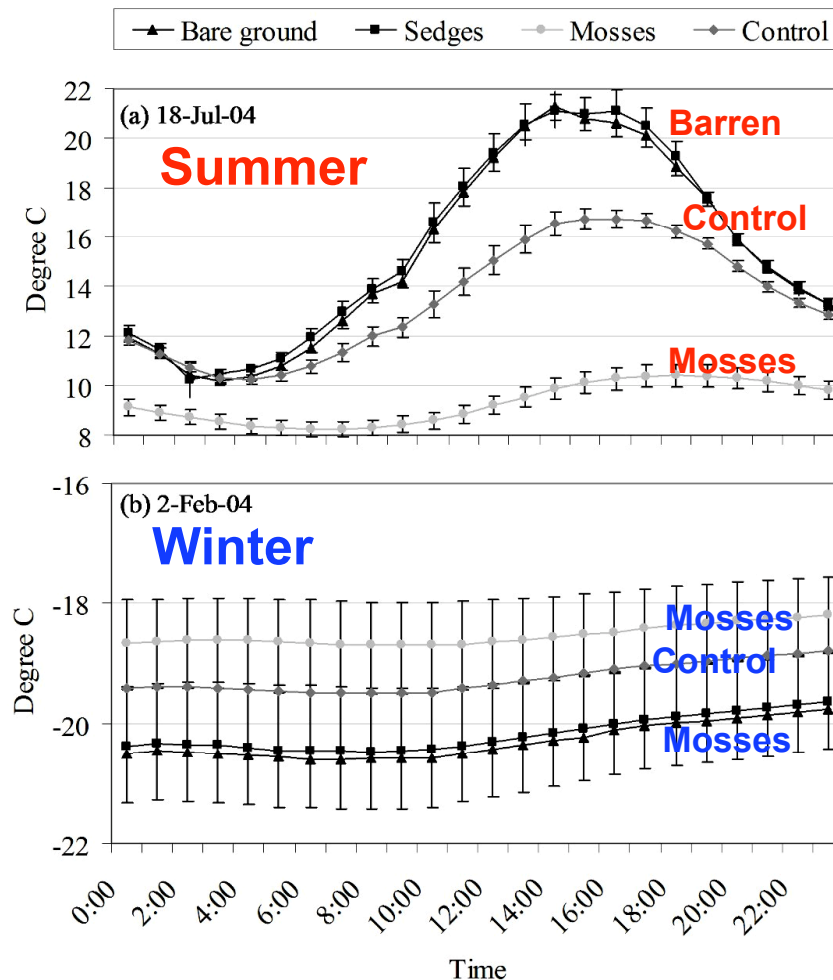
Response Variables: Frost Heave, Thaw Depth, Soil Moisture, Soil Temperature

Hypothesized effects of Kade experiment



Kade and Walker, 2008, *Arctic, Alpine and Antarctic Research*

Effects of vegetation on summer and winter soil surface temperatures.

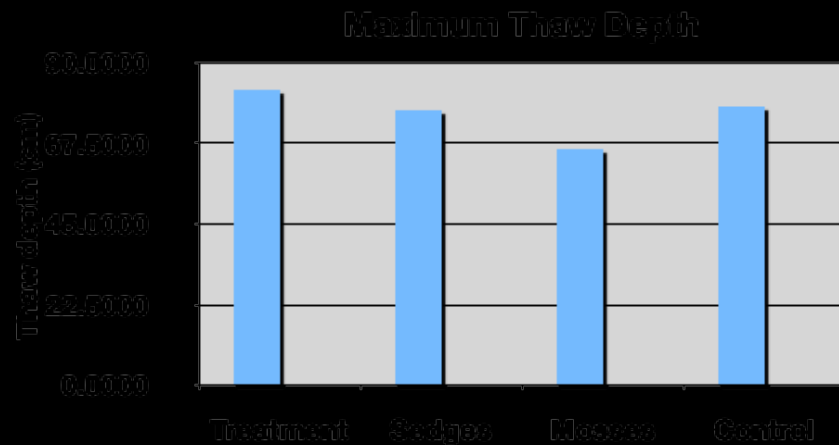


Mean Summer Temperature:
Vegetation removal: +1.5°C (+22%)
Moss addition: -2.8 °C (-42%)

Mean Winter Temperature:
Vegetation removal: -0.9°C (-6%)
Moss addition: +1.3°C (+7%)

•The sedge treatment had a similar response as the barren treatment.

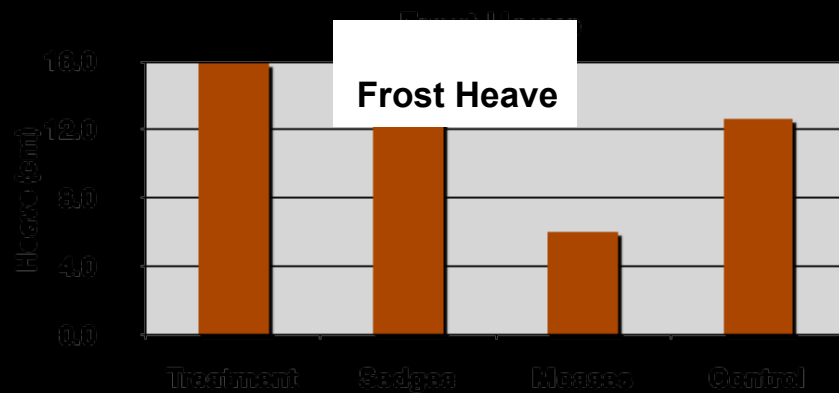
Effects vegetation on thaw depth and heave



Thaw:

Vegetation removal: +5 cm (+6%)

Moss addition: -11 cm (-14%)



Heave:

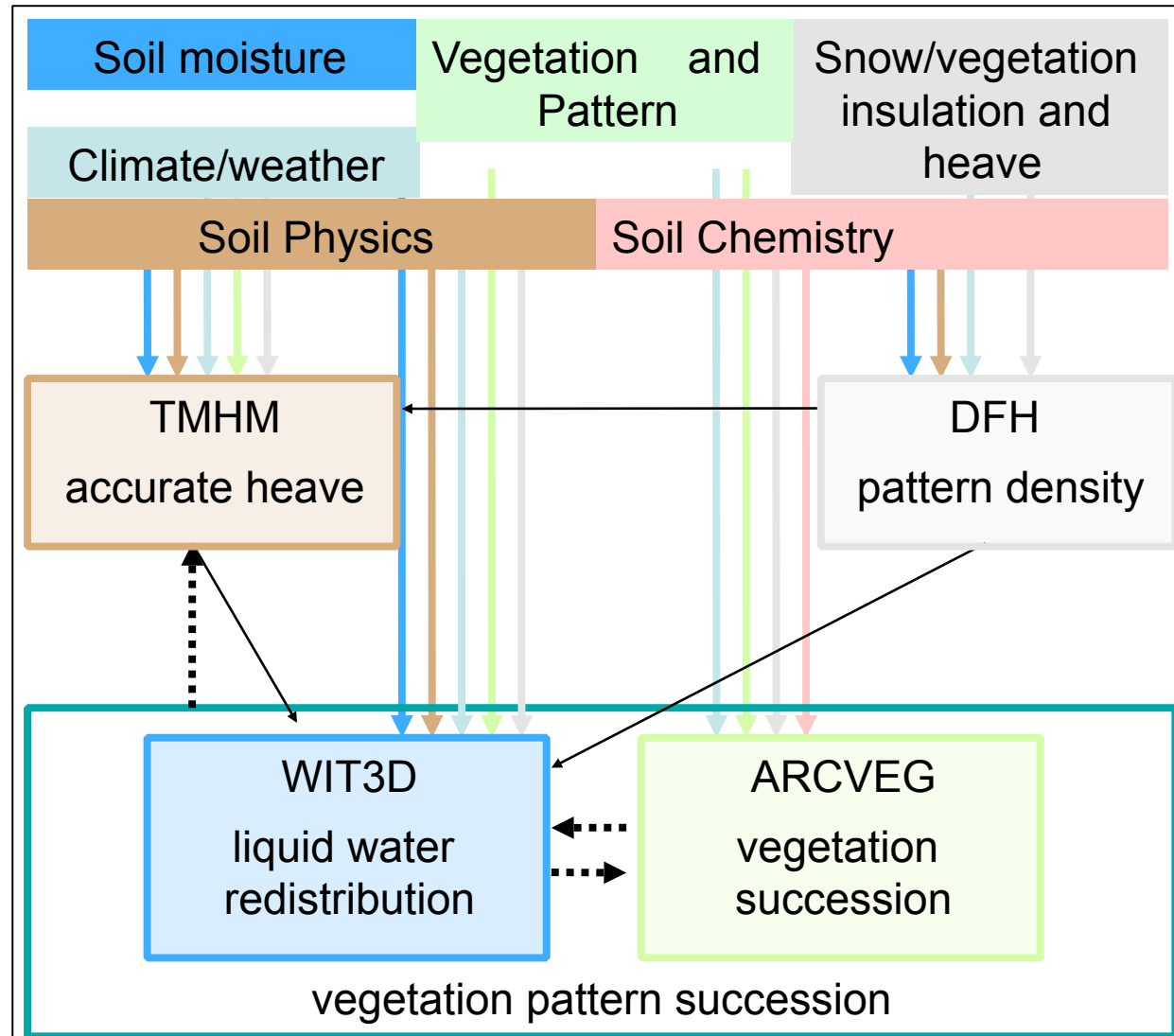
Vegetation removal: +3 cm (+24%)

Moss addition: -5 cm (-40%)

Environmental Variables



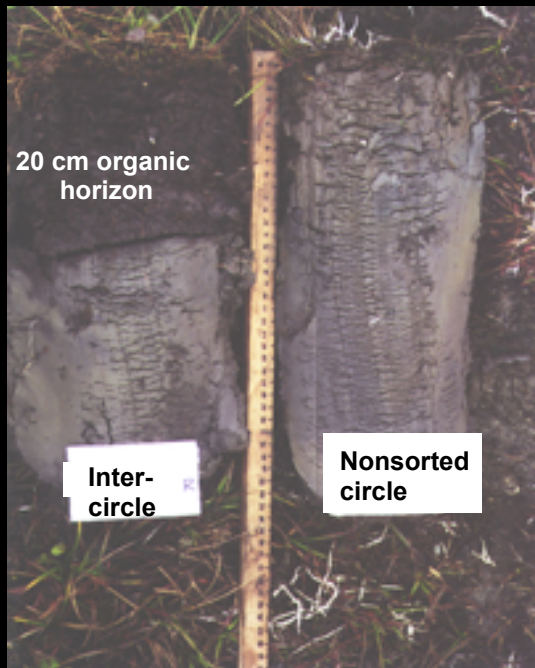
Models



-  Measured input and/or calibration data
-  Simulated calibration and/or Input data
-  Feedback

DFH: Differential Heave model
 TMHM: Thermo Mechanical Heave Model
 WIT3D: 3D Water Ice Temperature model
 ARCVeG: Arctic Vegetation succession model

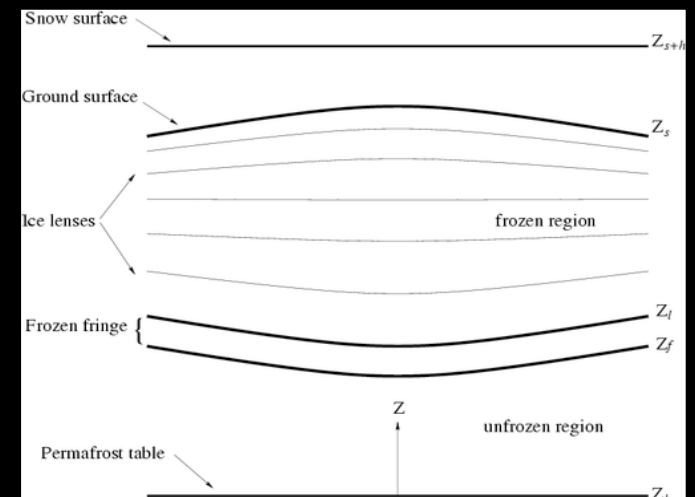
Differential frost heave (DFH) model of frost-heave feature formation (Peterson and Krantz 2003)



Lenticular voids in soil created by ice lenses.

Schematic of soil undergoing top-down freezing. Ice lenses exist in the frozen region and permafrost underlies the active layer.

- Heat preferentially escapes from the surface at high points of small irregularities in the surface.
- These high points self-organize into patterns controlled by mechanical properties of the soil (e.g., texture) and active layer thickness.
- These high points are sites of increased ice-lens development, and more heave.
- Theoretically, non-sorted circles should be more closely spaced in shallowly thawed soils.

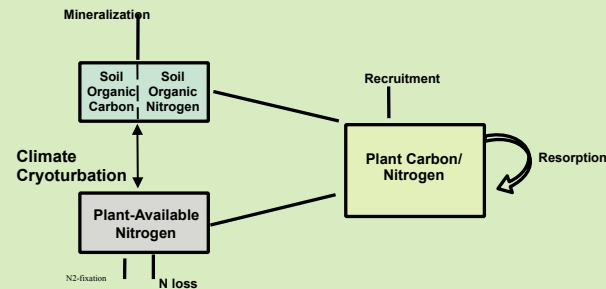


Modeling Components of the Project

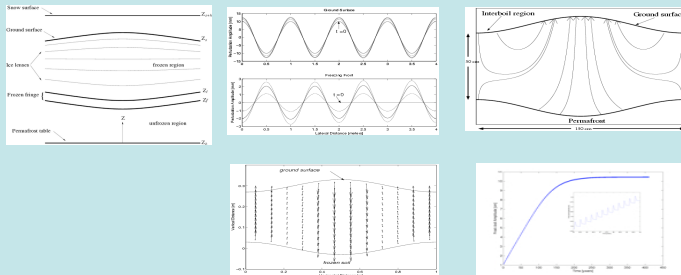
- **Differential Frost Heave (DFH) model (Peterson & Krantz):** Describes the self-organization of non-sorted circles in the absence of vegetation. Models the process of differential frost heave and spacing of frost features using linear instability analysis.
- **Thermo-mechanical model (TMM) of frost heave (Nikolskiy et al.):** Detailed simulation of heaving process within a non-sorted circle that includes mass, momentum and energy conservation laws for water, ice, and soil. Accounts for the observation that heave is considerably greater than can be accounted for by simply freezing the amount of the water in the soil.
- **WIT/ArcVeg (Daanen & Epstein):** A 3-dimensional model of frost heave. Mainly a hydrology-heave model driven by temperature differentials and changes in vegetation patterns.

Linking modeling efforts

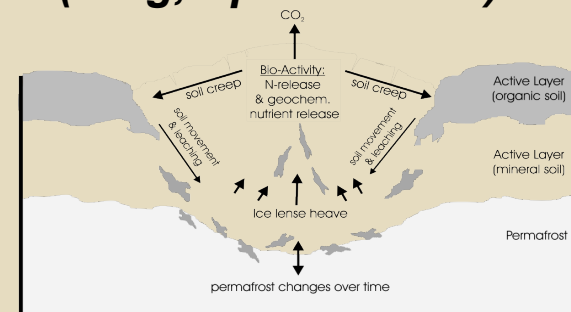
Vegetation Component (Epstein, Walker et al.)



Ice-lens Component (Krantz, Romanovsky, et al.)

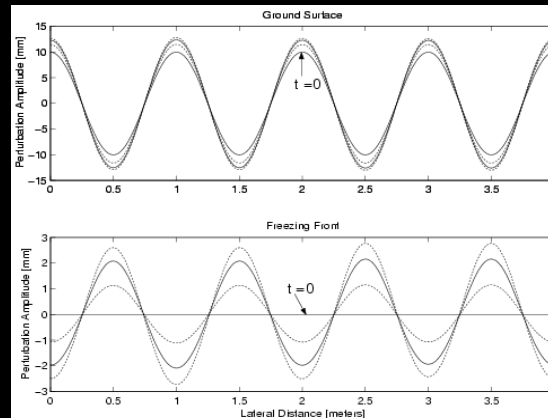


Soil Component (Ping, Epstein et al.)

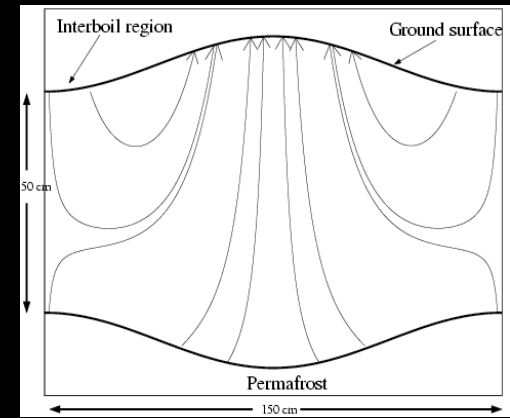


Differential Frost-Heave (DFH) Model

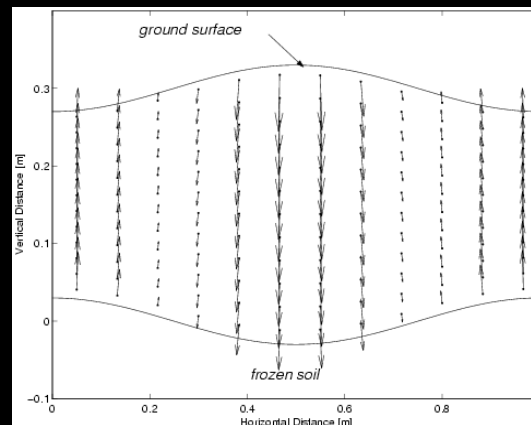
- The model successfully predicts order of magnitude heave and spacing of frost boils.
- Other predictions include effect of soil texture, air temperature, snow depth on magnitude of heave.



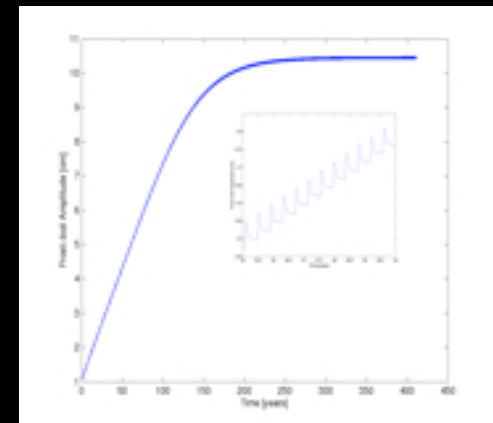
Position of ground surface and freezing fronts



Particle trajectories over several hundred years

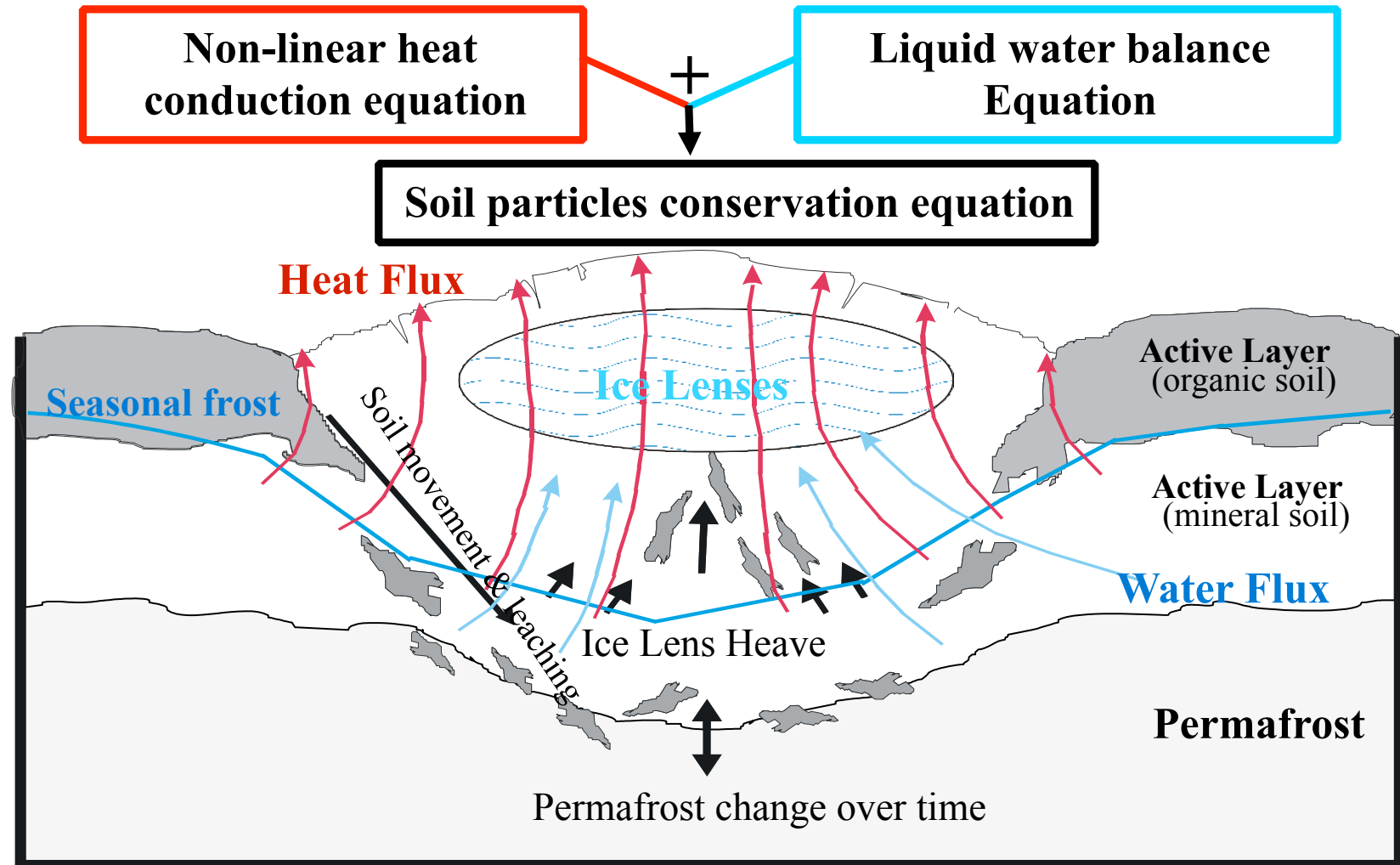


Soil creep



Time to stabilization

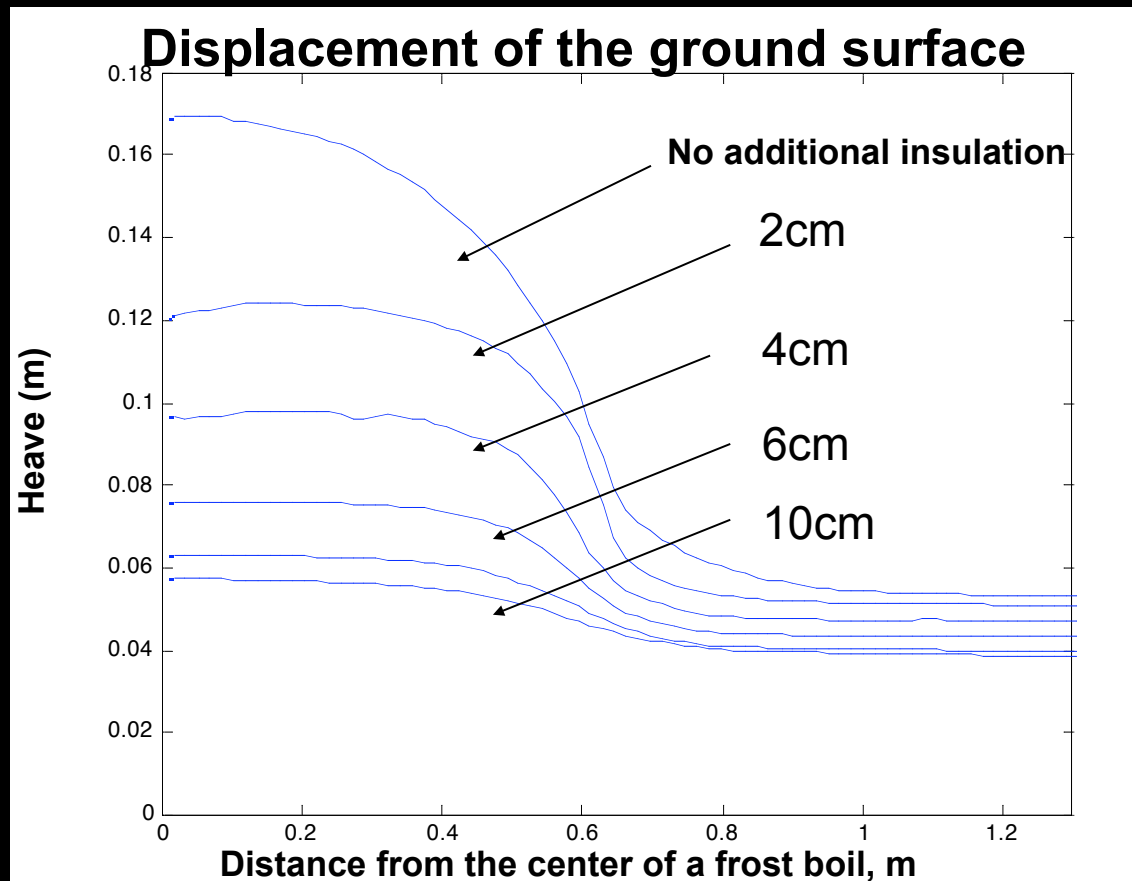
Thermo-Mechanical Model of Frost Heave



Nicolsky, D.J., Romanovsky, V.E., Tzipenko, G.S., Walker, D.A. 2008. Modeling biogeophysical interactions in nonsorted circles in the Low Arctic. *Journal of Geophysical Research - Biogeosciences*. 113:1-17.

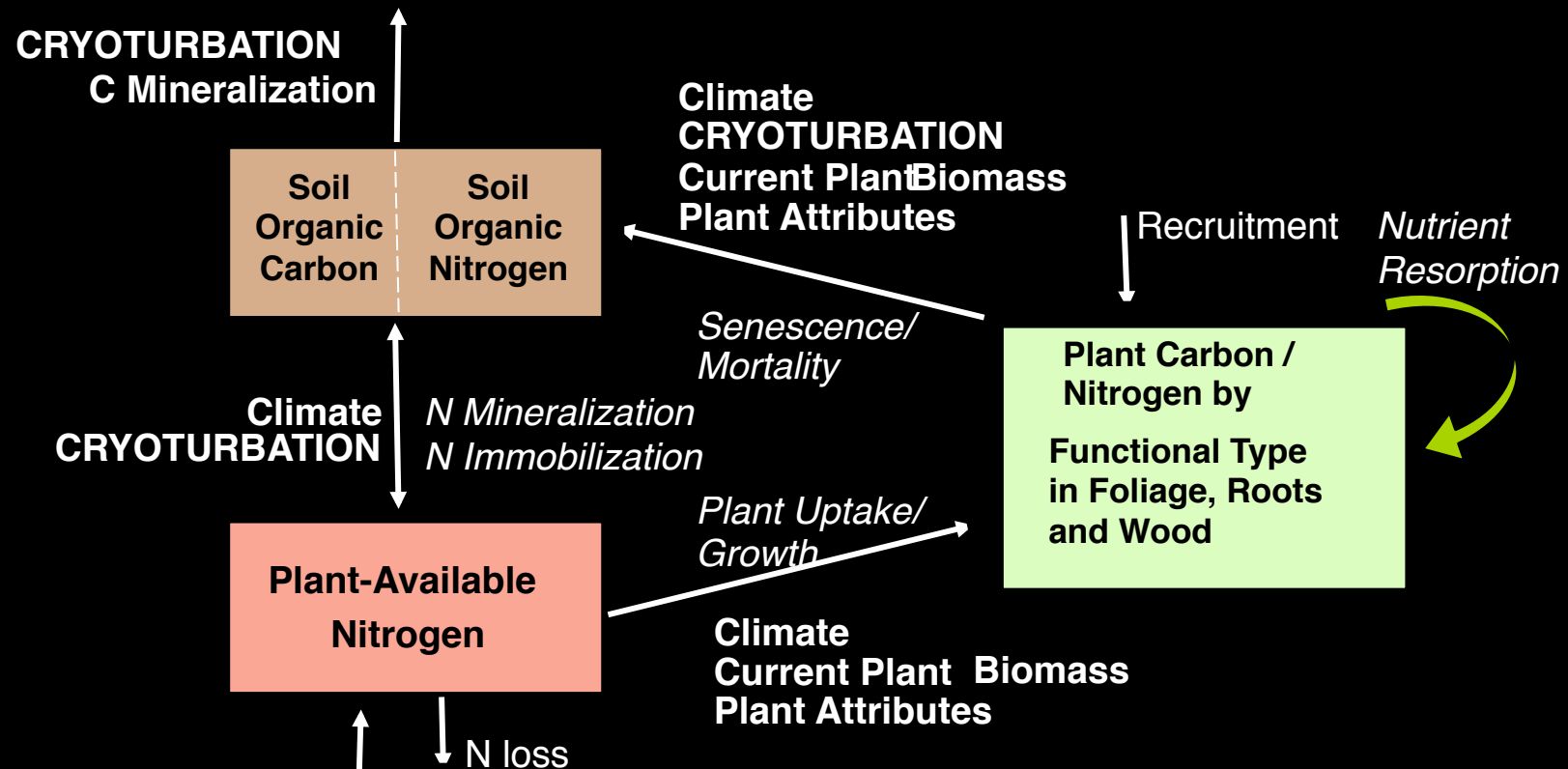
The effect of insulation:

Thermo-mechanical model of frost heave vegetation interactions



- Each blue line corresponds to the different depth of an additional insulation layer over boil.
- The insulation simulates the effect of vegetation cover on frost heave.
- Thicker vegetation layer causes better thermal insulation and lowers cryogenic suction, hence the smaller frost heave of the ground.

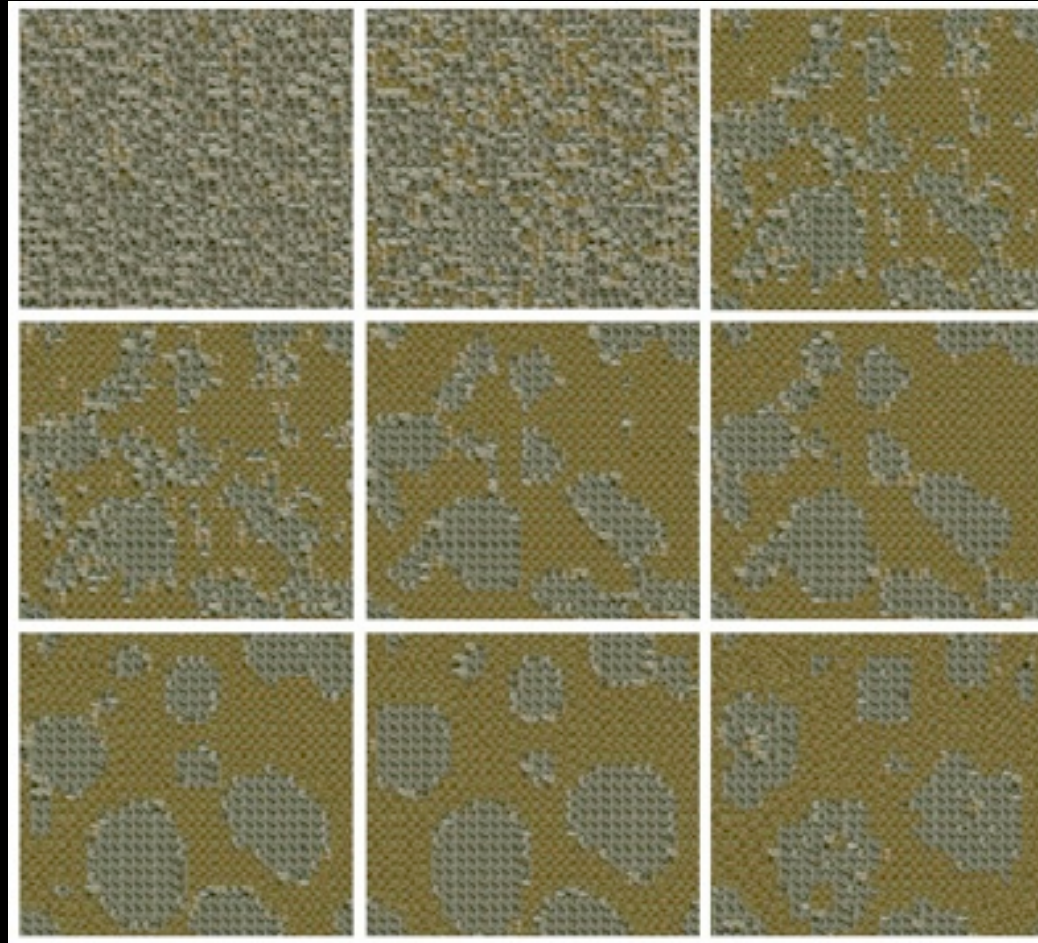
ArcVeg Model (Epstein et al. 2000)



- Simulates the interannual dynamics of tundra plant community composition and biomass.
- Parameterized for up to 20 plant growth forms.
- Based on nitrogen mass balance among pools of soil organic and inorganic nitrogen, and live plant nitrogen in live phytomass.
- Changes in temperature drive changes in net N mineralization and the length of the growing season and thereby alter the community biomass and composition.
- Climate and disturbance are stochastic forcing variables.

Modeling WIT-ArcVeg

Random vegetation
Year 1

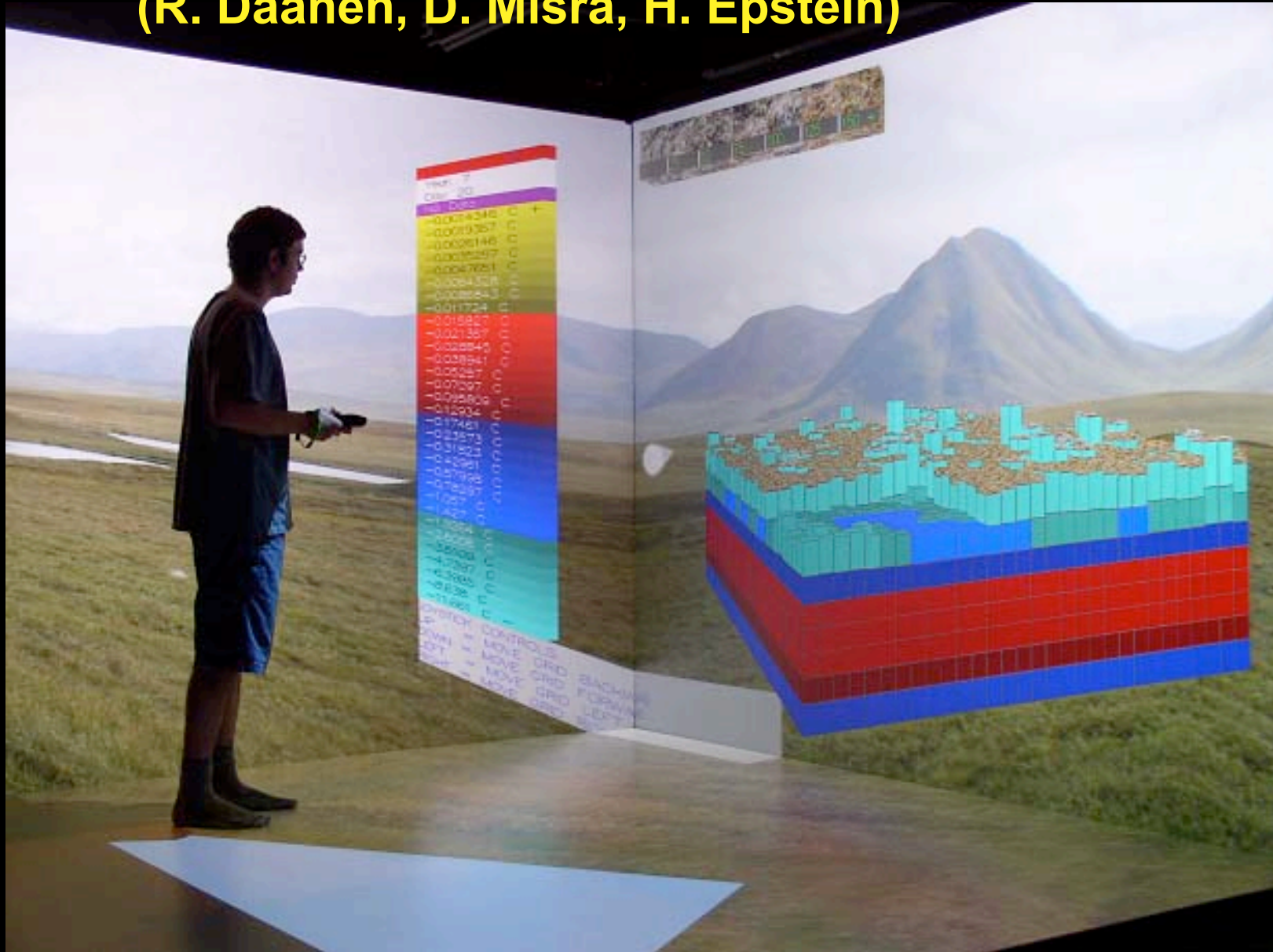


Organized vegetation
Year >1000

<http://snowy.arsc.alaska.edu/WIT3D/>

Daanen, R.P., Misra, D., Epstein, H., et al. 2008. Simulating nonsorted circle development in arctic tundra ecosystems. *Journal of Geophysical Research - Biogeosciences*. 113:1-10.

3-D Modeling of patterned-ground formation (R. Daanen, D. Misra, H. Epstein)



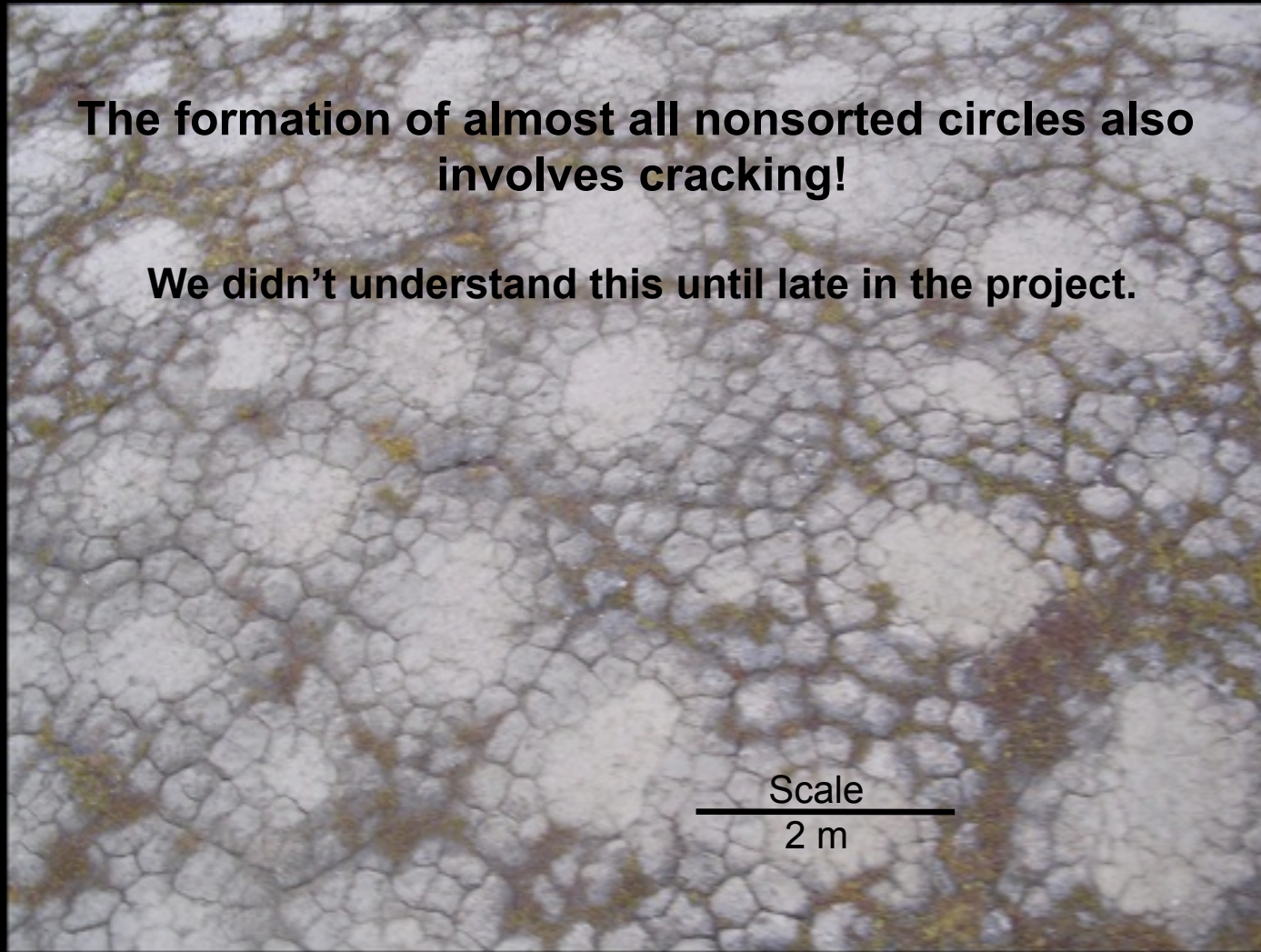
WIT3D/ArcVeg Model in ARSC Discovery Lab.

Photo: Ronnie Daanen

Modeling did not address issue of cracking.

The formation of almost all nonsorted circles also involves cracking!

We didn't understand this until late in the project.

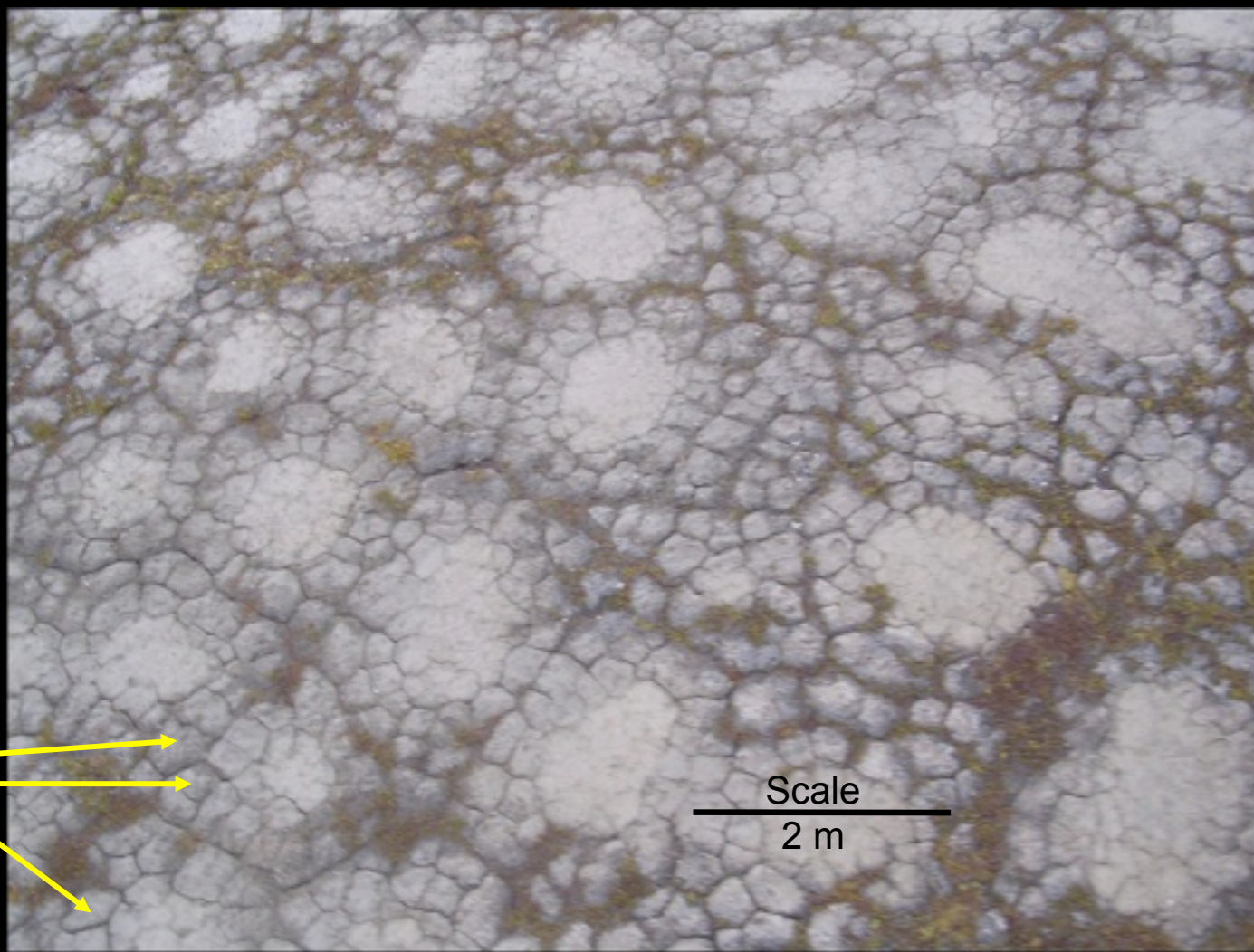


Howe Island, AK

Photo by Anja Kade

Small non-sorted polygons

**Small Non-
sorted
polygons
(35-50 cm)**



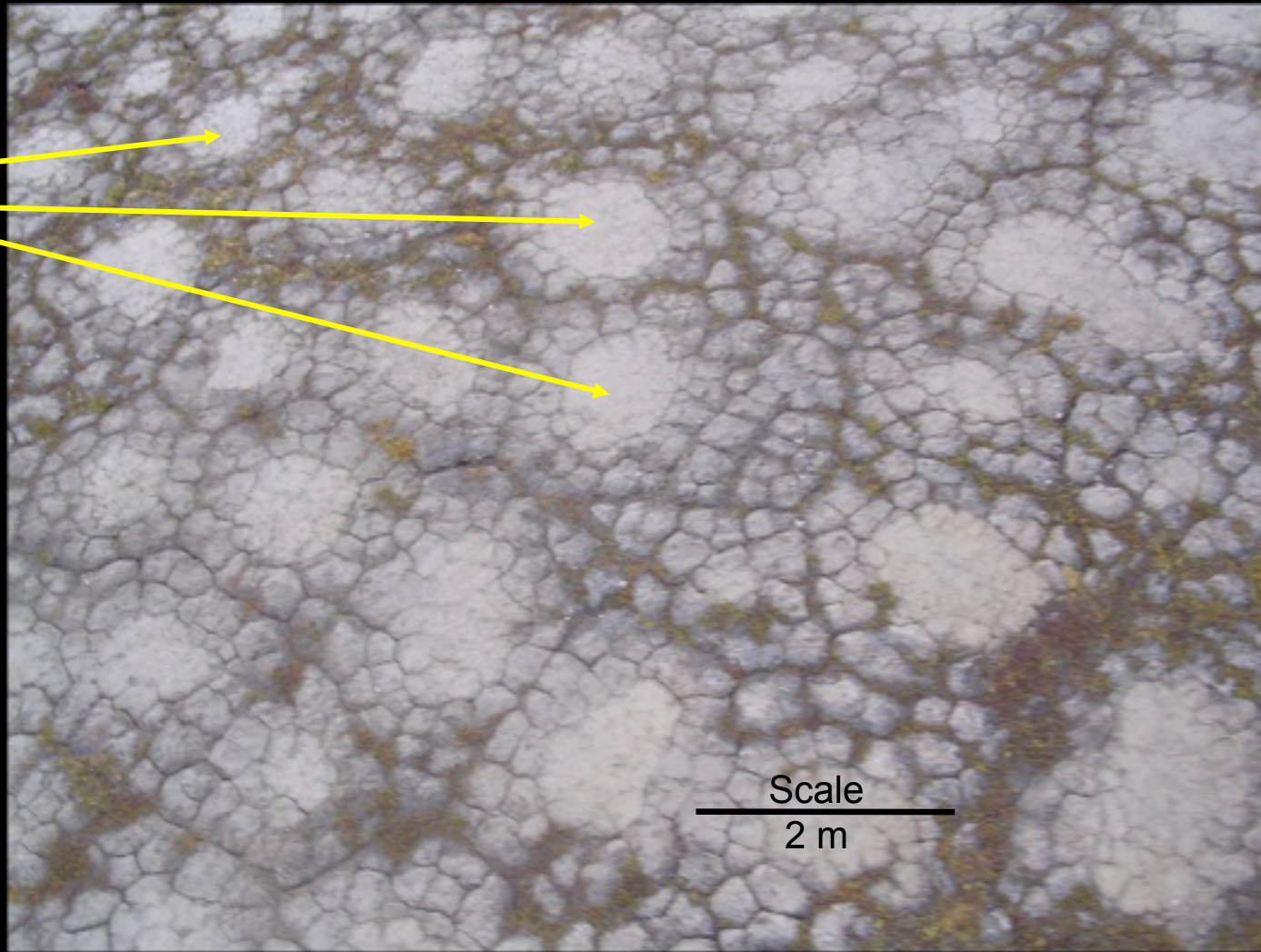
Scale
2 m

Howe Island, AK

Photo by Anja Kade

Non-sorted circles

Frost-heave
non-sorted
circles
(90-200 cm)

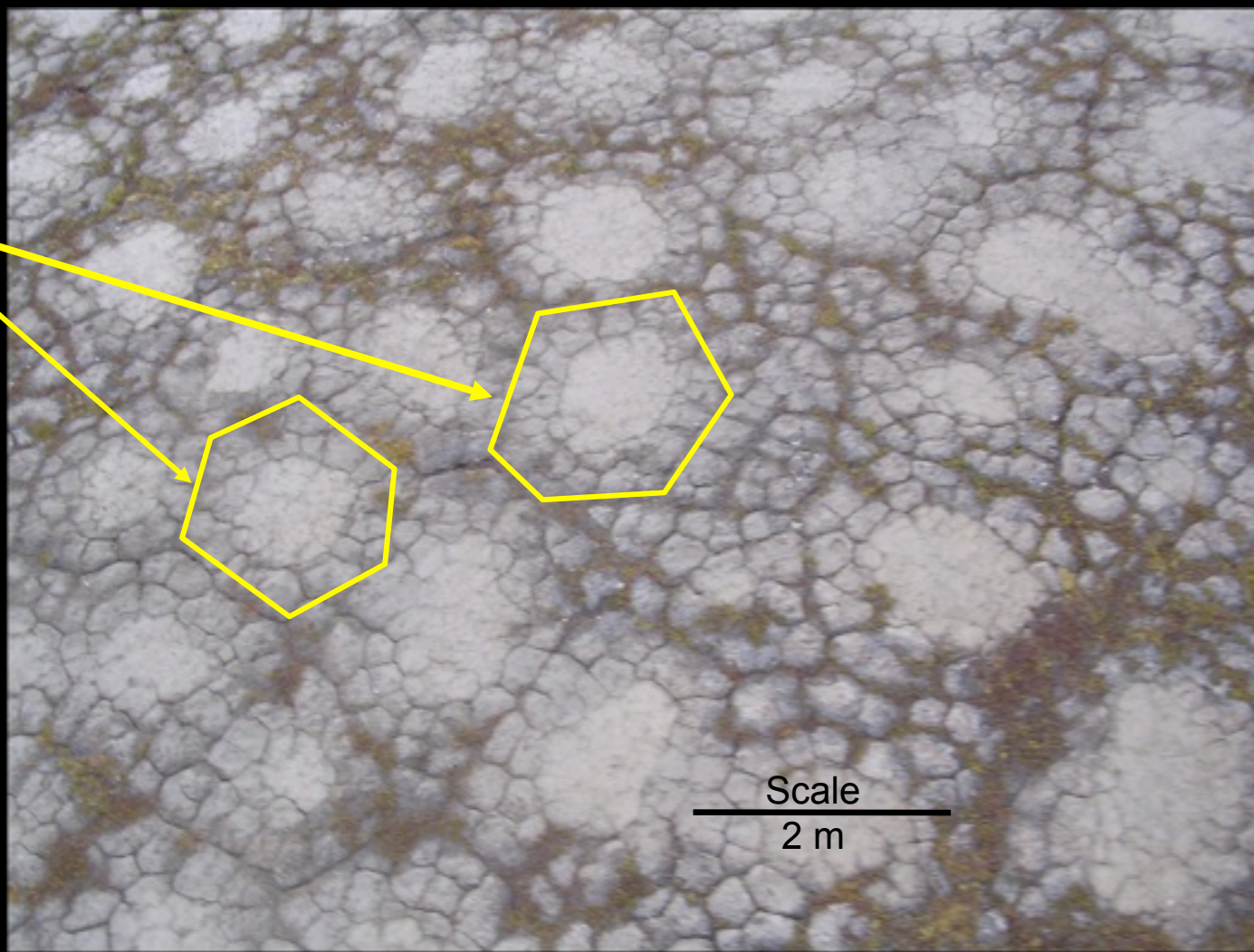


Howe Island, AK

Photo by Anja Kade

Medium-size non-sorted polygons

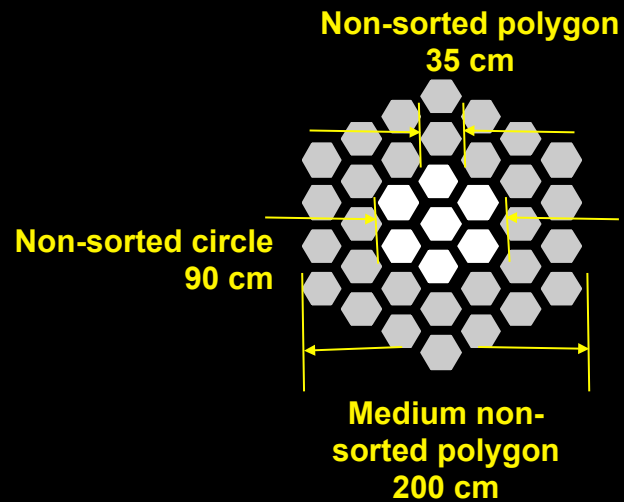
Medium
non-sorted
polygons
(200-300
cm)



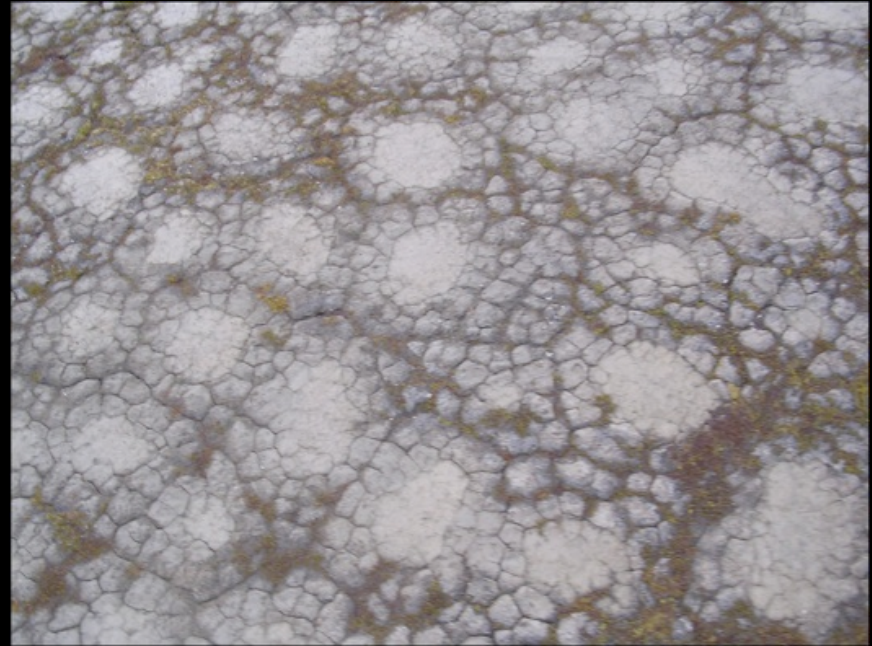
Howe Island, AK

Photo by Anja Kade

Components of landscape modified by both cracking and differential heave



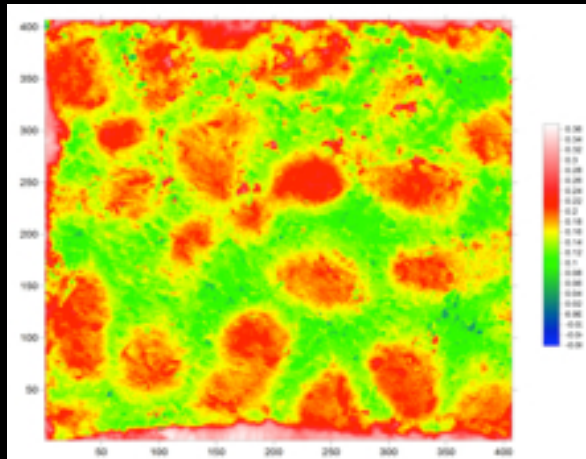
Large and small seasonal frost-crack non-sorted polygons,
Howe Island. Photo: Anja Kade



Large non-sorted permafrost crack polygons
(20-30 m diameter), Howe Island
Photo: D.A. Walker

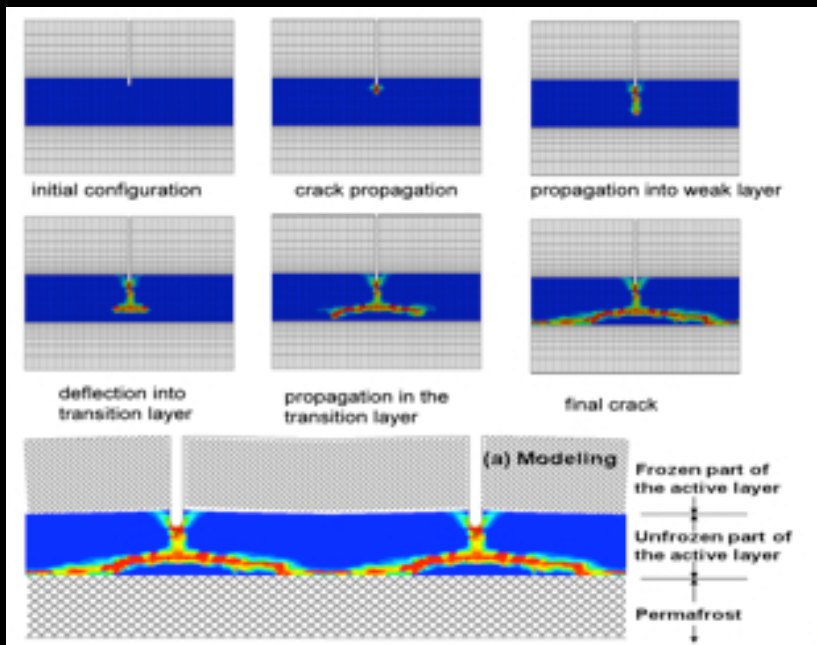


New tools for looking at complexity of patterned ground



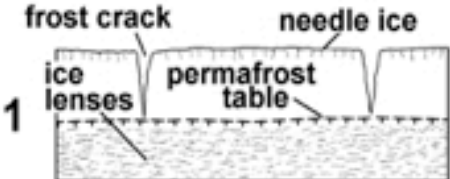
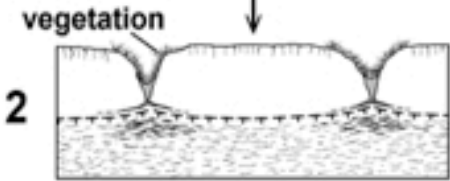
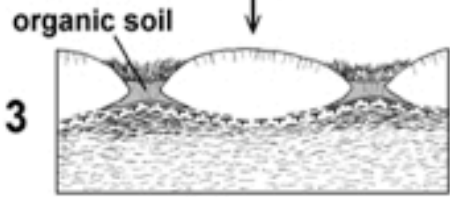
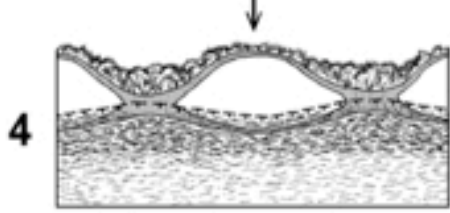
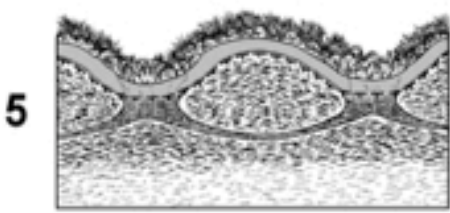
Ground-base LIDAR units for detailed 3-D views of frost heave:
Daanen et al. 2010.

Has shown that the annual frost
can exceed 25 cm!



Frost cracking model:
Zhang et al. (in progress):

Has replicated horizontal cracking
observed at the top of the
permafrost table and could help
explain development of
intermediate layer.

STAGE OF DEVELOPMENT	MAIN PROCESSES
 1	<i>Small polygons formation from contraction cracking</i> frost cracking; seasonal frost heave; needle ice formation
 2	<i>Vegetation colonization in troughs</i> frost cracking; beginning of aggradational ice formation; perennial differential frost heave; needle ice formation
 3	<i>Saturated flow of organic matter along sloping permafrost table</i> vegetation growth in troughs; peat accumulation in troughs; aggradational ice formation; perennial differential frost heave
 4	<i>Incorporation of organic matter into permafrost, complete vegetation coverage</i> active layer decrease; aggradational ice formation; perennial differential frost heave
FINAL STAGE UNDER FAVORABLE CONDITIONS	
 5	<i>Incorporation of frost boil into permafrost, earth hummock stabilization</i> vegetation canopy increase; active layer decrease; aggradational ice formation; perennial differential frost heave

Conceptual model frost boils and earth hummock formation in relationship to permafrost dynamics

Only model that invokes the
permafrost and cracking!

Others operate entirely in the
active layer.

Shur, Y., Jorgenson, T., Kanevskiy, M., and Ping, C.-L., 2008, Formation of frost boils and earth hummocks, in Kane, D.I., and Hinkel, K.M., eds., Ninth International Conference on Permafrost, Fairbanks, Institute of Northern Engineering, University of Alaska Fairbanks, p. 287-288.

High-resolution Quickbird imagery: Deadhorse Biocomplexity Site



Reveal that small-scale patterned ground features are nearly ubiquitous in Arctic landscapes!

Vlad's Deadhorse
climate station

Nonsorted circles covering much of the
image. Sizes about 2-4 m diameter.

Education component



Bill Gould, Grizelle Gonzalez, and students of Arctic Field Ecology course

Students both learned through a course offered by Bill Gould and Grizelle Gonzalez and they worked with the research team providing labor and insights and their own research projects.

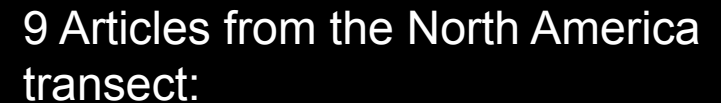


Photo: Heather Fuller

Conclusions

1. **Patterned-ground morphology on zonal sites changes in predictable ways with differences in climate, soil-moisture, soil-texture, and the structure of the vegetation.**
2. **Contrasts in the vegetation on and between patterned-ground features is best developed in Subzones C and D. These differences drive the movement of heat and water and the development of frost heave.**
3. **Strong thermal, hydrological, and chemical gradients help to maintain the position of these features in the same locality over long time periods.**
4. **Cryoturbation of organic material and aggrading permafrost tables act to sequester large amounts of carbon within the permafrost of these ecosystems.**
5. **Models have replicated the patterns related to frost heave (non-sorted circles and earth hummocks). Contraction cracking will require new models.**
6. **The presence of non-sorted circles strongly affect a wide variety of ecosystem properties (soil temperatures, active-layer depths, carbon storage, flux rates, biodiversity, successional pathways) and determine how these systems respond to disturbances including climate change.**

Synthesis of biocomplexity project



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Photo courtesy of Martha Raynolds

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Parks Canada
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Institute of Arctic Biology, UAF**

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Students of Bill Gould's Arctic Field Ecology Course (University of Minnesota)

Děkuji!

