Take home points for Lecture #2

- The Arctic is a maritime biome. But has relatively continental parts that are due to the presence of year-round sea ice. This has major effects on snow patterns and major implications for the circumpolar patterns of vegetation (slides 8-20).
- Other important aspects of the climate include a highly variable diurnal cycle, cold generally windy winter climate, generally low snow (except in maritime areas), late melting snow (which affects solar input to the vegetation, and a seasonal cycle with 6 distinct seasons related to snow cover (slides 21-29).
- The Arctic Tundra Bioclimate Zone is divided into 5 subzones based on accumulated summer warmth index, and dominant plant functional types (slides 30-69).
- The bioclimate gradient corresponds to major transitions in available summer warmth, soil carbon, plant productivity, biomass, and species diversity (slides 31-33 & 69-70.
- Macro-topographic variations are associated with major physiographic regions and elevation gradients associated with mountains.
- Five altitudinal belts based mainly on the adiabatic lapse rate of 6 ˚C/1000 m elevation generally reflect the same trends in plant functional types as the 5 latitudinal subozone, but the boundaries of these belts are affected by local climatic influences such as continentality (slides 71-80).

Lecture 3: Arctic vegetation and the role of permafrost and microtopography

Prof. D.A. "Skip" Walker
University of Alaska Fairbanks

Thermal erosion of massive ground ice,
Kara Sea coast near Amderma, Russia
Photo: D.A. Walker

Arctic Vegetation Ecology
University of Alaska Fairbanks,
Spring Semester, 2012

Distribution of permafrost

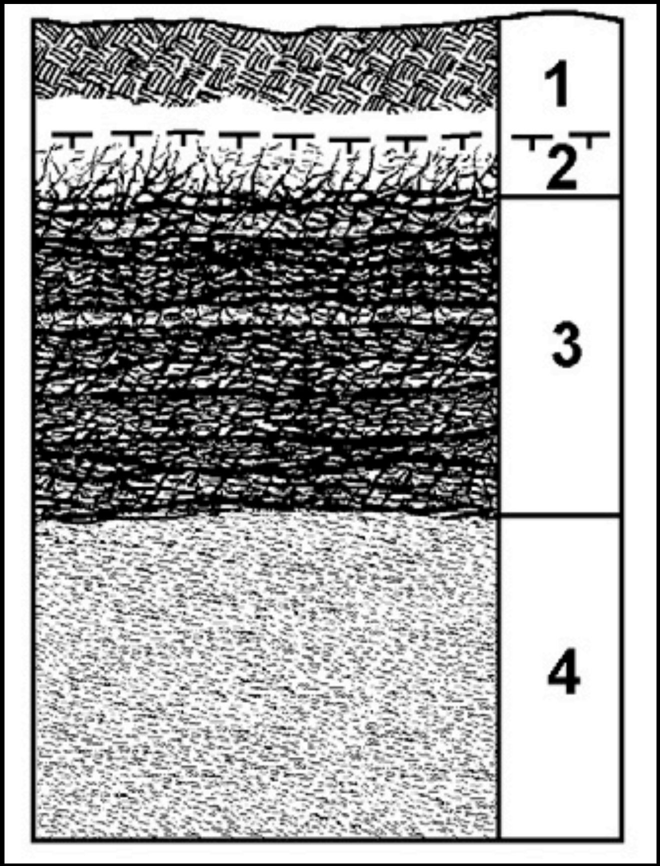
- Continuous: permafrost nearly everywhere
- Discontinuous: Large areas mainly on south-facing slopes without permafrost.
- Sporadic: Large areas with permafrost, mostly in wetlands and bogs.
- Isolated: Mostly in alpine areas.

Permafrost

- Permanently frozen ground
- Defined exclusively on the basis of temperature (below 0˚C all year for at least 2 years).
- Independent of soil texture, water content, or lithologic character.
- Can occur in soil, or other surficial material or bedrock.
- Can range from dry permafrost to massive ground ice as in photo.

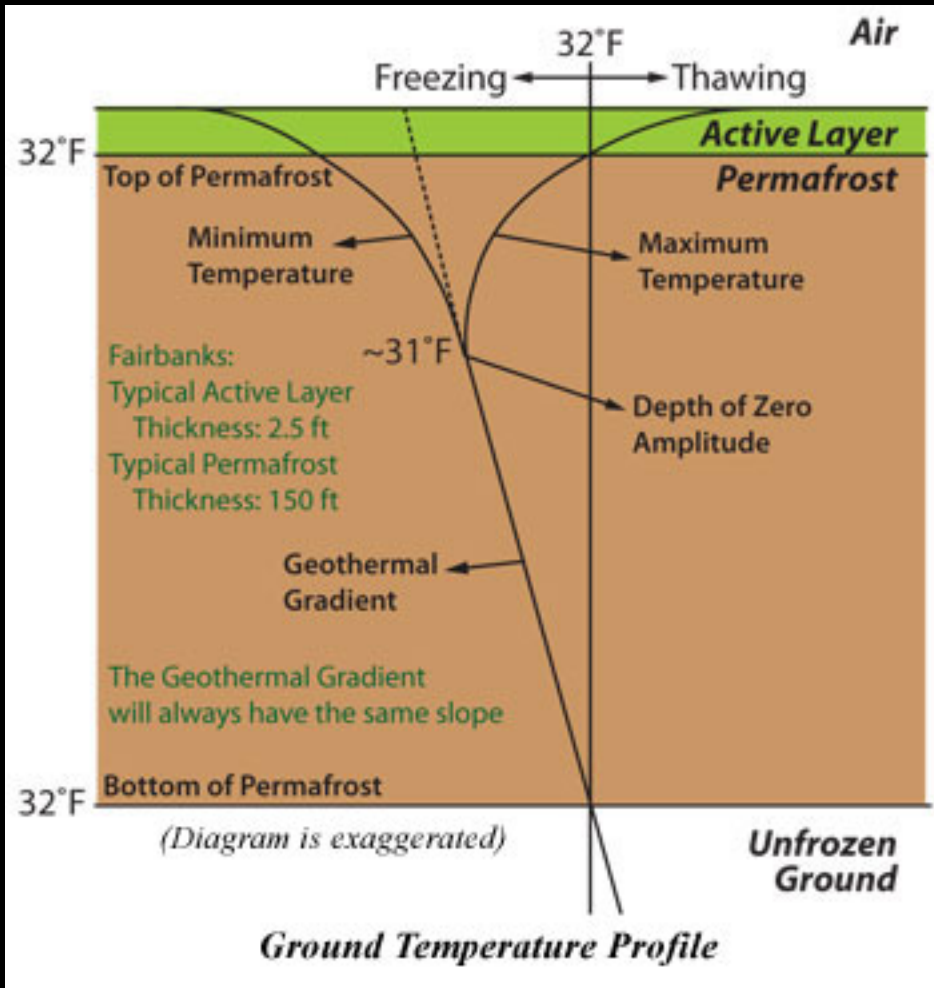
Yedoma deposit, Yakutia, Russia
Photo A.L. Washburn 1980

Active layer-permafrost interface



- 1 – Active layer (zone of annually thawed soil).
- 2 – Transient layer (which is frozen in some summers and thawed in others and defines variation in the active layer depth in the contemporary climate).
- 3 – Intermediate layer (ice-rich and organic-rich zone at the top of permafrost, which is slowly aggrading, i.e. increasing in thickness and moving upward due to organic-matter accumulation and changing microenvironment).
- 4 – Original permafrost.

French, H. and Shur, Y. 2010. The principles of cryostratigraphy. Earth Science Review. 101: 190-206.



Permafrost temperature gradient

- X-axis is temperature, Y axis is depth.
- Left curve shows gradient in winter. Right curve shows gradient in summer.
- Point where they meet is point of zero annual amplitude and is also referred to as the "temperature of the permafrost".
- The degree that soil warms in summer is dependent on several factors, such as vegetation, snow, soil moisture, soil type, and exposure to the sun.
- The depth of the bottom of the permafrost is primarily dependent on the geothermal gradient from the earth's molten core that defines a temperature slope from.

Courtesy of US Army CRREL Permafrost Tunnel Research Facility: http://permafrosttunnel.crrel.usace.army.mil/permafrost/climate_change.html

Ice lenses in the active layer during winter

- Numerous closely spaced lenses form as the soil freezes downward from the surface.
- The increased volume due to the ice causes heave.

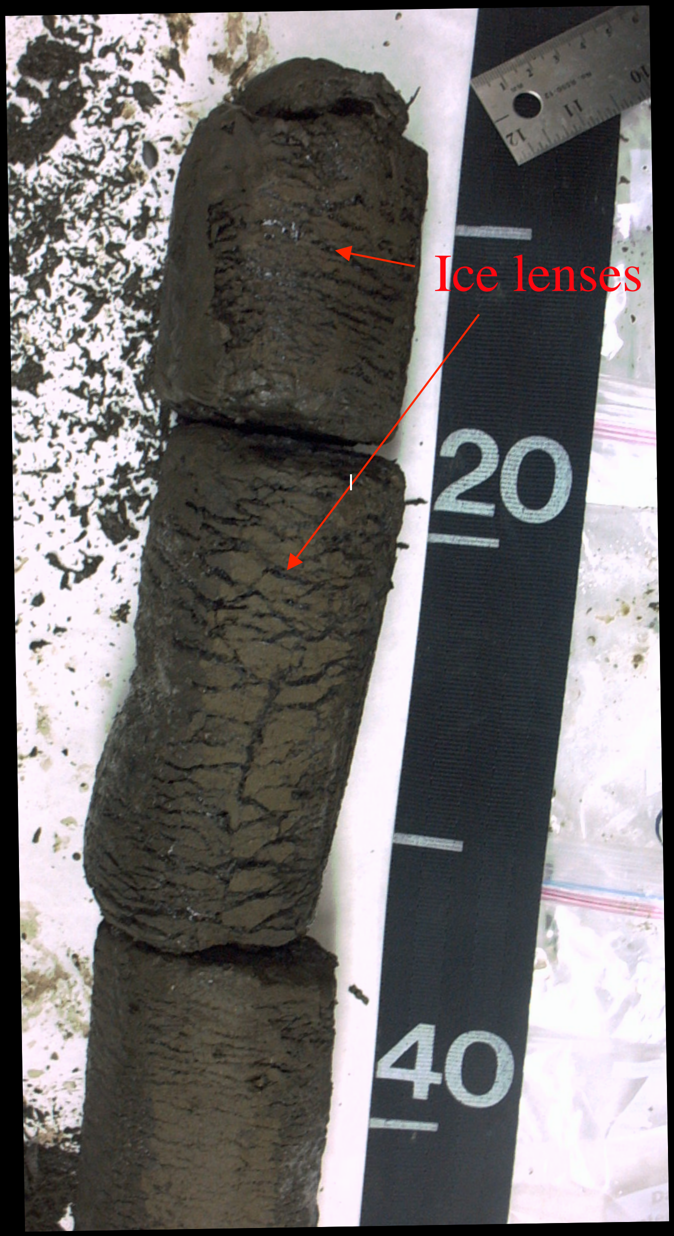
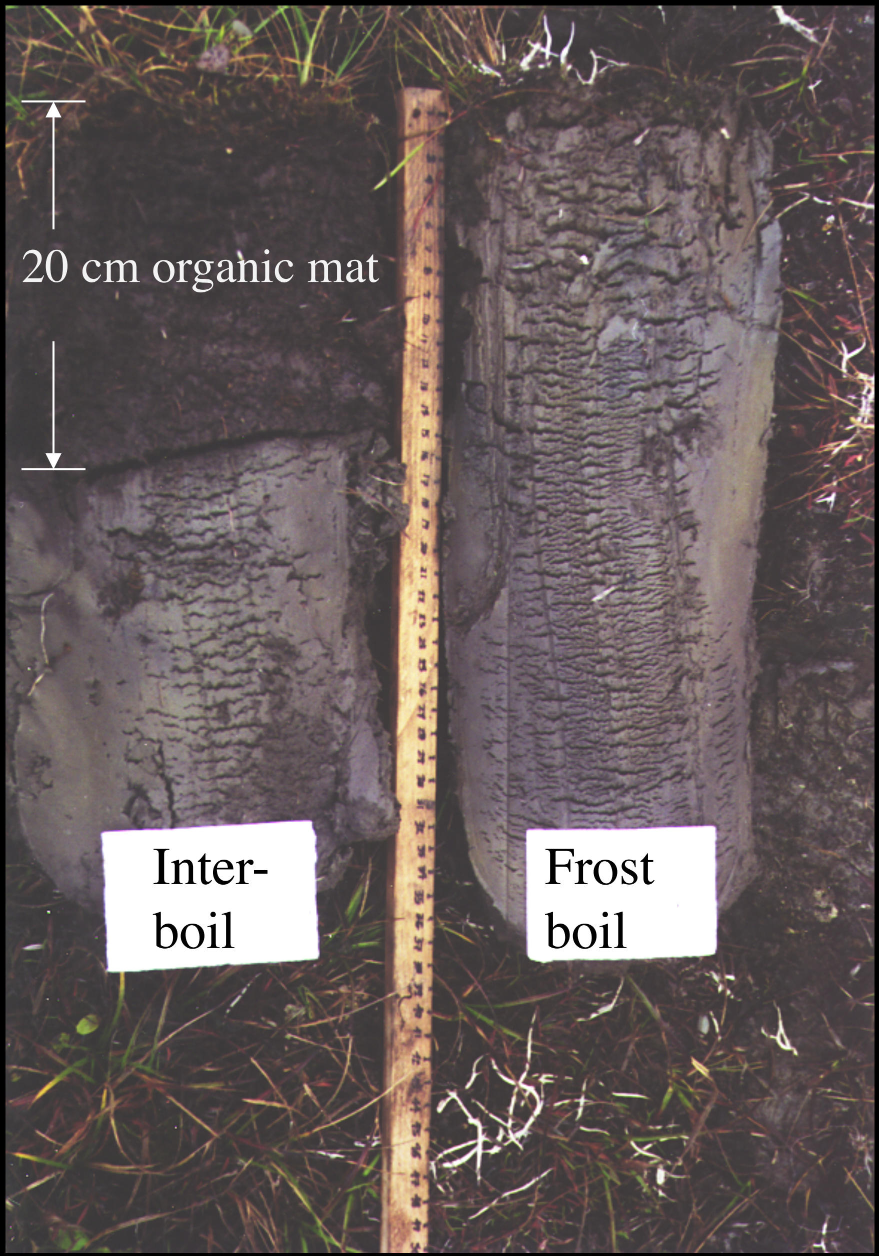


Photo: D.A. Walker

Differential frost heave: a function of the number of and size of ice-lenses

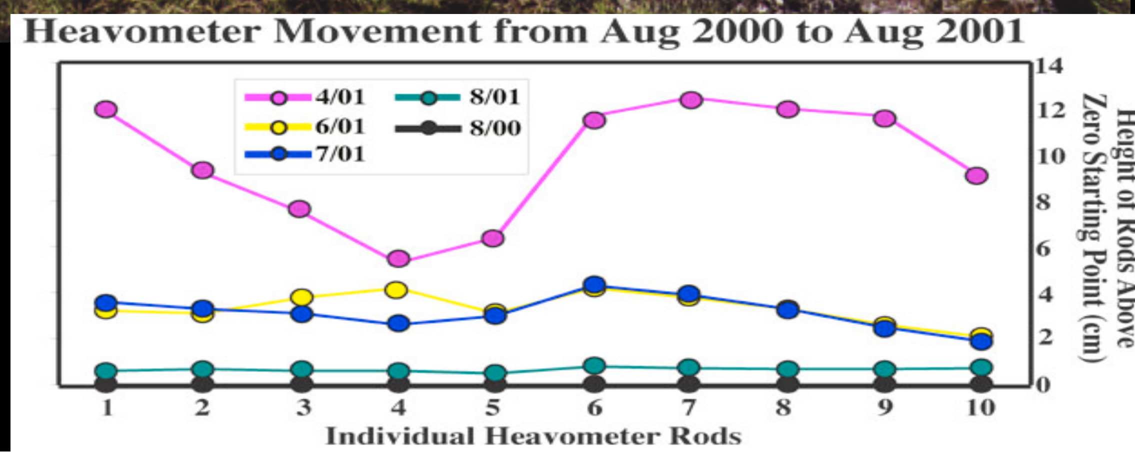


- Deep organic layer of inter-frost-boil areas insulates the soil reducing the active-layer thickness and hence the number of lenses and the amount of heave.

Photo: D.A. Walker

Measuring differential frost heave

Vlad Romanovsky: Proud inventor of heavometer



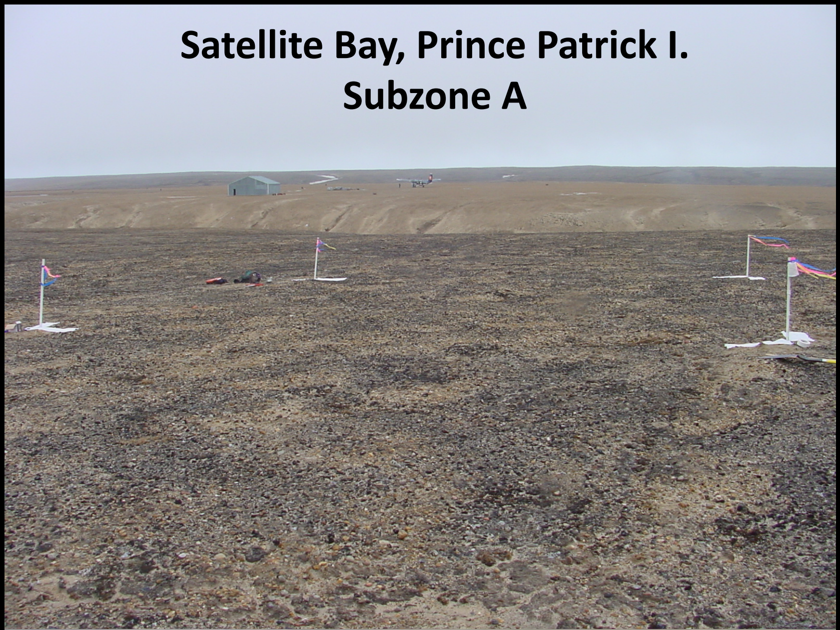
Cryostatic suction may pull water from the interboil areas to increase the amount of heave in the frost boil.

Non-sorted circles

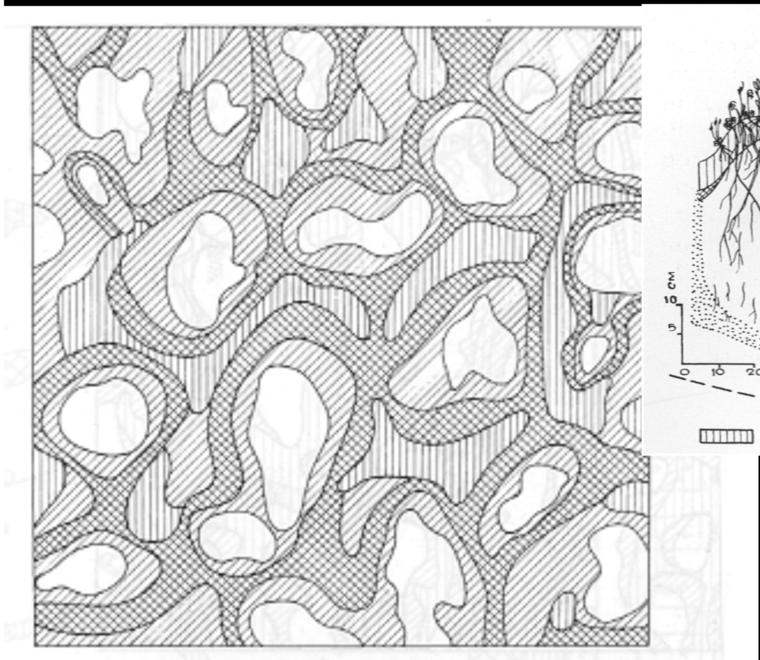
- 1-3 m diameter circles caused by frost heave.
- Ubiquitous feature of landscapes in northern tundra areas.
- Result in patchy landscapes,

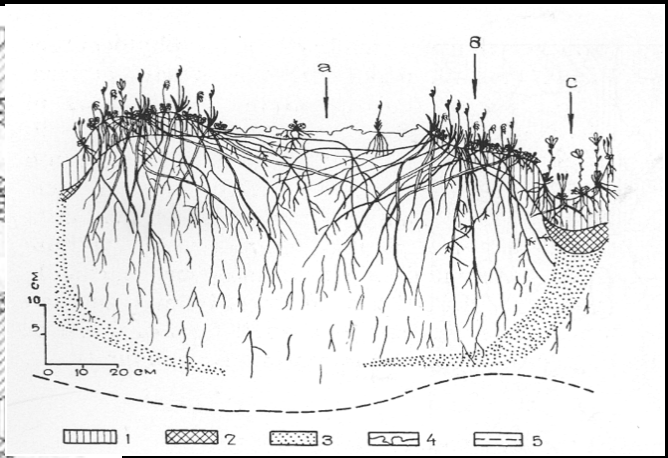
Aerial photo: Nonsorted circles, southern Yamal Peninsula, Subzone E, 2009
Insert: Prudhoe Bay, AK, subzone D, 1971.
Photos: D.A. Walker

Examples of frost boils and hummocks in different climates



Vegetation on frost boils





- Matveyeva - Russia, Taimyr Peninsula
- Steere - Alaska, bryophytes

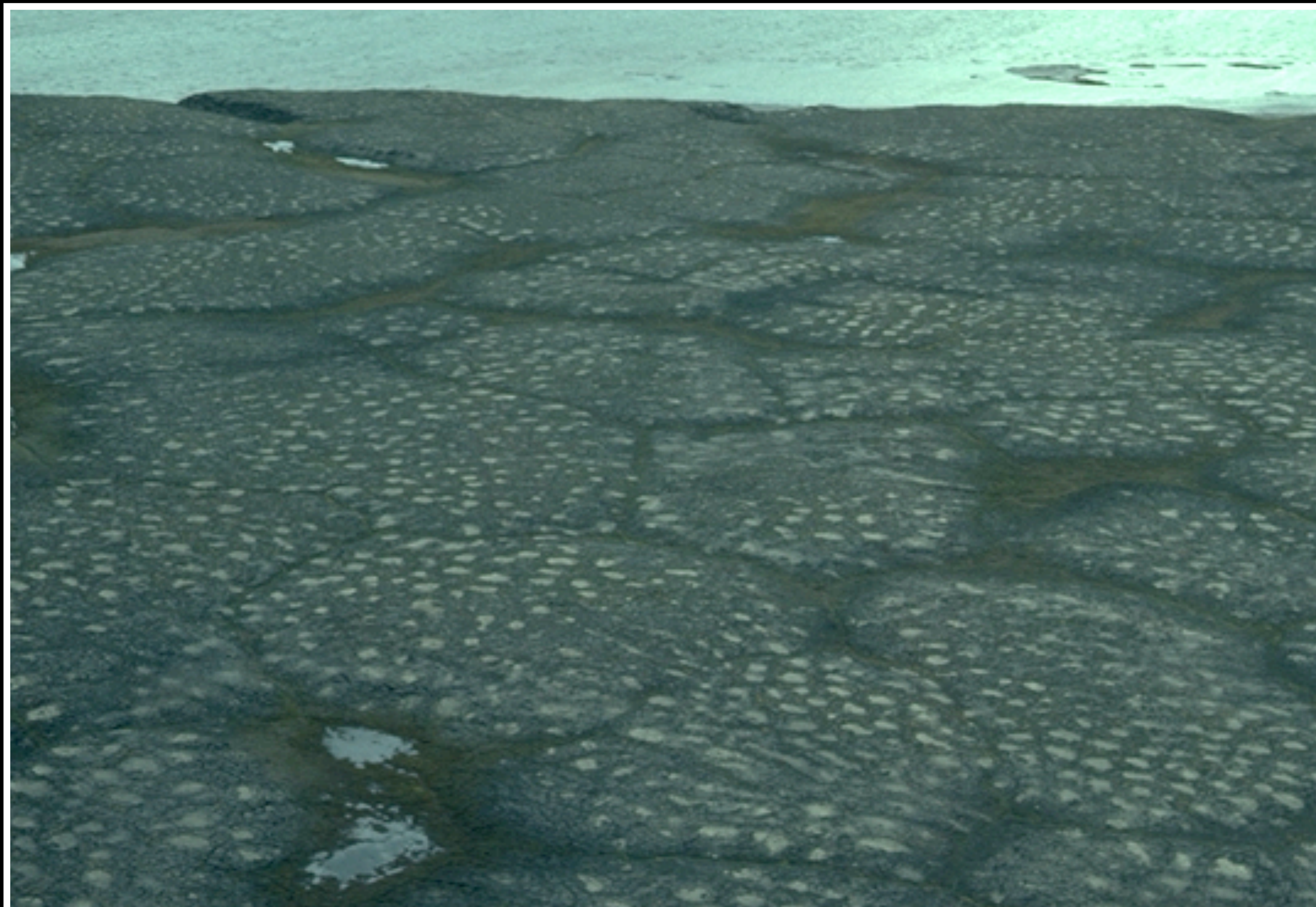
Bill Steere collecting *Bryum wrightii* on a frost boil at Prudhoe Bay
Photo: D. A. Walker, July, 1971.

Soils of nonsorted circles

- Thinner O horizons
- 10-20 cm of heave within the circles, compared to less than 5 cm between the boils.
- Fewer plants
- Greater heat flux
- Deeper active layers
- Carbon sink between circles

Ostrov Belyy, Russia, Subzone B/C
Photos: D.A. Walker

Patterned ground

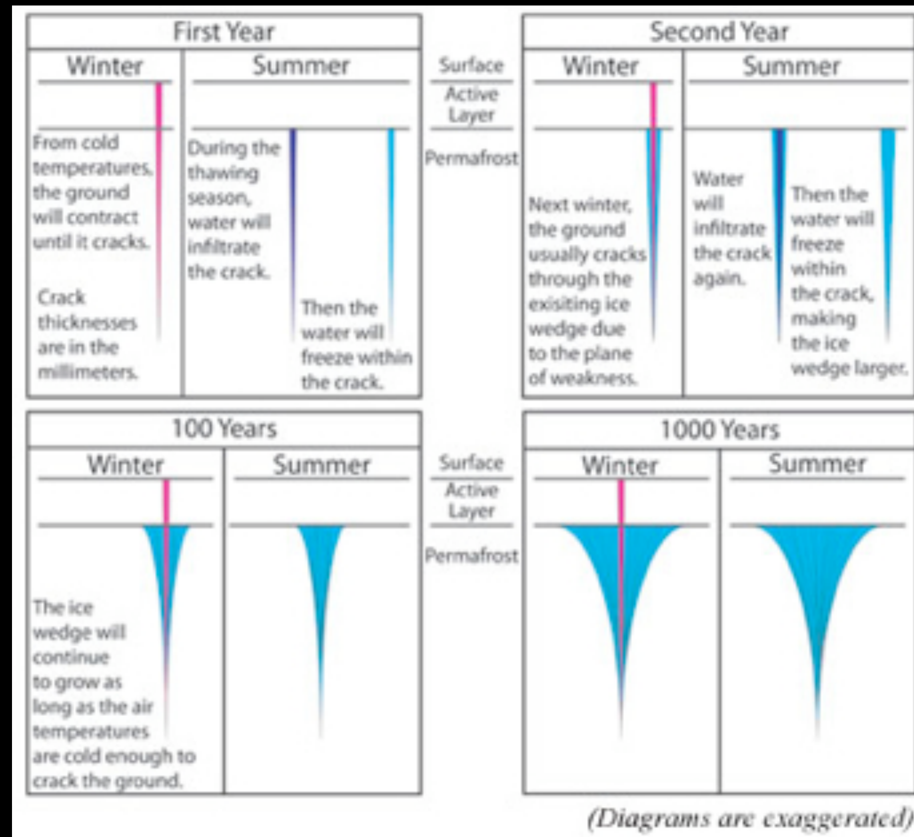


Non-sorted circles on flat ice-wedge polygons
Howe Island, northern Alaska
Photo: D.A. Walker

Patterned ground: ice-wedge polygons

Prudhoe Bay vicinity, Alaska, Photo: D.A. Walker

Ice wedge



From: U.S. Army CRREL Permafrost Tunnel website: http://permafrosttunnel.crrel.usace.army.mil/permafrost/massive_ice.html.

From: Washburn A L 1980 Geocryology: A Survey of Periglacial Processes and Environments (New York: Halsted Press, John Wiley and Sons) 406 pp.

Thermal contraction-crack analogue: desiccation cracks

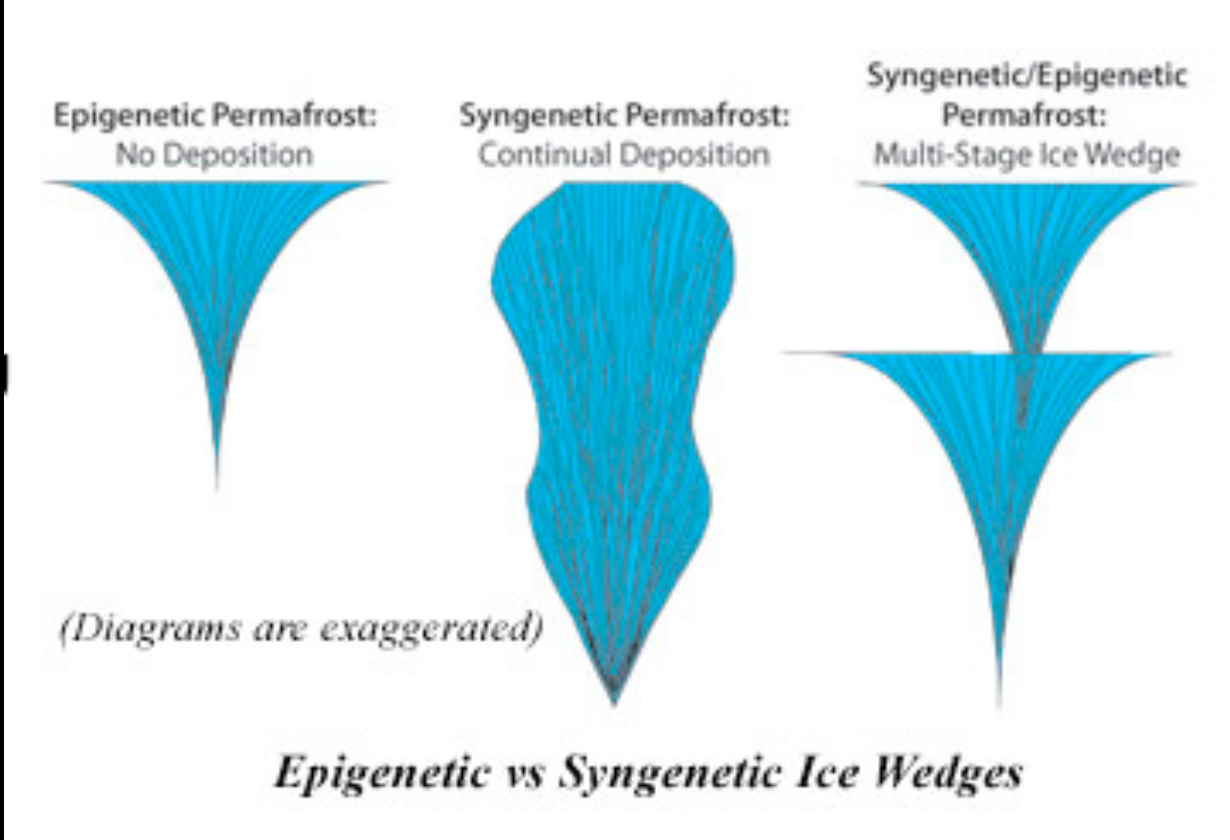
Desiccation cracks in organic sediments in drained thaw-lake basin, Prudhoe Bay, Alaska. Photo: D.A. Walker

Epigenetic vs. syngenetic permafrost

Epigenetic permafrost: forms <u>after</u> soils are deposited by wind, water, and/or gravity through the thousands of years of geological action, and after are subjected to a colder climate causes freezing and creates permafrost.

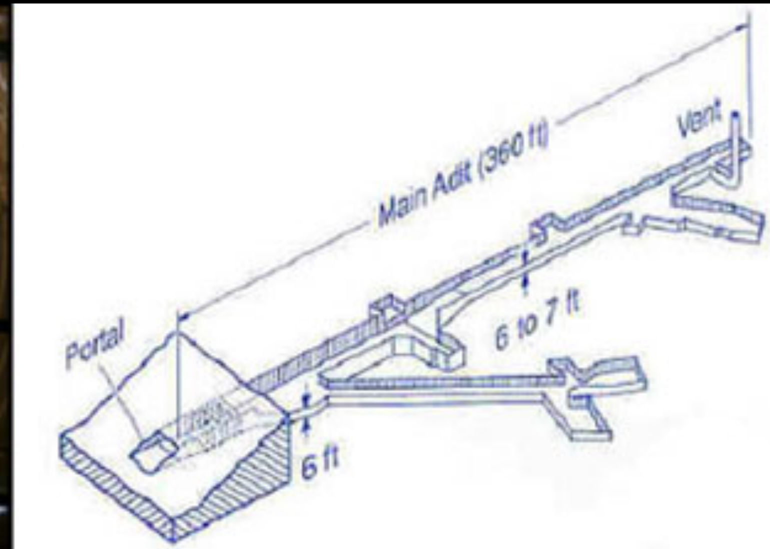
Syngenetic permafrost occurs <u>as</u> the soils are being emplaced by wind, water, and/or gravity.

The segregated ice and other ice features that are created at the base of the active layer can become captured as the sediments accumulate and will then exist throughout of the depth of the syngenetic permafrost layer.



Courtesy of US Army CRREL Permafrost Tunnel Research Facility: http://permafrosttunnel.crrel.usace.army.mil/permafrost/climate_change.html

CRREL Permafrost Tunnel



- Goldstream Creek, 16 miles north of Fairbanks in Fox.
- 110 meters in length, 2 to 2.5 meters high, 4 to 5 meters wide, and 15 meters below the surface.
- Good place to observe syngenetic ice features.

Courtesy of US Army CRREL Permafrost Tunnel Research Facility: http://permafrosttunnel.crrel.usace.army.mil/permafrost/climate_change.html

Low-centered ice-wedge polygons

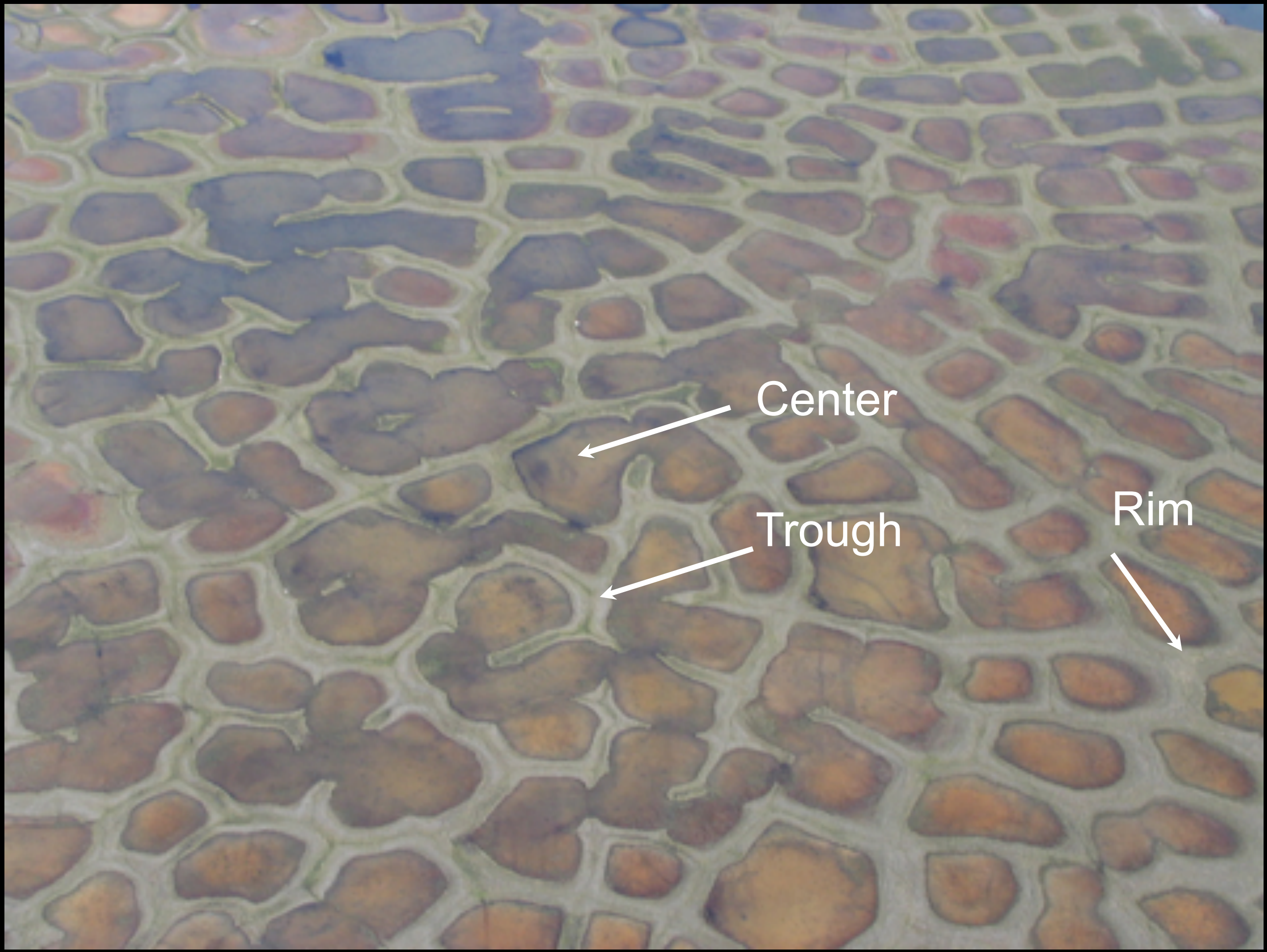
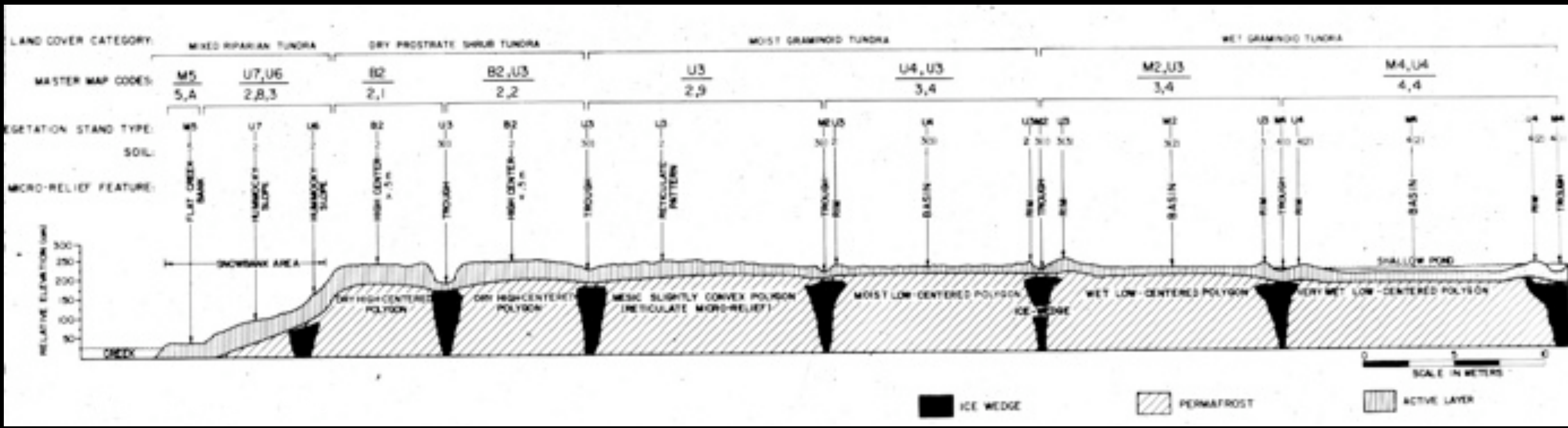


Photo: D.A. Walker

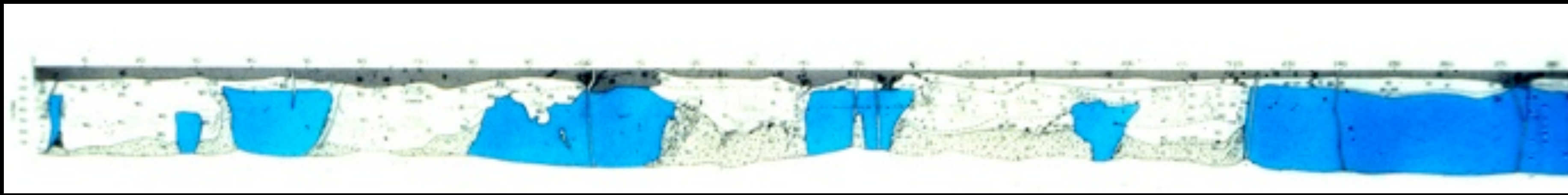
- Centers: wet tundra or water.
- Rims: moist tundra, soil displaced by the ice wedge.
- Troughs: wet cracks between rims, position of ice wedge.

Ice wedges in relation to microtopography

Idealized cross section through ice-wedge polygons showing the position of the ice-wedge in relation to microtopographic elements

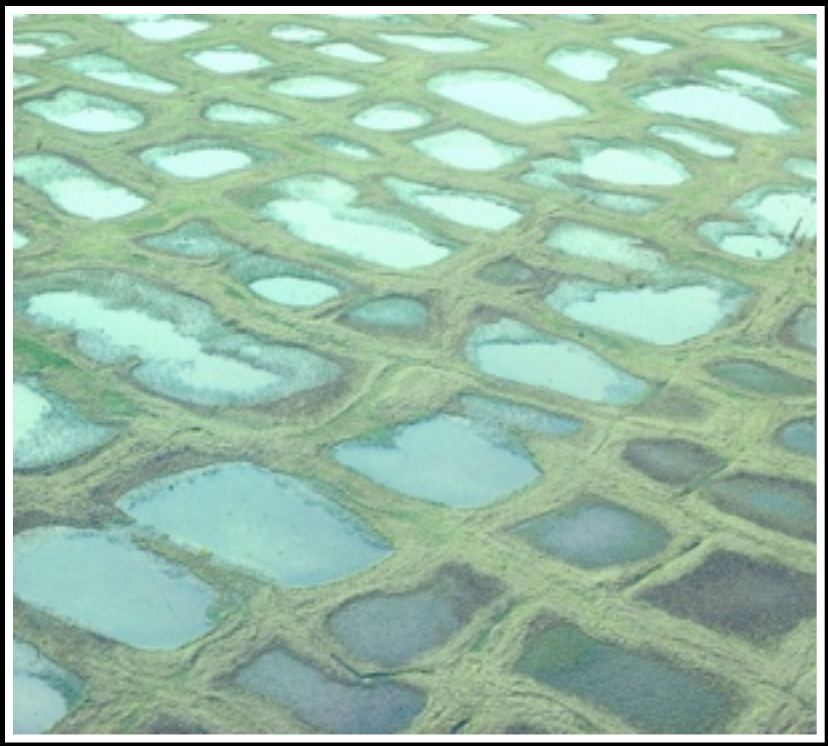


Schematic of an actual 300-m trench through ice-wedge polygons showing the areas of massive ground ice (blue)



Based on Walker D A and Everett K R 1991 Loess ecosystems of northern Alaska: regional gradient and toposequence at Prudhoe Bay Ecological Monographs 61 437-464 doi/abs/10.2307/2937050

Vegetation patterns associated with ice-wedge polygon terrain



Low-centered polygons,
Kuparuk River Delta, Alaska

Friophorum angustifolium,
in troughs of flat-centered polygons,
Arctic Foothills, Alaska

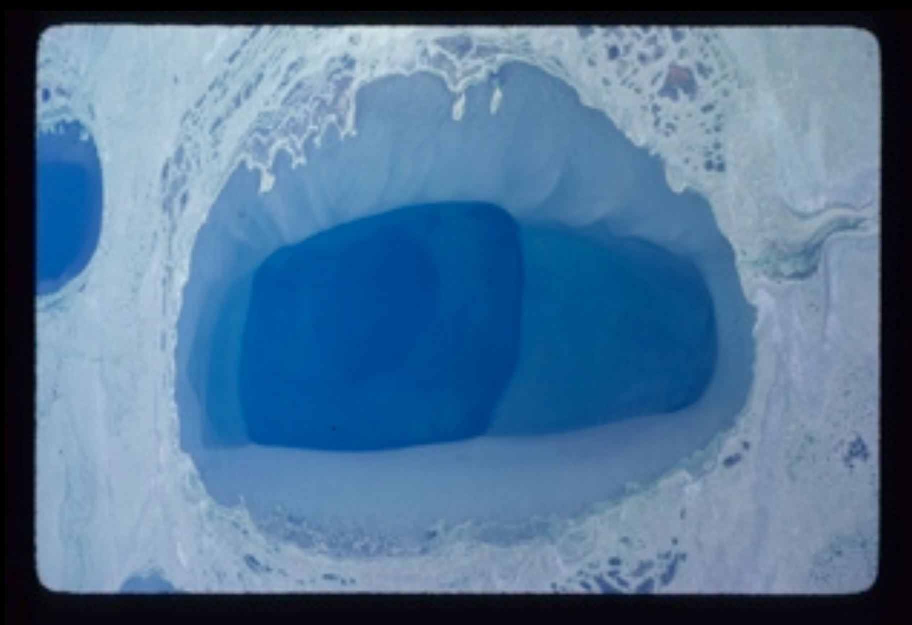
Photos: D.A. Walker

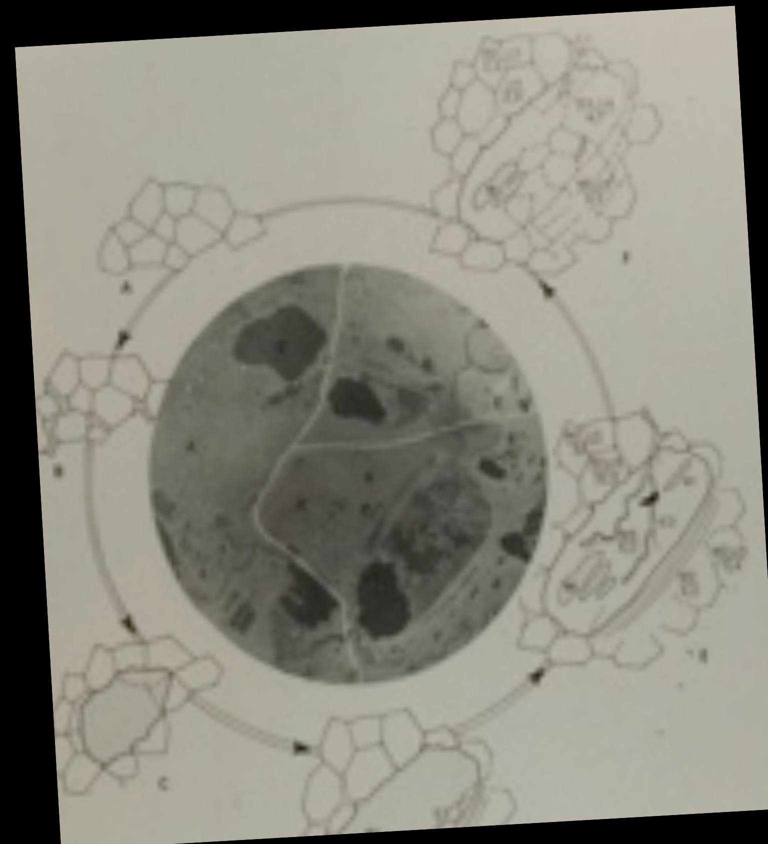
Thermokarst formation

Photos: D.A. Walker

- Thermokarst: Depressions formed by the melting of permafrost.
- Thermokarst "pits": Commonly form at the intersection of ice wedges.
- Ice wedge melting: Caused by bulldozing of vegetation mat, altering the flux of heat into the wedge.

Thaw lakes

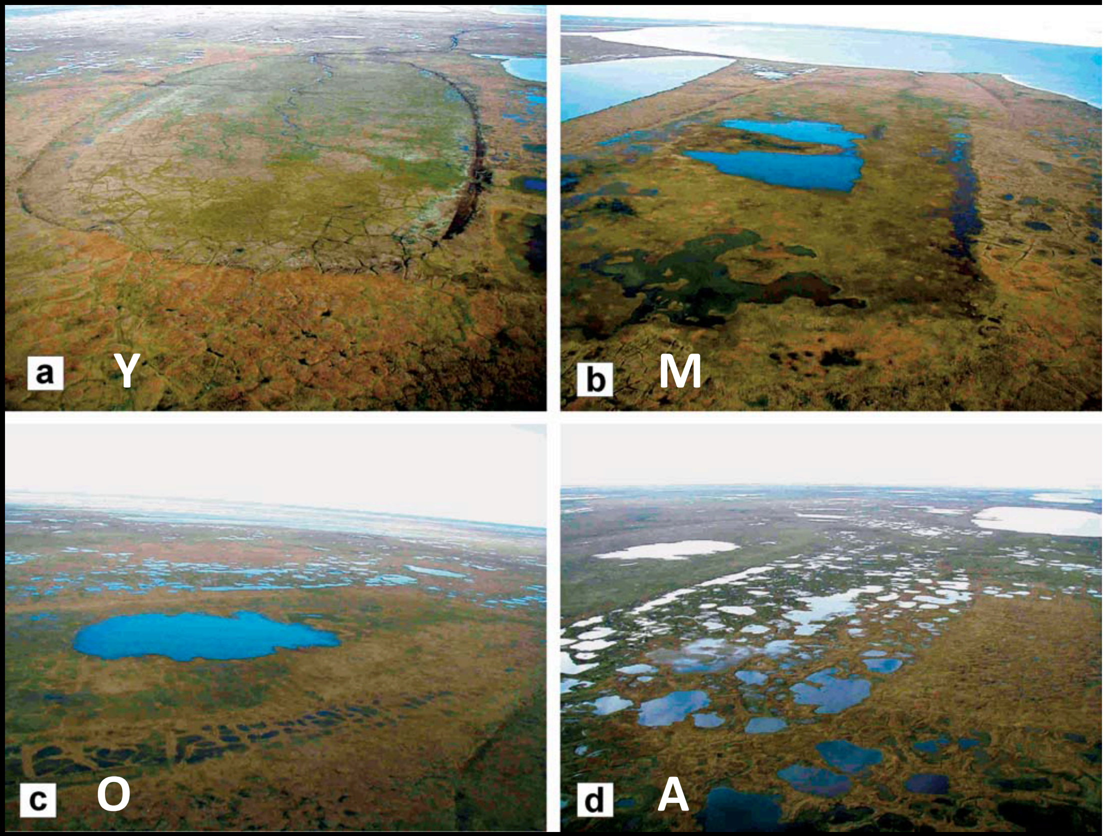


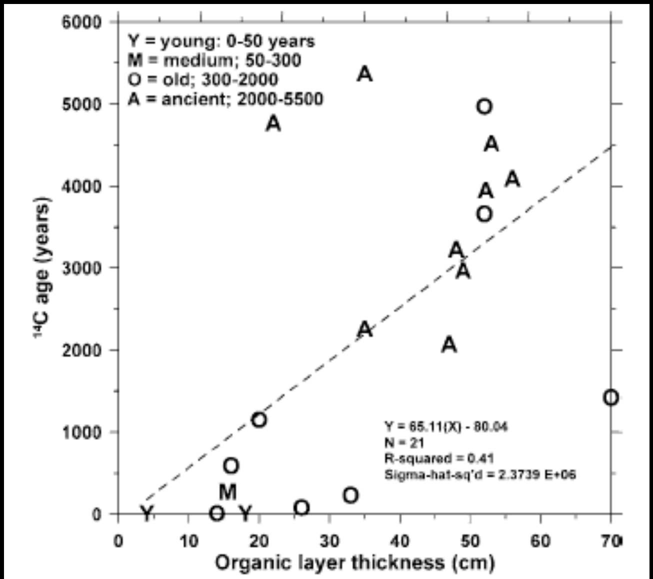


Cycle as shown was described by Britton and others and probably does not commonly occur.

Photos: Top: Courtesy U. of Lapland, Arctic Studies Program, http://arcticstudies.pbworks.com/w/page/13623327/Thermokarst/ bottom: D.A. Walker, Right: Walker et al. 1981. Prudhoe Bay Geobotanical Atlas.

Oriented thaw lakes

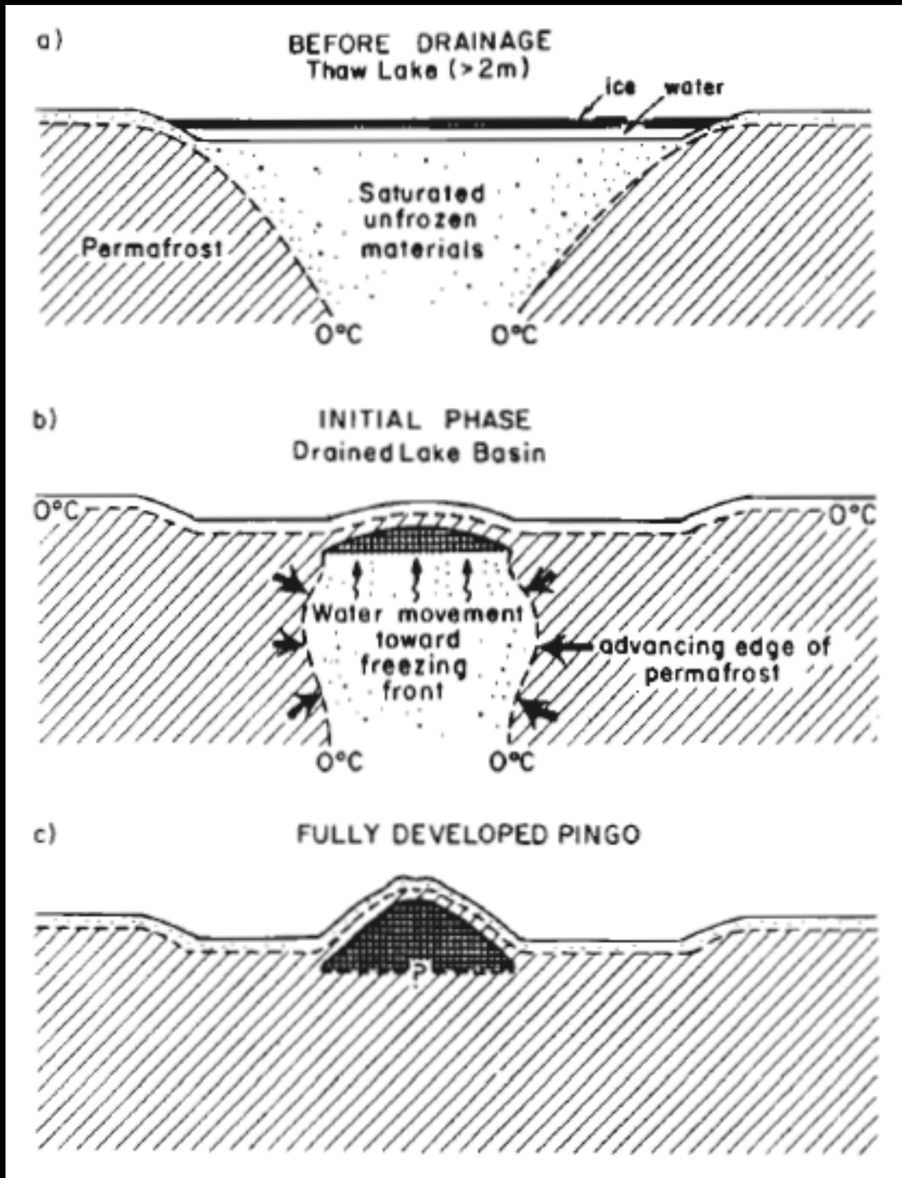




Hinkel, K.M. et al. 2003. Spatial extent, age and carbon stocks in drained thaw lake basins on the Barrow Peninsula, Alaska. AAAR 35: 291-300

High centered polygons formed by enhanced drainage of low-centered polygons on a pingo

Pingo formed in middle of network of low-centered polygons, http//wikipedia.ord/wiki/File melting pingo wedge ice.



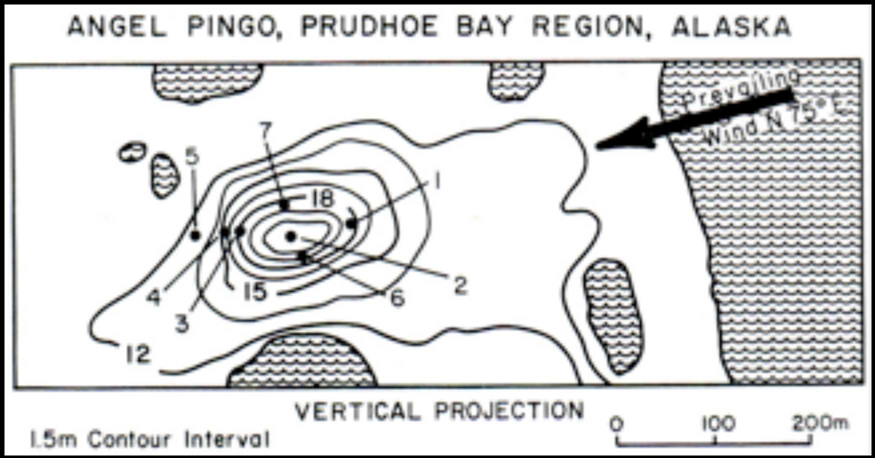
K.R. Everett 1980. Landforms. In: Walker et al. Geobotanical Atlas of the Prudhoe Bay Region. CRREL Report 80-41.

Closed-system Pingo formation

a. Lake with ice and layer of unfrozen water, which creates with an area of unfrozen sediments (Talik) beneath the lake.
b. After drainage of the lake and exposure of sediments to cold winter climate, the lake bottom begins freezing.
c. A pingo may develop in part of the lake basin with latest freezing sediments.
    - A ice lens forms.
    - As water moves to the freezing front of the lens, the surface begins to bulge.
    - The lens continues to grow forming the pingo.

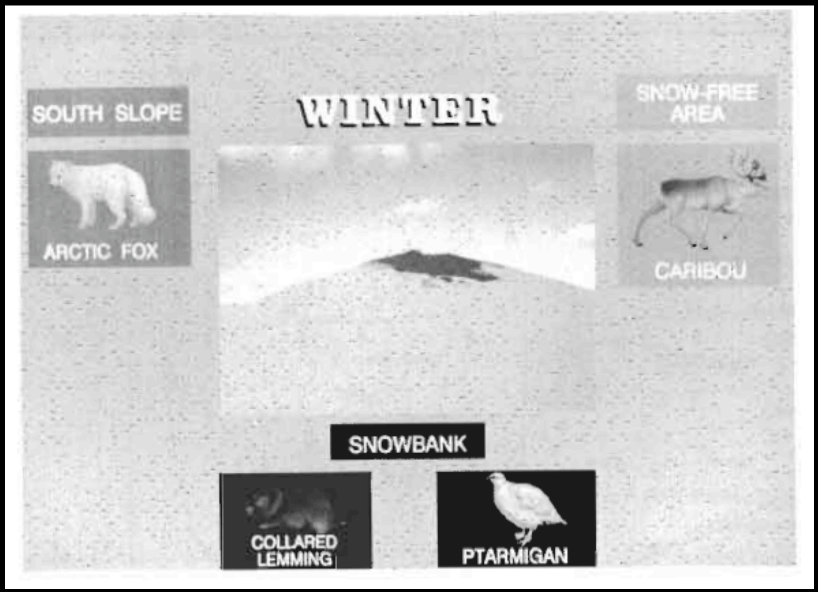
Vegetation studied in 7 habitats on 41 pingos of northern Alaska by M.D. Walker

Walker, DA et al. 1985. Pingos of the Prudhoe Bay area, Alaska. AAR 17: 321-336



1. ENE wind-exposed crest.
2. Summit (usually site of animal dens and bird perches),
3. Dry leeward side above the snowbank,
4. Middle of snowbank on leeward side (well drained),
5. Bottom of snowbank at leeward base of pingo (poorly drained),
6. South slope, diverse steppe tundra comm.
7. North slope. Sites 2, 3, 4 and 5 formed a toposequence (M.D. Walker 1990).

Habitats on a typical pingo



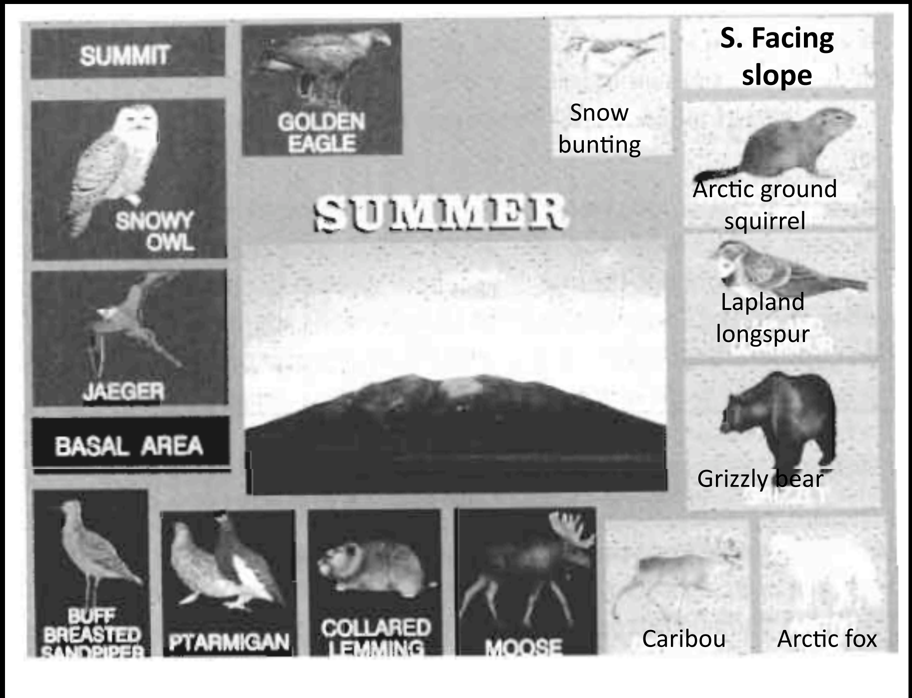


Figure 69. Mammals and birds that use pingos in summer. (Illustrations Burt and Grossenheider [1976] and Robbins et al. [1983].)

- **Study described the microclimates, soils, floristics, plant communities, plant succession, and animal occurrence on 41 pingos.**
- **20 distinctive plant communities were characteristic of the habitats.**

Walker, M.D. 1990. Vegetation and floristics of pingos, Central Arctic Coastal Plain, Alaska. *J. Cramer. Stuttgart, Germany. 149.* 283 pp .

Effects of topography: Toposequences

Imnavait Creek, Subzone E, northern Alaska,
Photo: D.A. Walker

Toposequence or "catena"

Catena (from Latin: "Chain")

- "…a mapping convenience…a grouping of soils which while they fall wide apart in a natural system of classification on account of fundamental and morphological differences, are yet linked in their occurrence by conditions of topography and are repeated in the same relationship to each other wherever the same conditions are met with" (Milne 1935) cited in (Warkentin 2006).

Other terms

Hill slope gradient, mesotopographic gradient (Billings 1973), ecohydrological gradient (de Molenaar 1987), synthetic alpine slope model (Burns and Tonkin 1982)

Typical Subzone C toposequence, Banks Island, Canada

Ellesmere Island, East Wind Lake vicinity
Photo: D.A. Walker

1. Hill crest: Dry barrens with scattered forbs, sedges, lichens

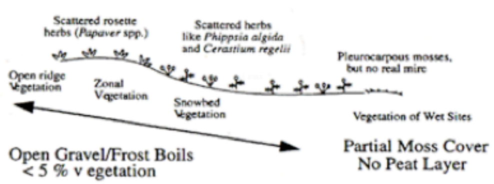
2. Upper backslope: Dry polygons and stripes with Dryas

3. Lower backslope: Zonal vegetation, Cassiope tetragona community

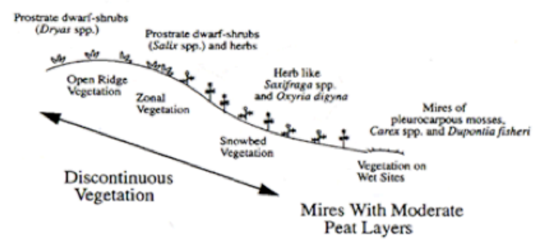
4. Footslope: Wet meadow

Idealized toposequences in each subzone

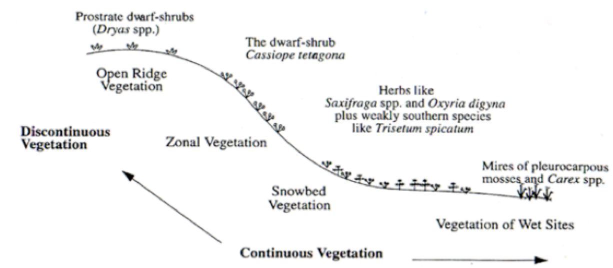
Subzone A



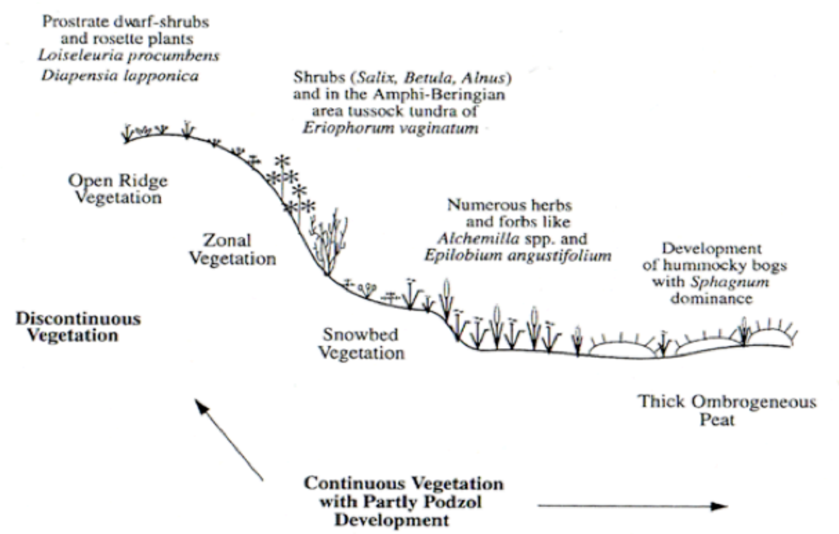
Subzone B



Subzone C

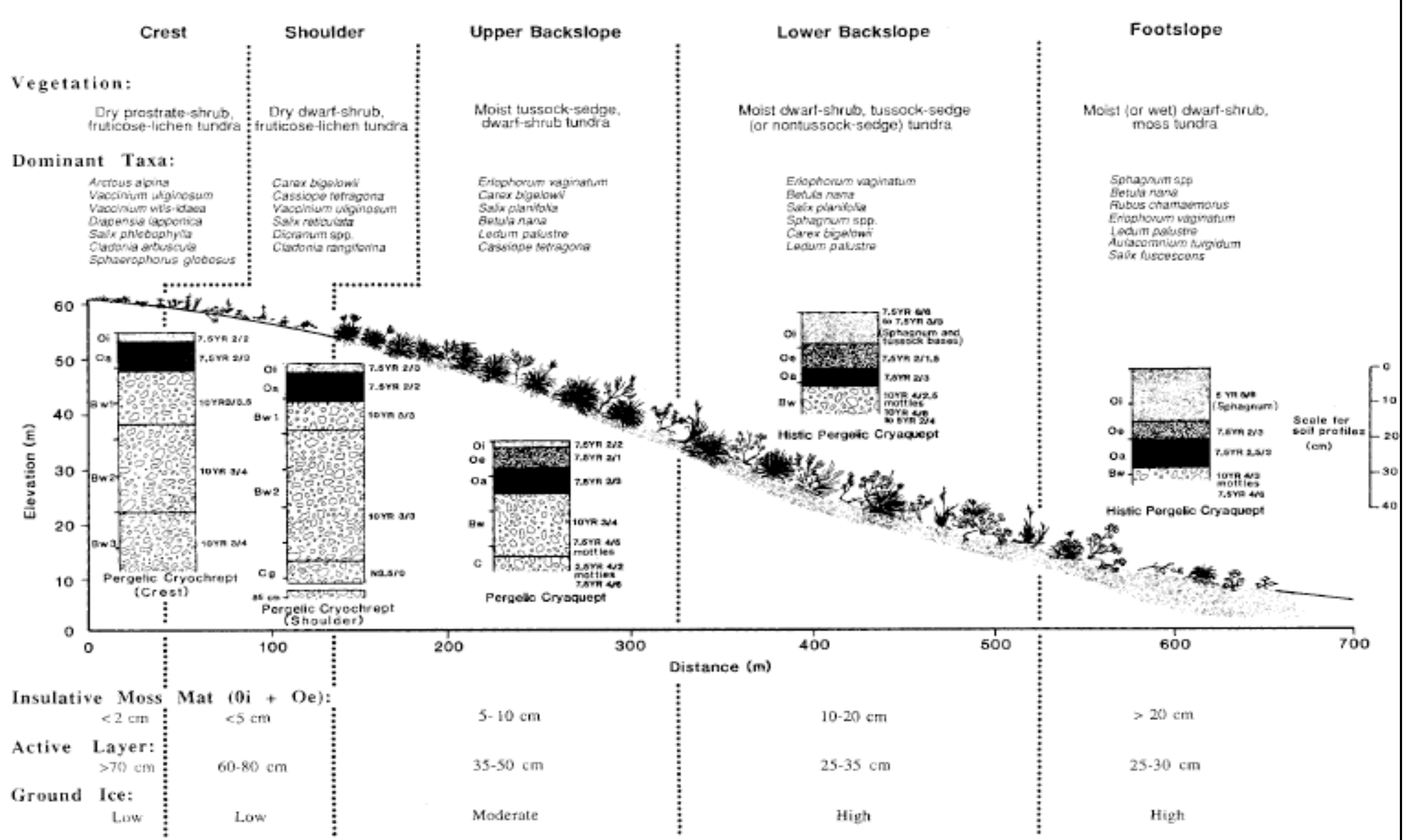


Subzone E



Based on Elvebakk A 1999 Bioclimatic delimitation and subdivision of the Arctic The Species Concept in the High North - A Panarctic Flora Initiative (Oslo: The Norwegian Academy of Science and Letters) 81-112

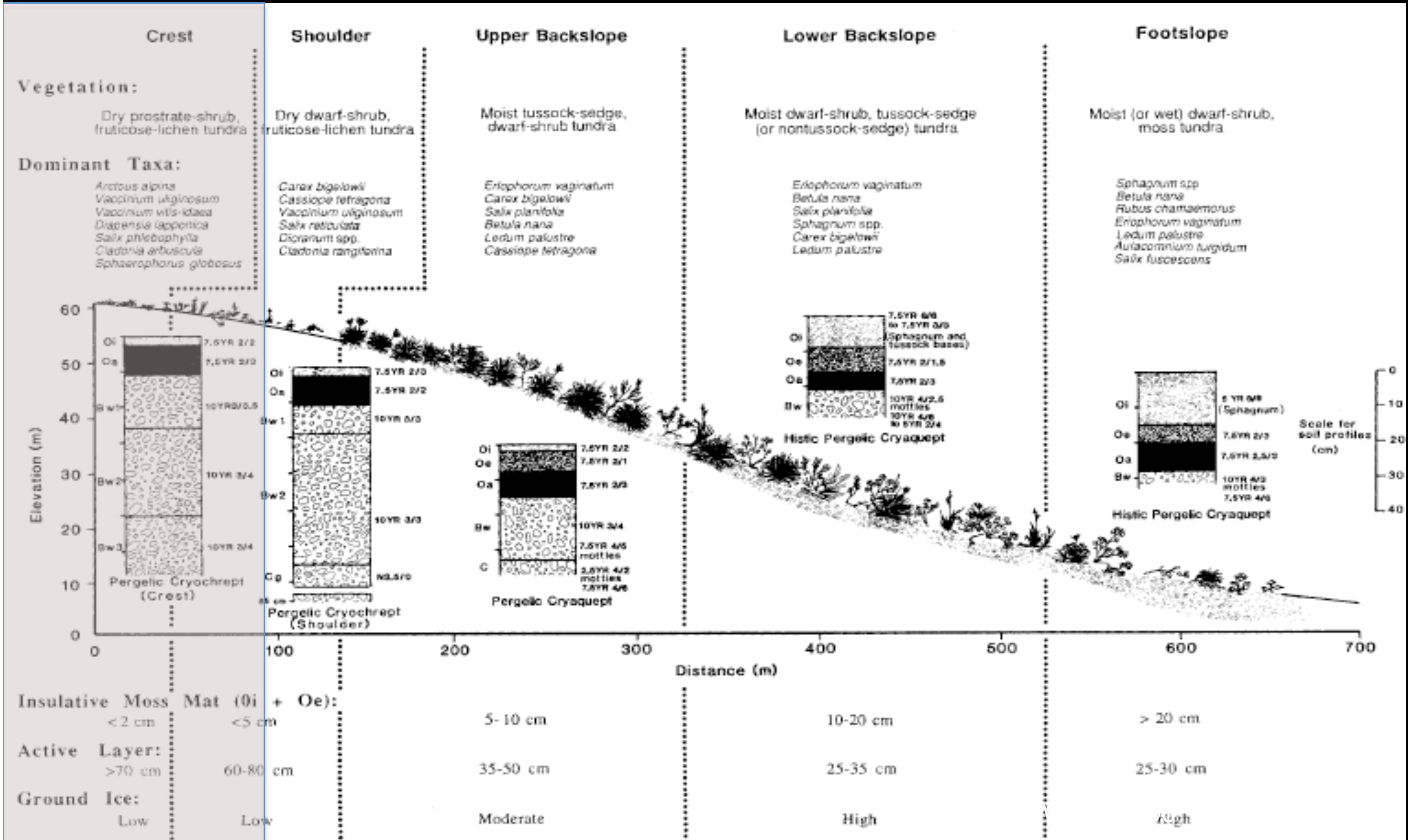
Subzone E, Imnavait Creek, AK toposequence



Walker, D.A., Walker, M.D. 1996. Terrain and vegetation of the Imnavait Creek Watershed. **in** *J. F. Reynolds, J. D. Tenhunen (eds.) Landscape Function: Implications for Ecosystem Disturbance, a Case Study in Arctic Tundra.* Springer-Verlag. New York. 120 pp. 73-108.

Photo: D.A. Walker

Subzone E, Imnavait Creek, AK toposequence



Walker, D.A., Walker, M.D. 1996. Terrain and vegetation of the Imnavait Creek Watershed. **in** *J. F. Reynolds, J. D. Tenhunen (eds.) Landscape Function: Implications for Ecosystem Disturbance, a Case Study in Arctic Tundra*. Springer-Verlag. New York. 120 pp. 73-108.

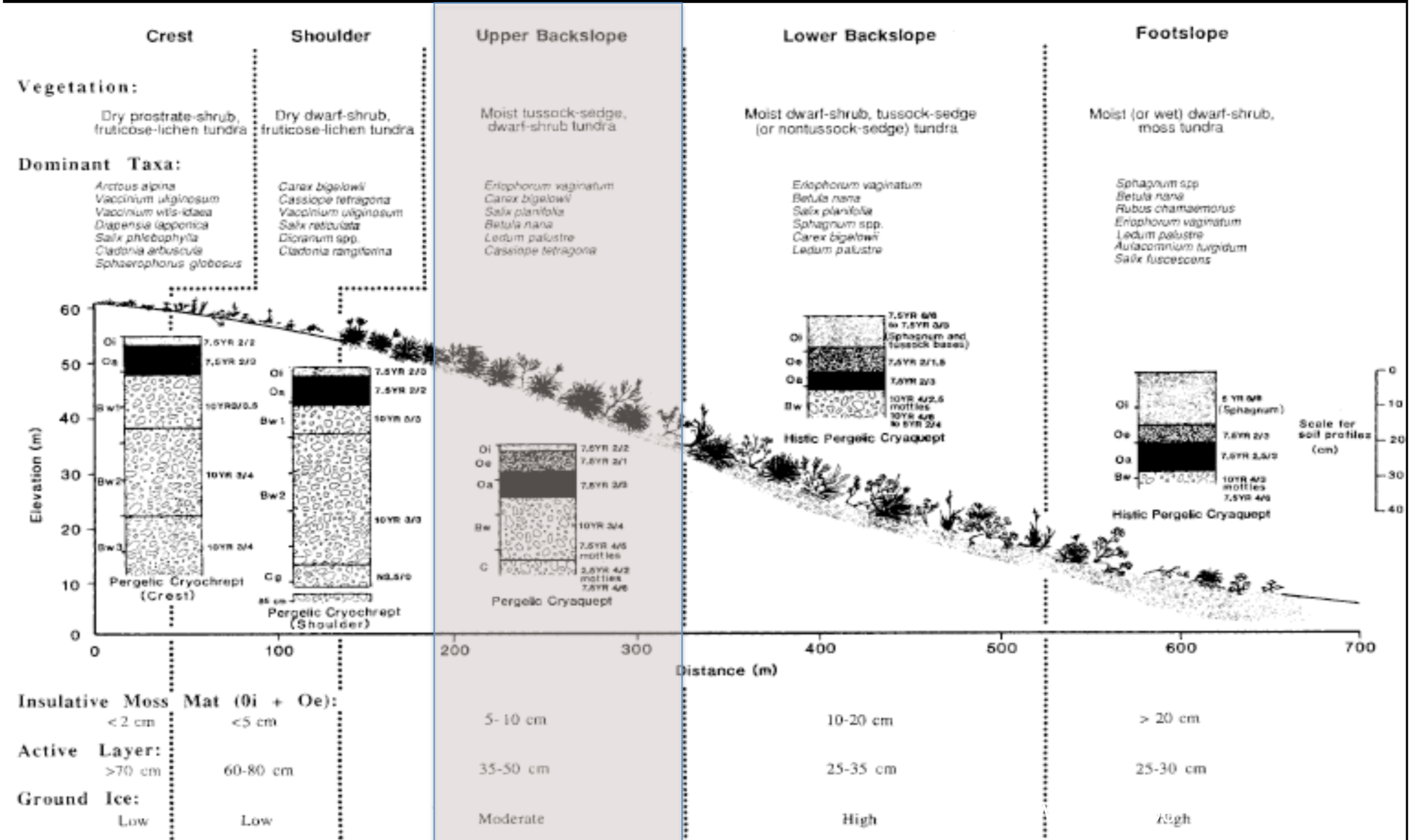
Imnavait Creek: hill crest

Photo: D.A. Walker

Hill crest soil: Pergelic Cryochrept

Photo: D.A. Walker

Subzone E, Imnavait Creek, AK toposequence



Walker, D.A., Walker, M.D. 1996. Terrain and vegetation of the Imnavait Creek Watershed. **in** *J. F. Reynolds, J. D. Tenhunen (eds.) Landscape Function: Implications for Ecosystem Disturbance, a Case Study in Arctic Tundra*. Springer-Verlag. New York. 120 pp. 73-108.

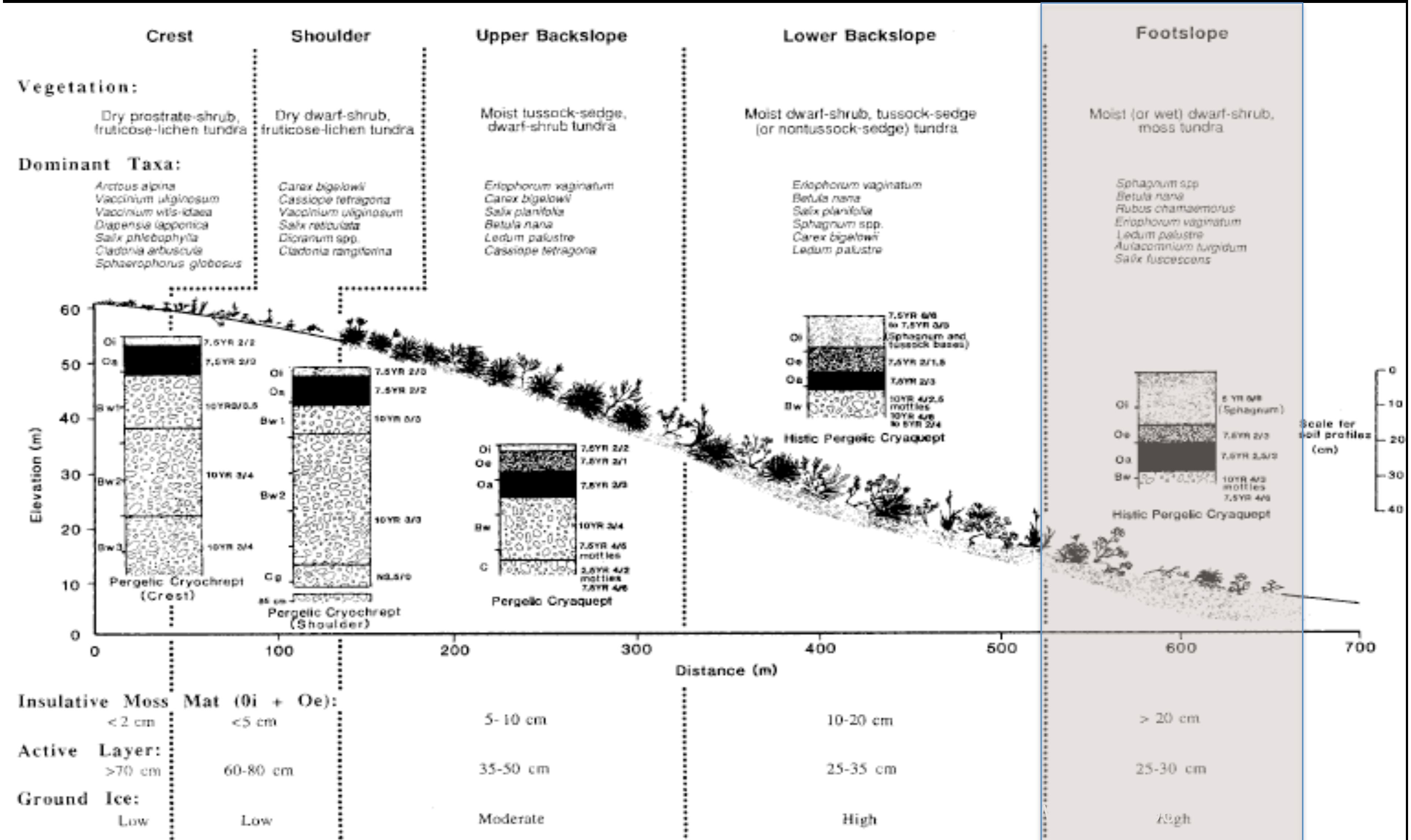
Imnavait Creek: backslope vegetation

Photo: D.A. Walker

Backslope soil: Pergelic Cryaquept

Photo: D.A. Walker

Subzone E, Imnavait Creek, AK toposequence



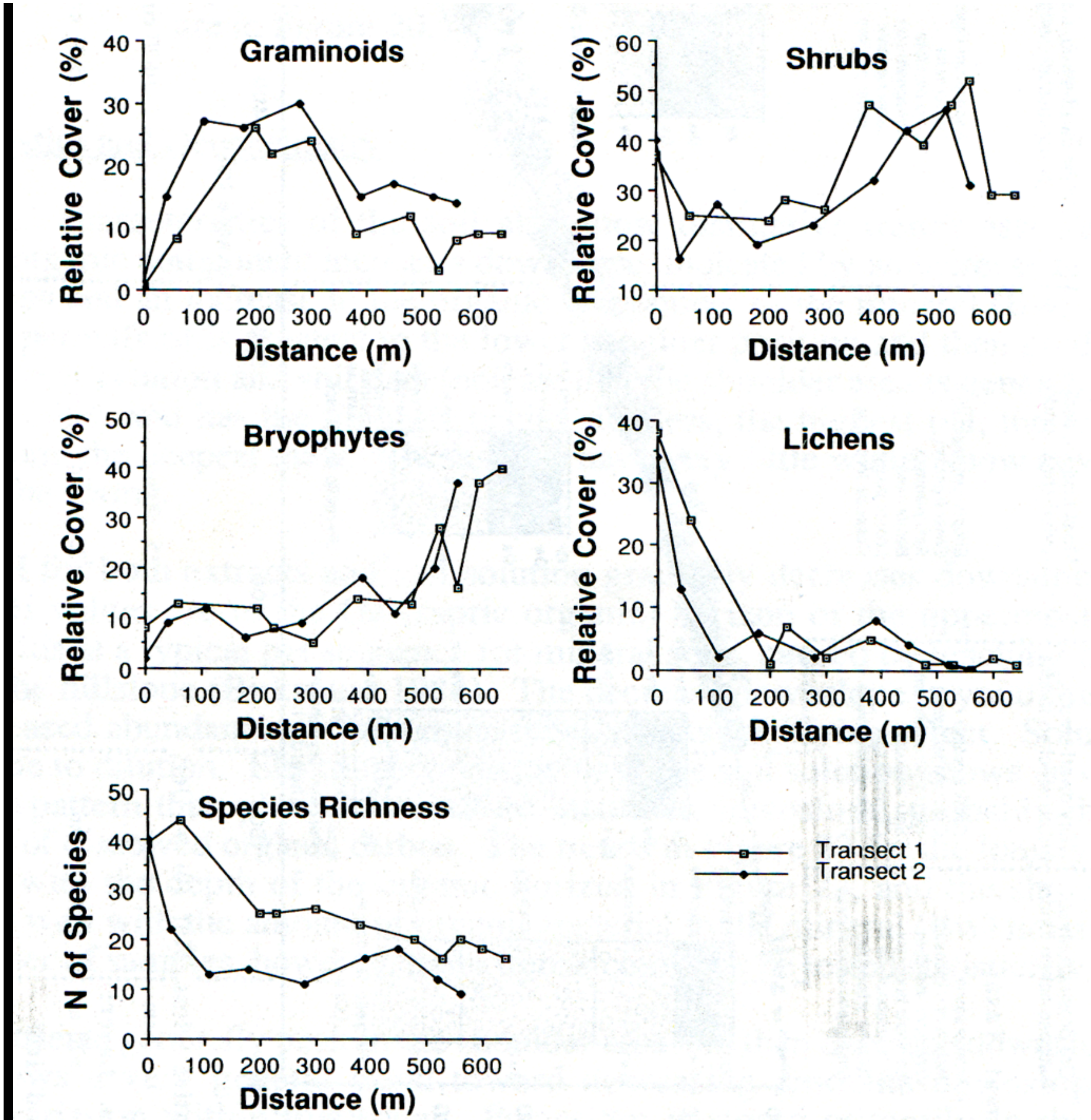
Walker, D.A., Walker, M.D. 1996. Terrain and vegetation of the Imnavait Creek Watershed. **in** *J. F. Reynolds, J. D. Tenhunen (eds.) Landscape Function: Implications for Ecosystem Disturbance, a Case Study in Arctic Tundra*. Springer-Verlag. New York. 120 pp. 73-108.

Imnavait Creek: toe slope vegetation

Photo: D.A. Walker

Toeslope soil: Histic Pergelic Cryaquept

Photo: D.A. Walker



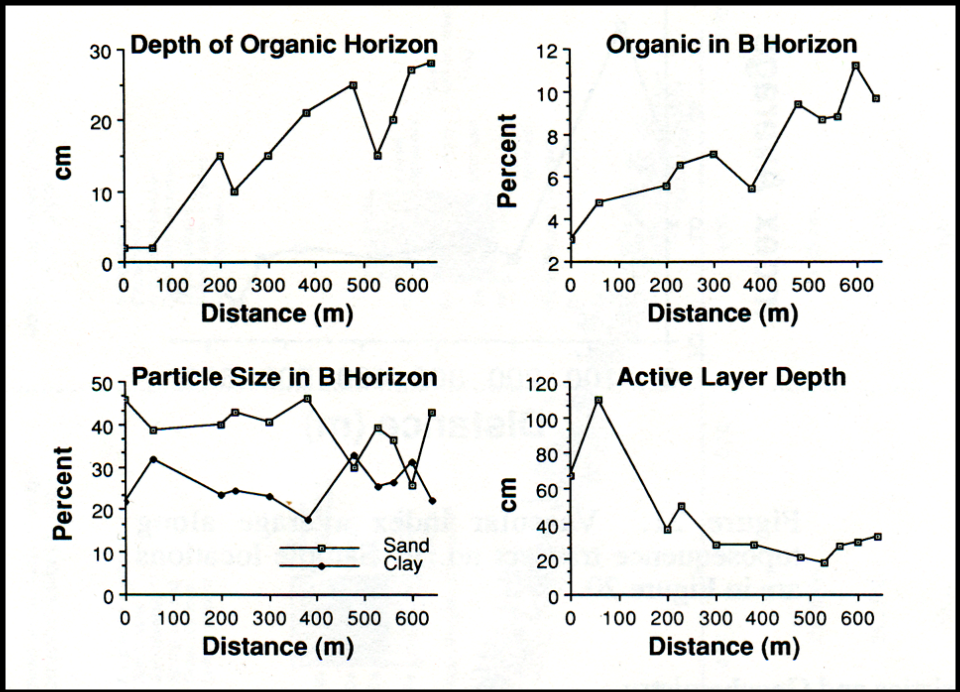
Imnvait Creek Toposequence

Trends in plant functional types and species richness

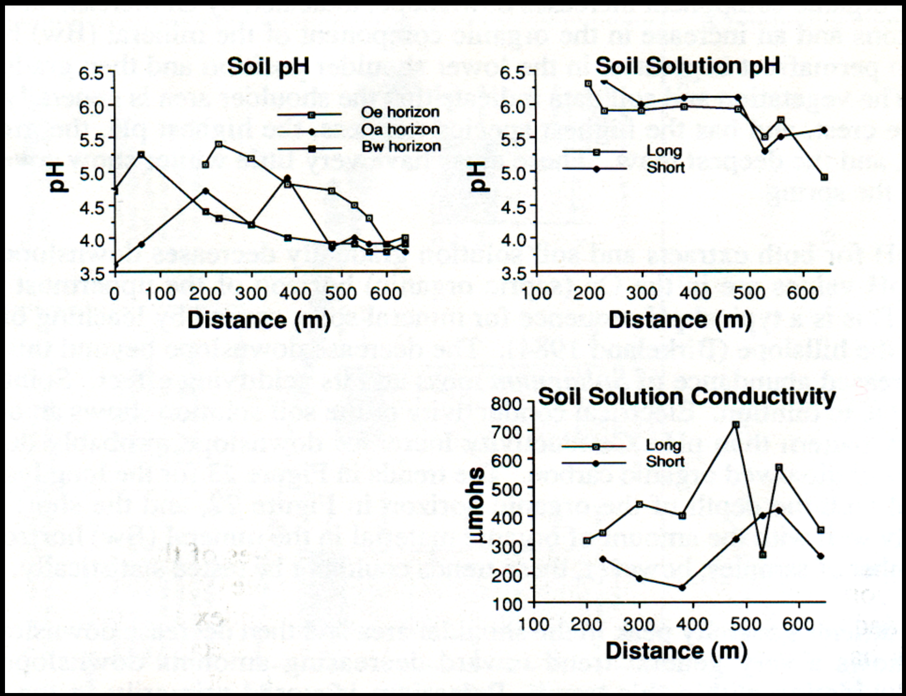
Walker, M.D., D.A. Walker, K.R. Everett. 1989. Wetland soils and vegetation, Arctic Foothills, Alaska. USFWS Biological Report 89(7), 90 pp.

Imnvait Creek Toposequence
Soil properties

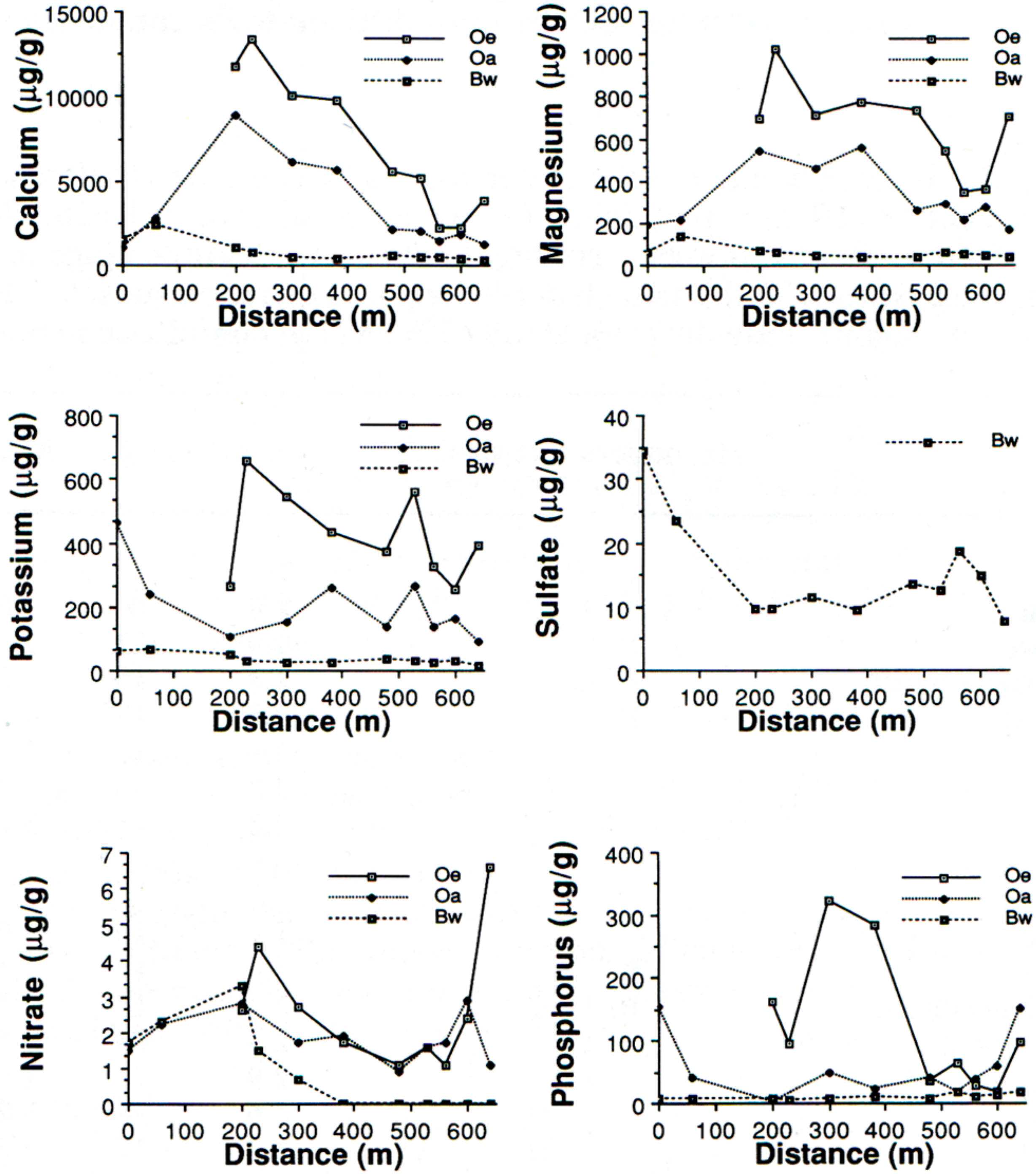
Physical properties



Chemical properties



Walker, M.D., D.A. Walker, K.R. Everett. 1989. Wetland soils and vegetation, Arctic Foothills, Alaska. USFWS Biological Report 89(7), 90 pp.



Imnvait Creek Toposequence

Nutrient concentrations

Walker, M.D., D.A. Walker, K.R. Everett. 1989. Wetland soils and vegetation, Arctic Foothills, Alaska. USFWS Biological Report 89(7), 90 pp.

General trends in soil properties downslope in the Low Arctic, Subzone E, acidic tundra on ice-rich permafrost

- Increasing
  - Depth of O horizon
  - Depth of the A horizon
  - Percent clay in the B horizons
  - Soil moisture
  - Ice content in permafrost
- Decreasing
  - Active layer thickness
  - Soil pH (opposite to pattern in temperate regions due to organic soils)
  - Soil nutrients (opposite to pattern in temperate regions due to organic soils)

Take-home points for lecture 3

- Continuous permafrost is a characteristic feature of most of the tundra biome. The interaction between the permafrost and the active layer are highly relevant to Arctic Vegetation. It is important for Arctic vegetation ecologists to understand permafrost terminology related to soil temperatures, differential frost heave, storage of carbon in the permafrost, and periglacial landforms (slides 2-32).
- Permafrost affects the vegetation by such things as as creating unique microhabitats (associated with patterned ground, slides 14-27) and pingos, slides 30-34), soil heave (slides 10-15).
- A shallow active layer maintains saturated soils and cold soils in the rooting zone, and strongly affects nutrient availability, plant productivity and decomposition.
- Vegetation can affect permafrost and active layer through its insulative effect of the plant canopy and organic mat and water-hold properties.
- Topographic gradients (toposequences) of vegetation and soils occur along hill slopes (catenas) and in association with microtopography within networks of patterned-ground features (slides 34-57). Topographic gradients (toposequences) of vegetation vary with bioclimate subzone (slides 36-43).
- The interaction between vegetation and permafrost strongly alters the active layer, hydrology, soil properties and vegetation along typical toposequences (slides 44-57).