Intro to Permafrost: Geology and Microbiology

2013 Svalex Expedition

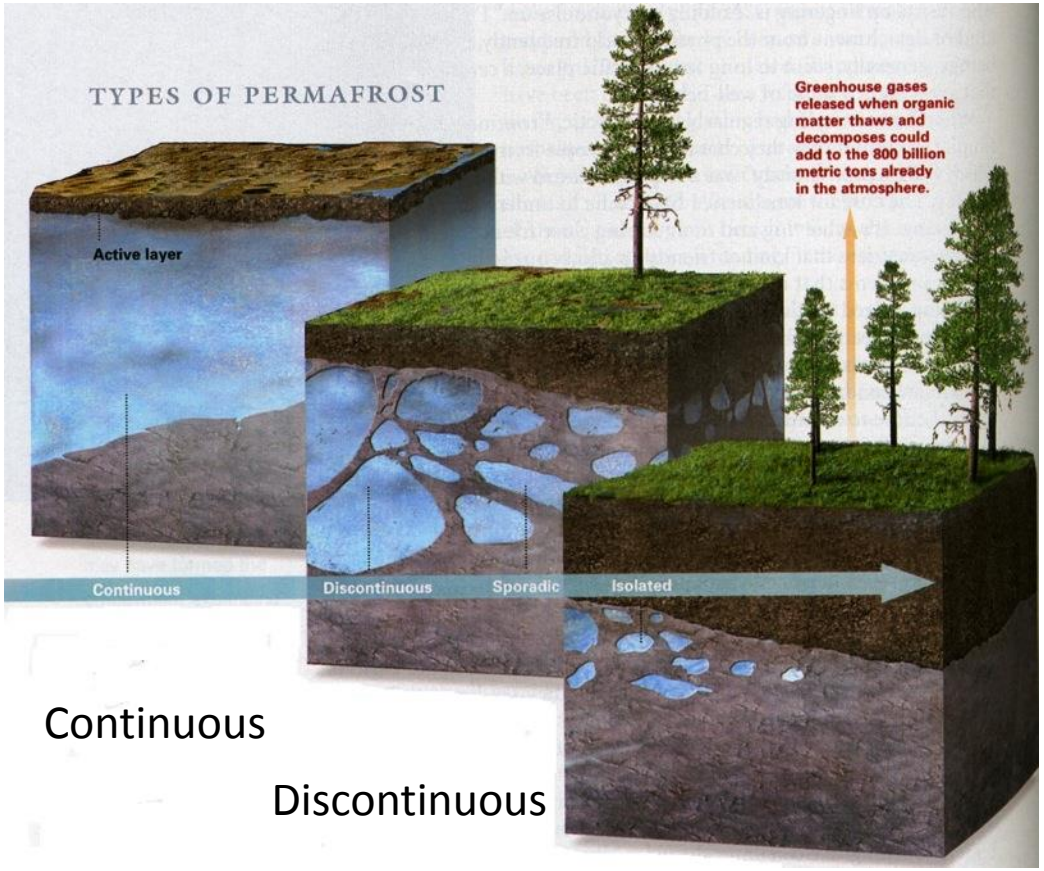
What is Permafrost

- Any rock/soil at or below 0° C for two or more years . Defined solely by temperature
- Permafrost is not defined by soil moisture content, overlying snow cover, or location;
  - Ice is not necessarily present.
- The ‘active layer’ is the overlying surface that freezes in the winter, and thaws in the summer.

permafrost

- Permafrost underlies approximately 22.79 million square kilometers (about 24 percent of the exposed land surface) of the Northern Hemisphere.
- It occurs as far north 84°N in northernmost Greenland, and as far south as 26°N in the Himalayas

Permafrost Primer



Continuous

Discontinuous

Isolated

Skiklomanov [2007]

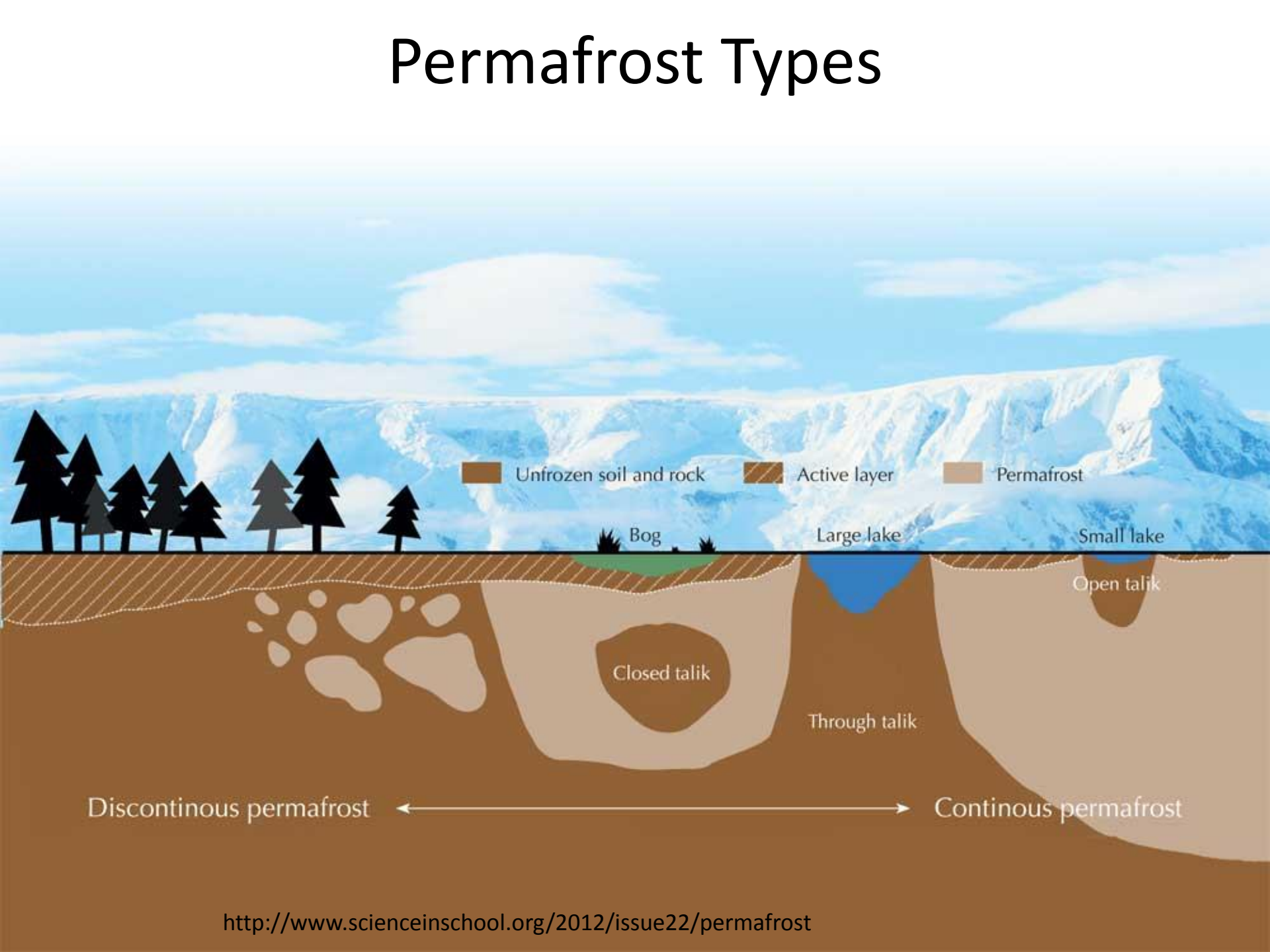
Permafrost: Ground at or below 0° C for at least 2 consecutive years. Depth is a function of mean air temperature and local geothermal gradient

Active Layer: A layer over permafrost that freezes and thaws annually

Talik: Area of ground that remains unfrozen due to local influences (pressure, salinity, recharge, etc.)

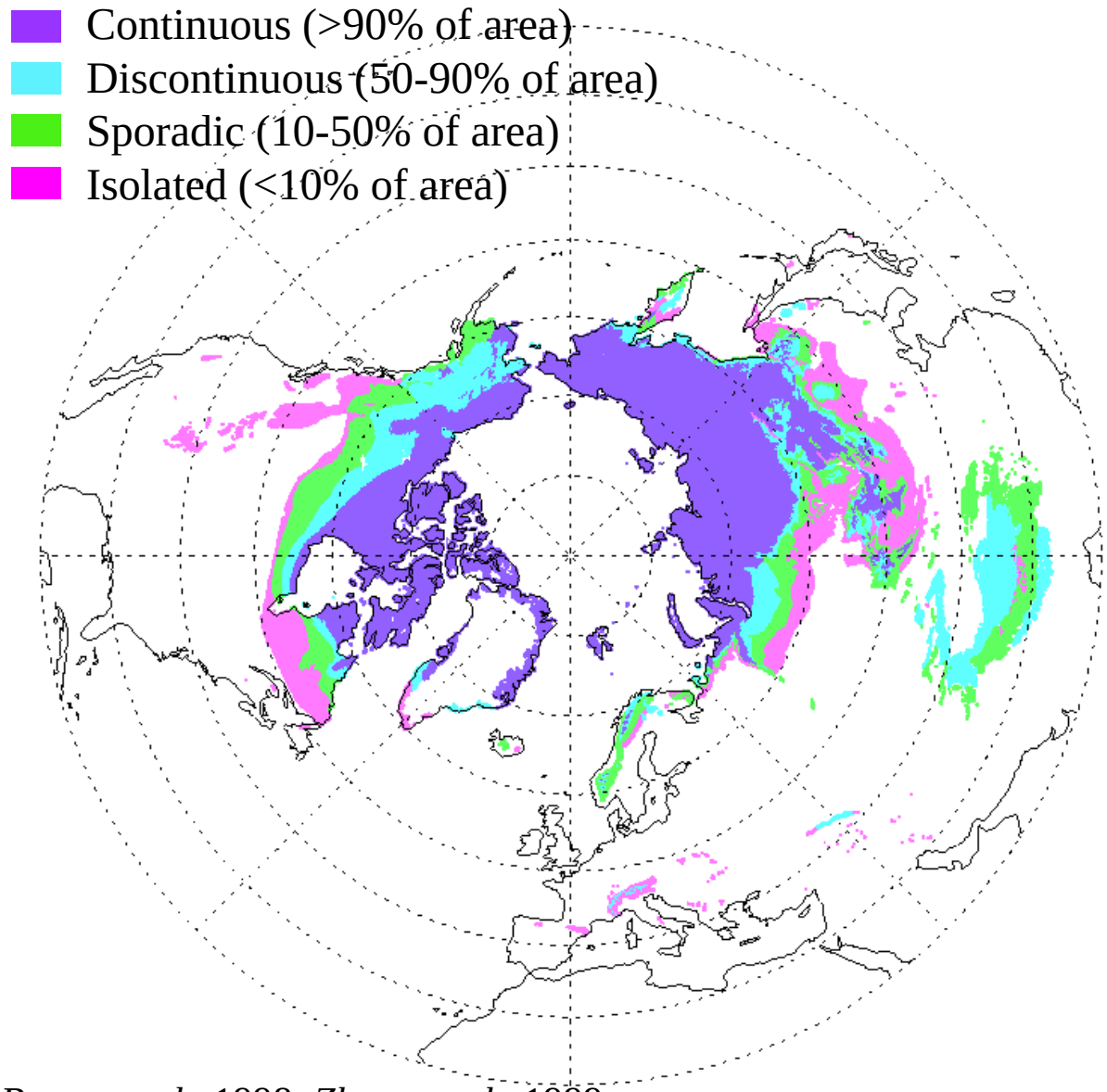
Permafrost Degradation: A decrease in permafrost extent; an increase in active layer thickness.

Permafrost Types



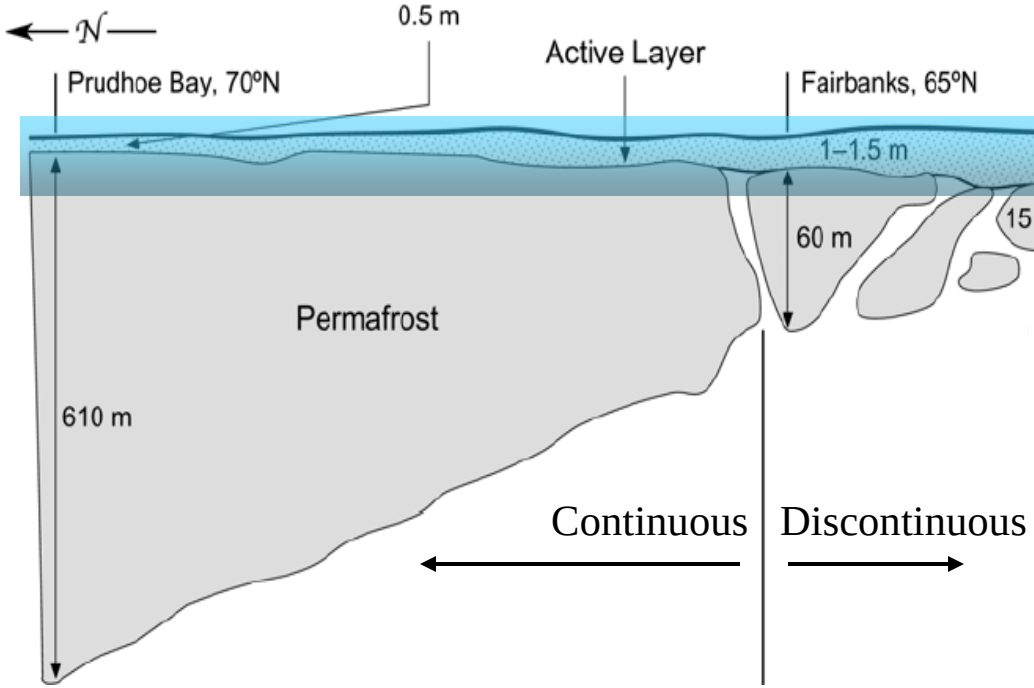
http://www.scienceinschool.org/2012/issue22/permafrost

Permafrost Classification by Area

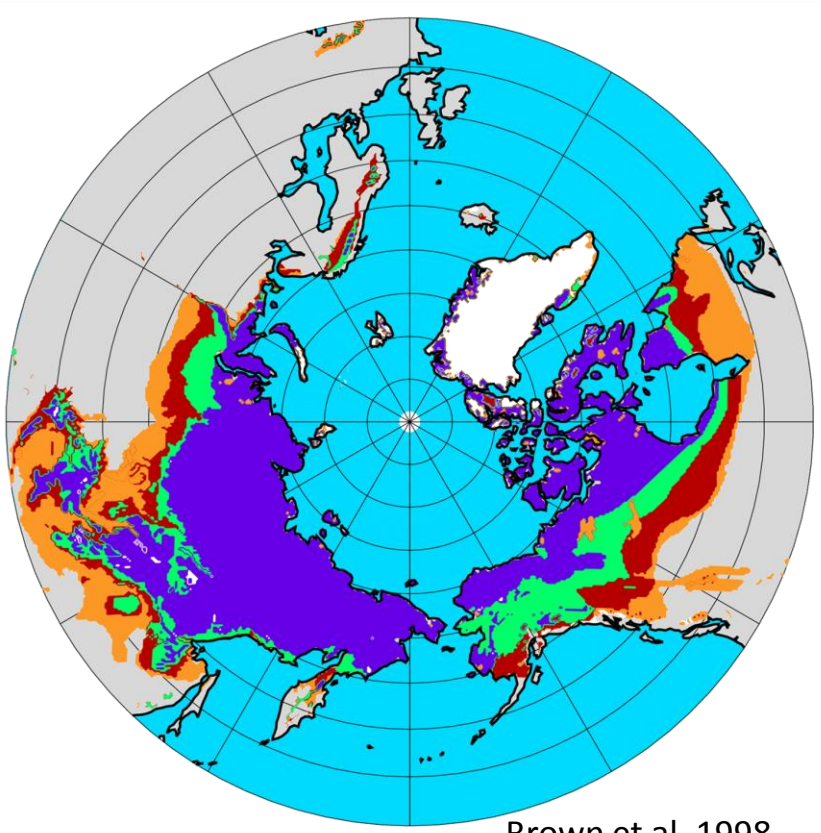


Brown et al., 1998; *Zhang et al.*, 1999

Permafrost



IPA Permafrost Distribution Map



Continuous (90 – 100% coverage)

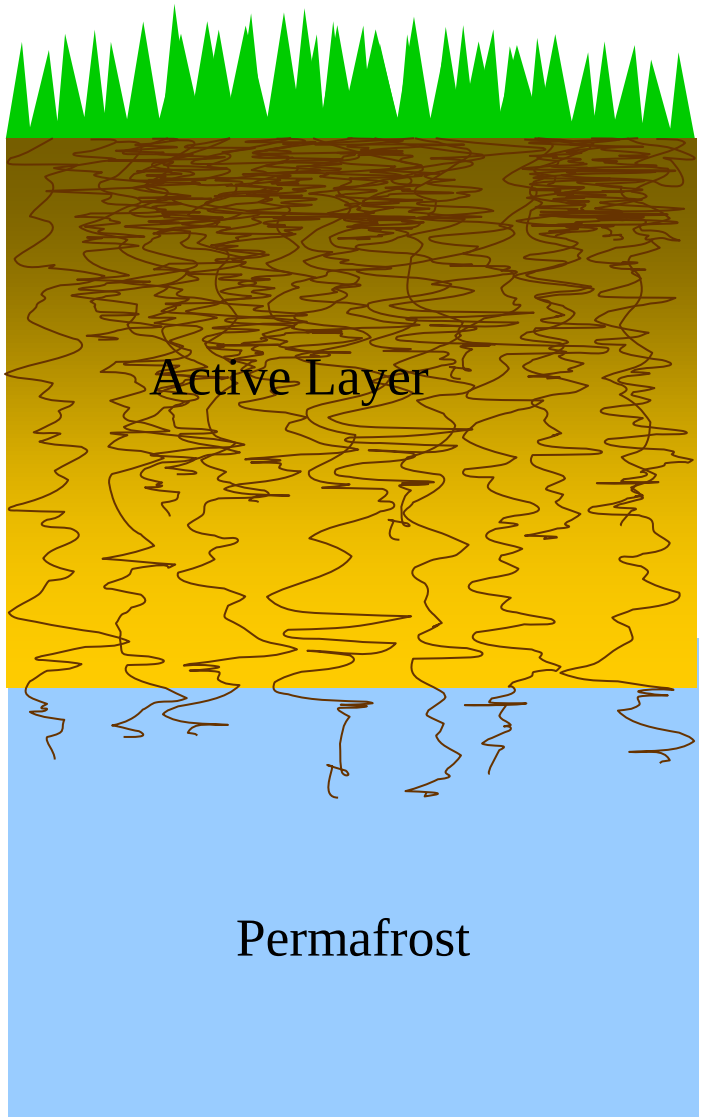
Discontinuous (50 – 90%)

Sporadic (10 – 50%)

Isolated (0 – 10%)

Brown et al. 1998

Permafrost Profile



Vegetation

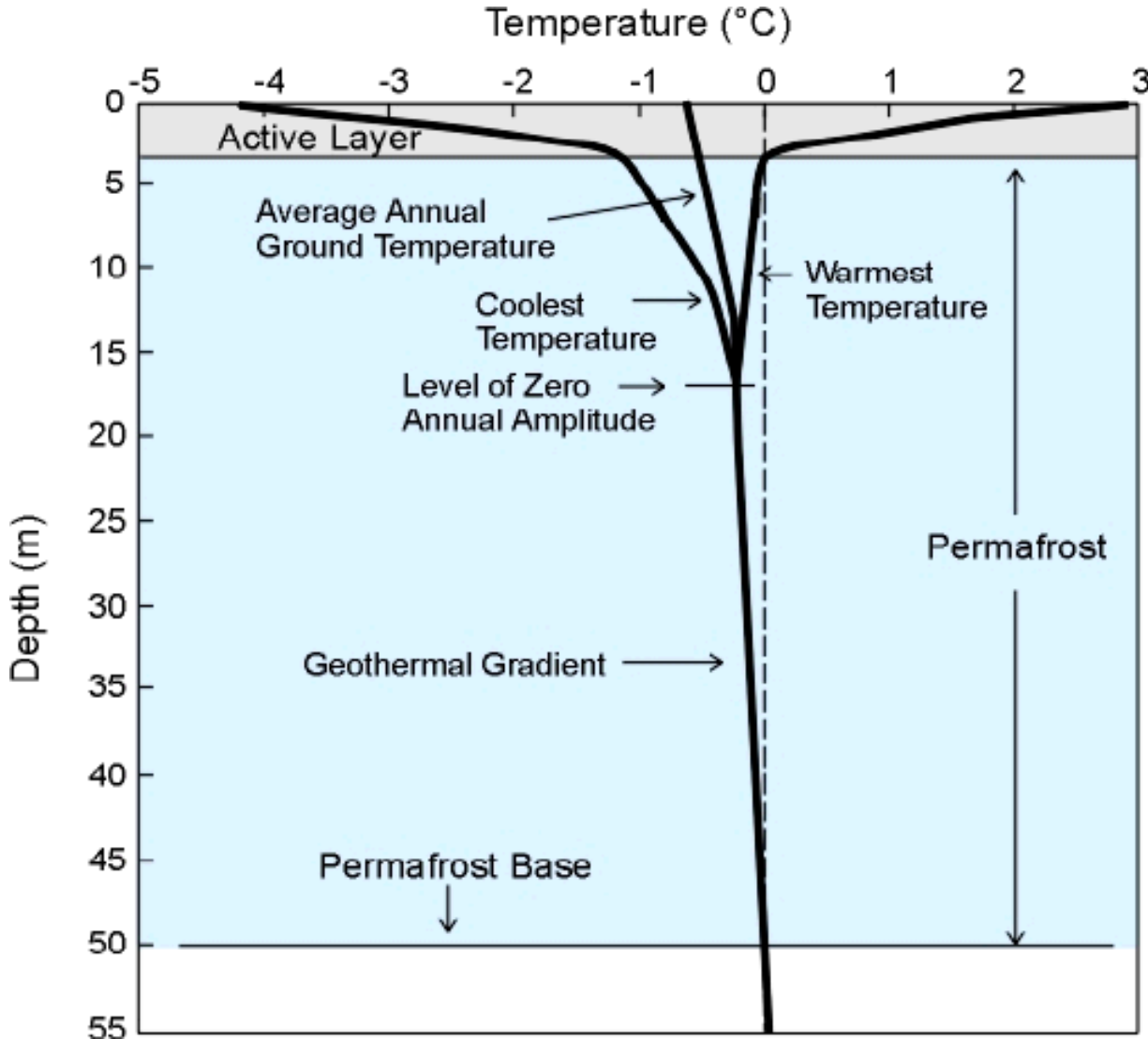
Active Layer

Permafrost

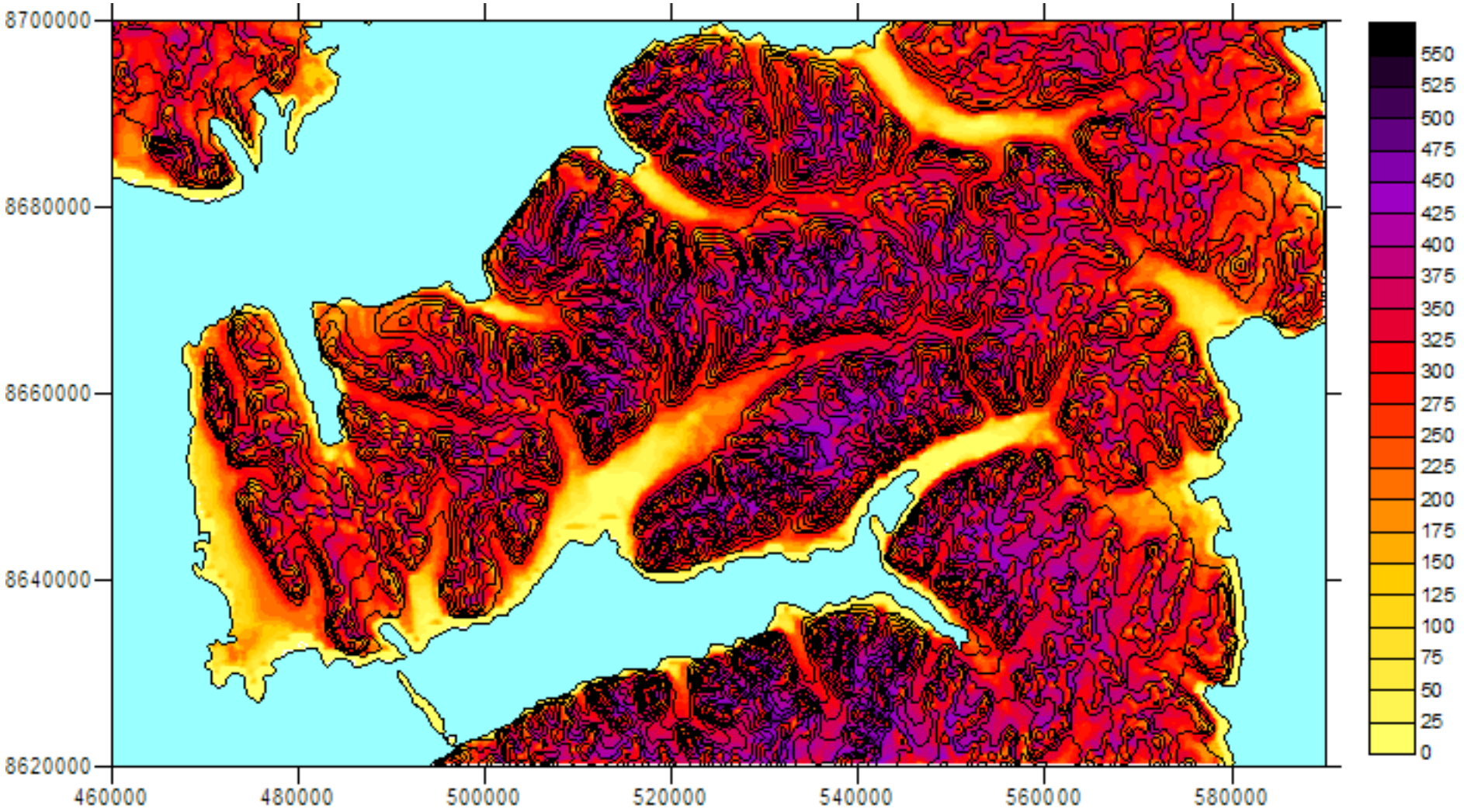
Kevin Schaefer

Geothermal gradient

Depth of permafrost is a function of air temperature and geothermal gradient

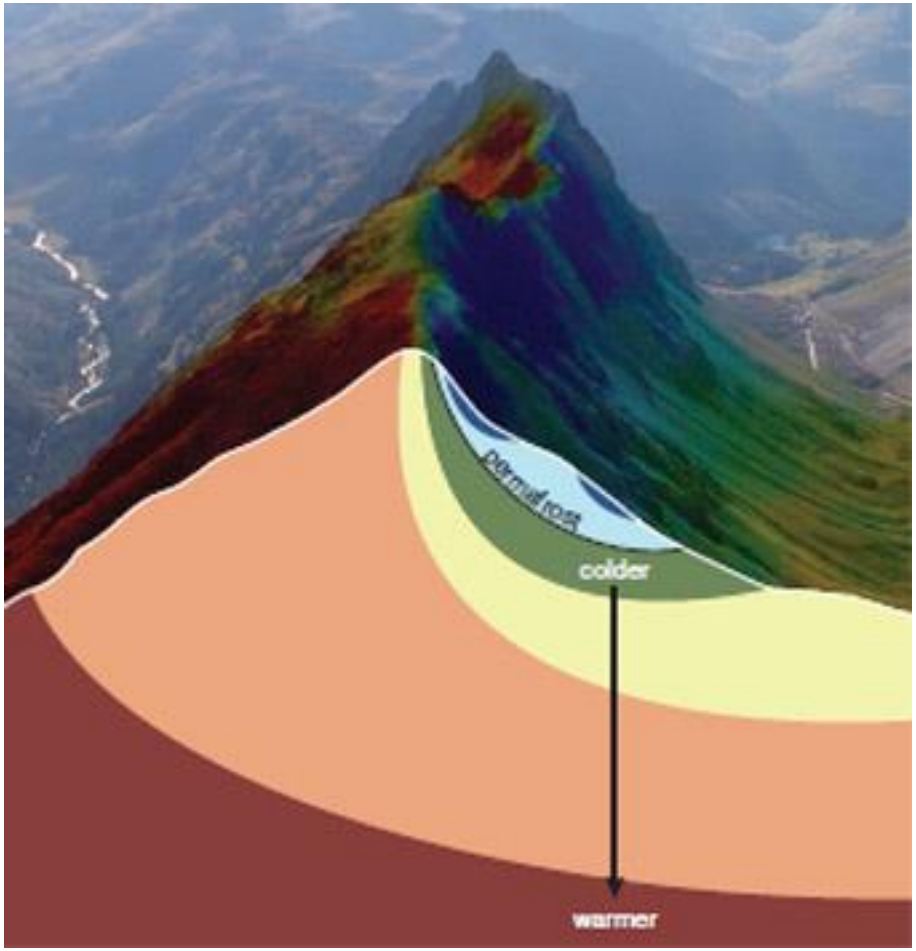


Permafrost Thickness: Svalbard



Rough estimate of stable permafrost thickness (m) in Nordenskiöldland. Figure from Ole Humlum (www.unis.no)

Mountain Permafrost

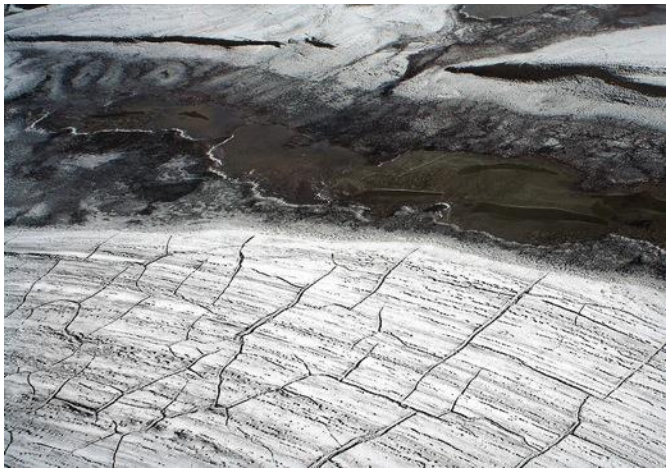


Source: S. Gruber, photo from Christine Rothenbühler

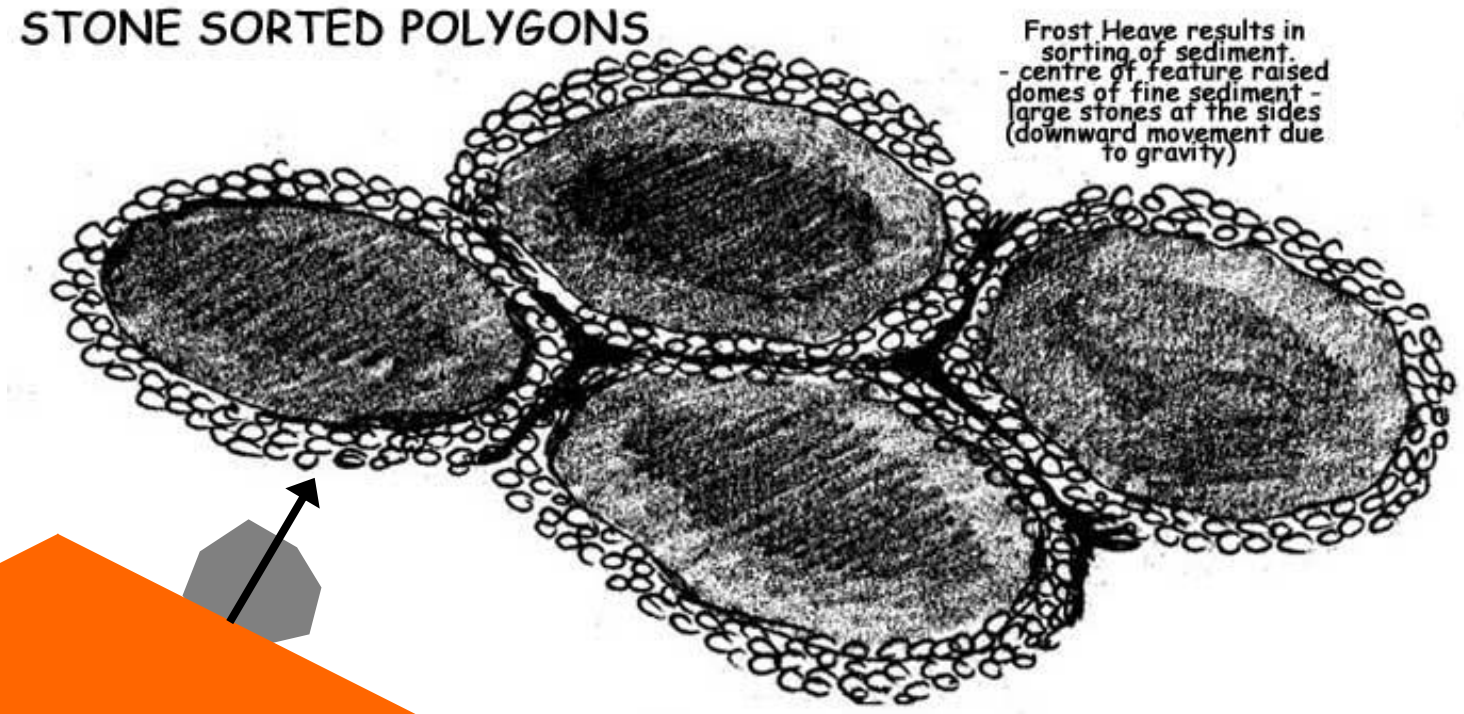
More Types of Permafrost

- ***Cold Permafrost:*** Tolerates considerable heat without thawing. Remains between 10 – 30°F.
- ***Warm Permafrost:*** Introducing very little heat may cause thawing. Just below 34°F.
- ***Ice Rich:*** 20% – 50% visible ice.
- ***Thaw-Stable:*** Permafrost in bedrock is well-drained. Coarse grained sediments.
- ***Thaw-Unstable:*** Poorly drained, fine-grained sediment (clays and silts). Thawing results in so much moisture that it flows.

Ground Patterns



Stone Sorted Polygons



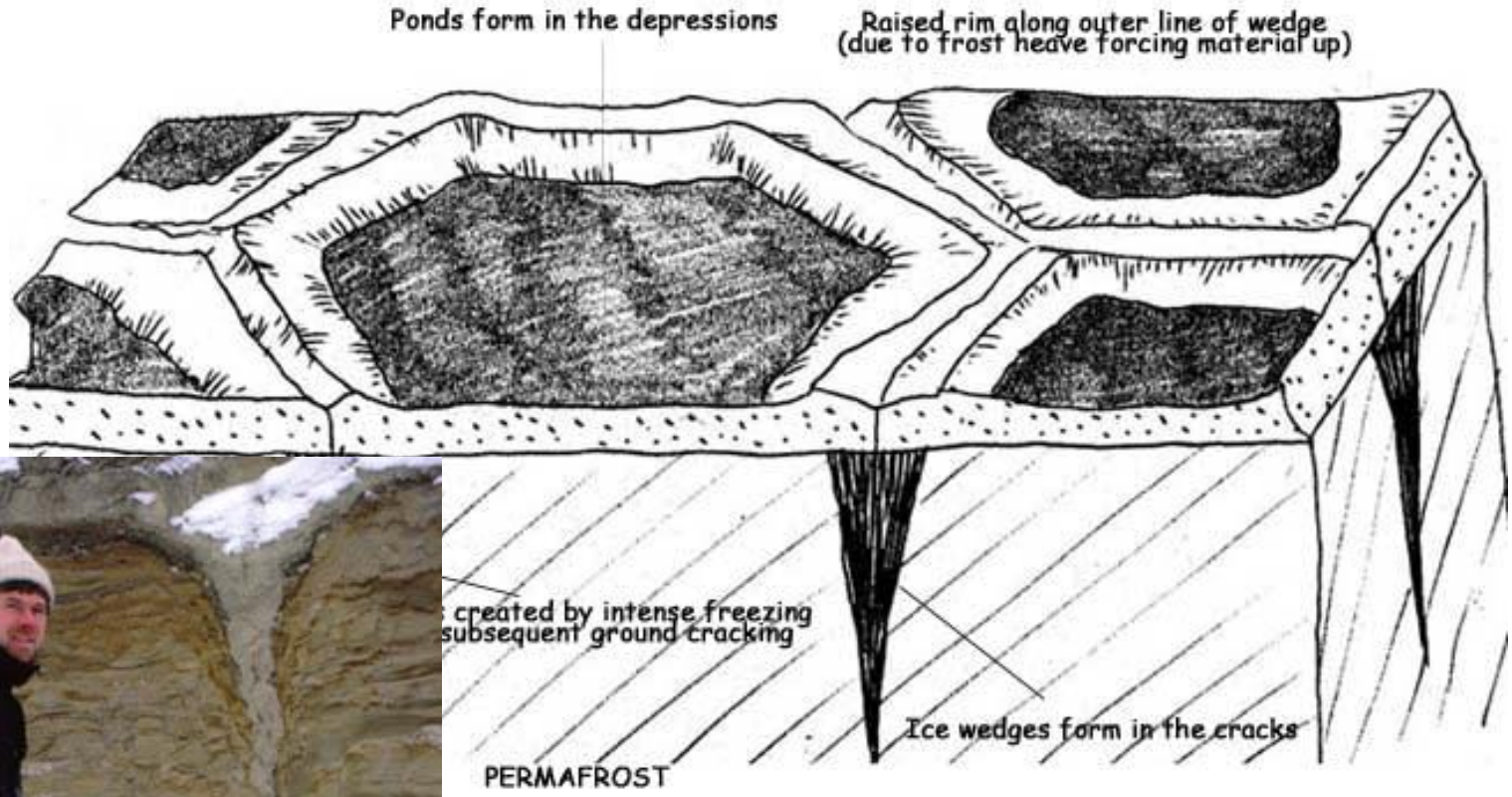
Sorted circles Kvadehukken, Svalbard

Ina Timling

Sorted circles Svalbard

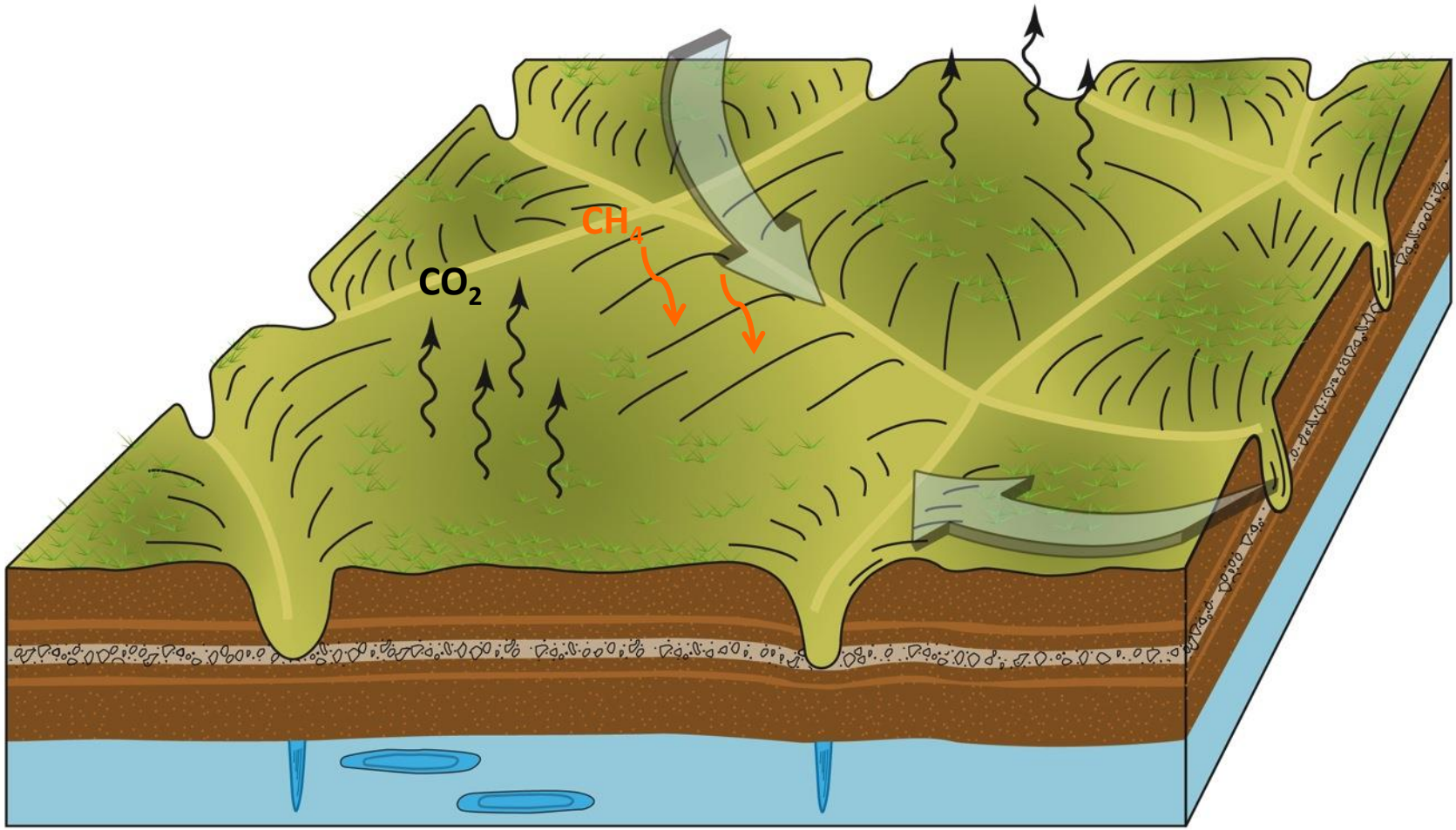
Permafrost features on Kvadehuksletta. 1999.

ICE WEDGE POLYGONS

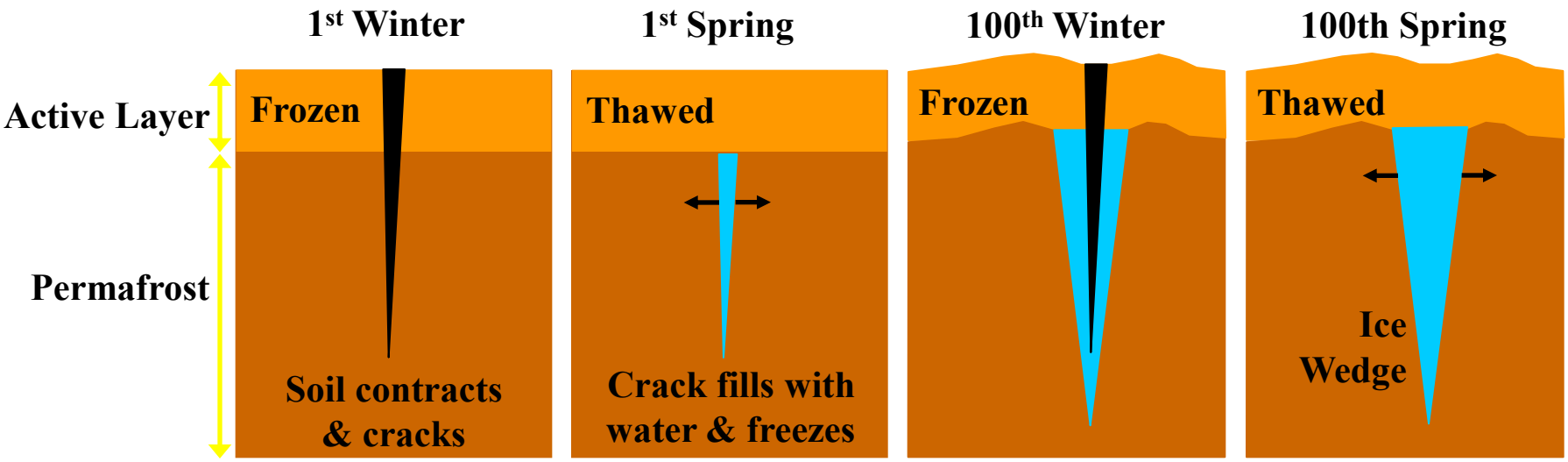


LarsBr: Ice wedge polygons on Alkepynten

Ice wedge polygons along the SW coast of Brøggerhalvøya (JA).


CH_4
CO_2

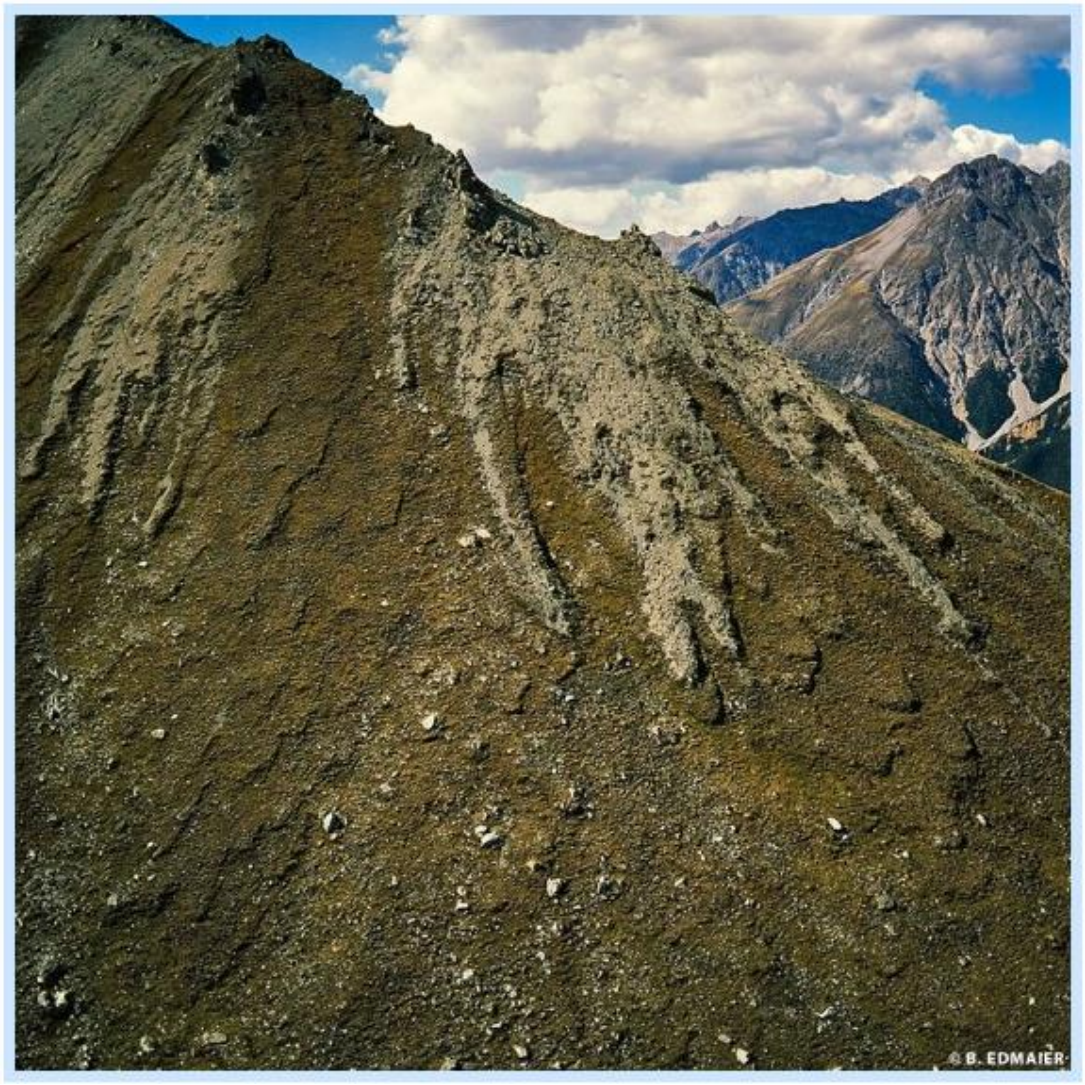
Ice Wedges and Polygons



Polygons, Yena

Polygons, Prudhoe Bay [Zhang, 2009]

- Solifluction – Slow down slope flow of saturate unfrozen earth minerals



Solifluction is evident in Longyerbyen where posts formerly used as foundations of tramway pylons have tilted downslope (JA)

Cryoturbation

- Movement of soil or rock due to repeated freezing and thawing

Vegetation

Active Layer

Permafrost

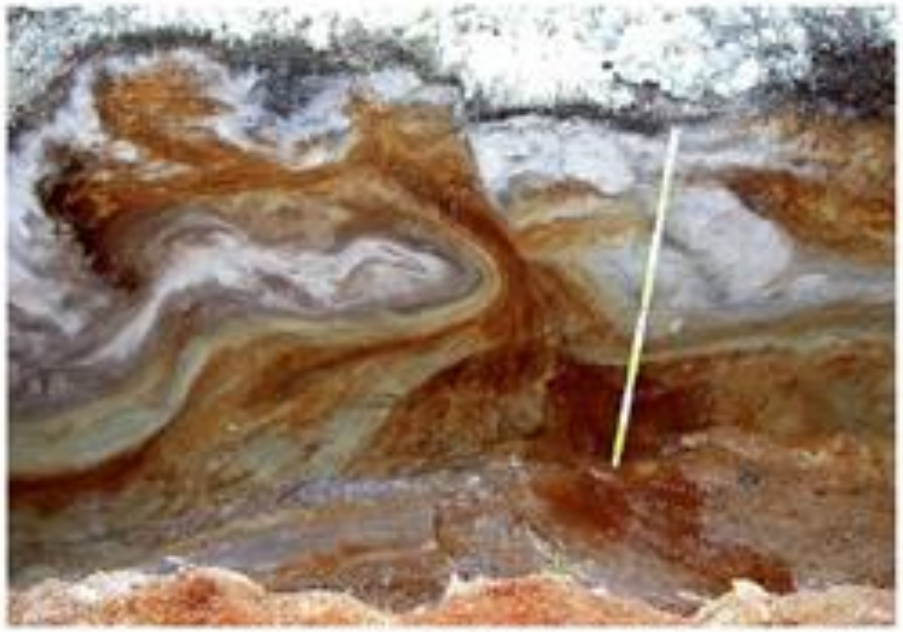


Photo : http://131.130.57.239/sibirien/Taiga_Nord.htm

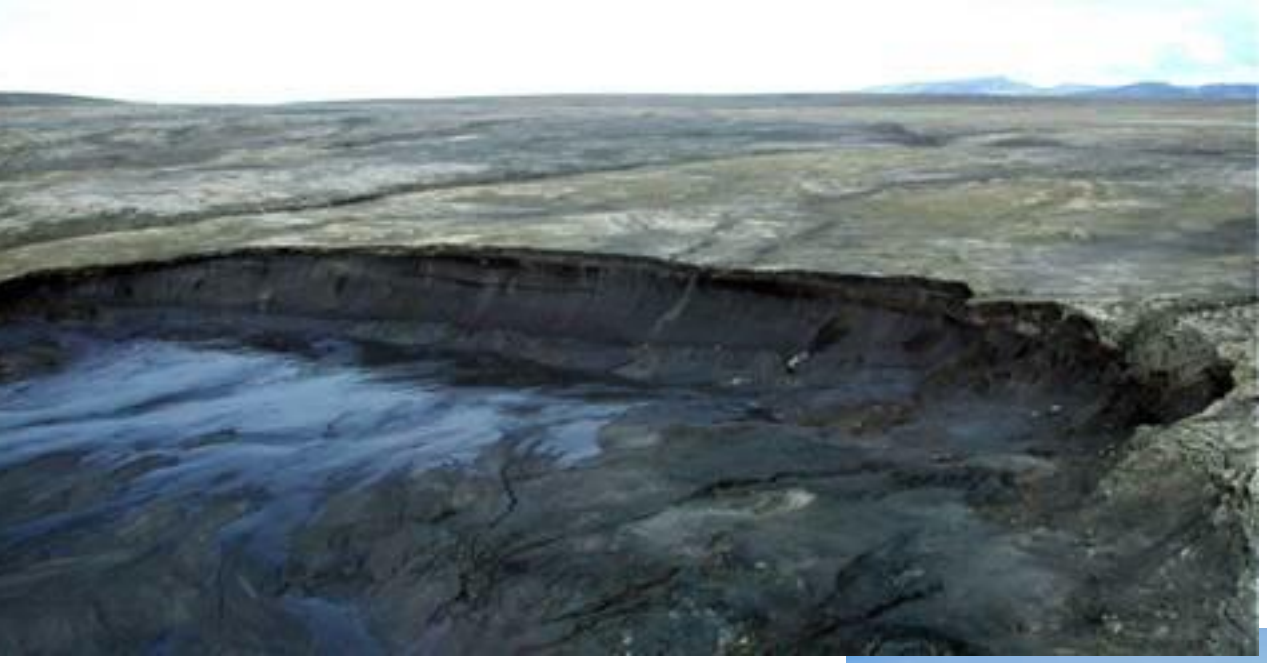
adapté de Pech 1998

Pleistocene Cryoturbation, France

Thermokarst

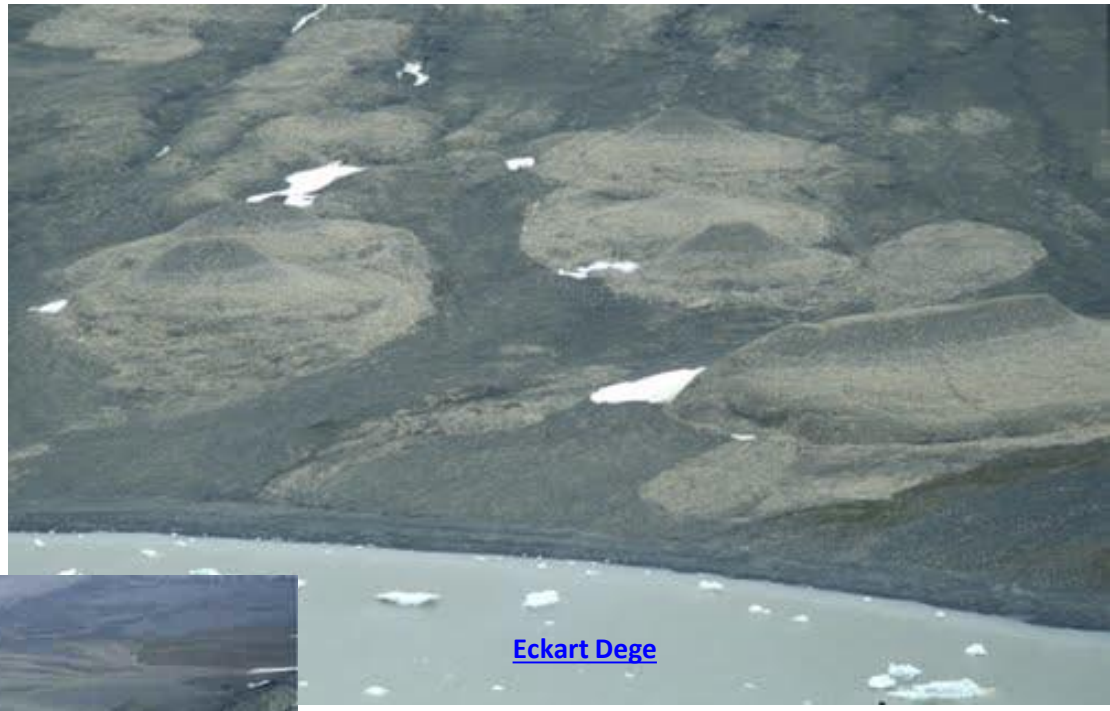
- ***Thermokarst***: subsidence or collapse of ground surface due to melting of ground ice

Slope Mountain, Alaska [Schaefer, 2012]



Thermokarst

Pingos



Eckart Dege

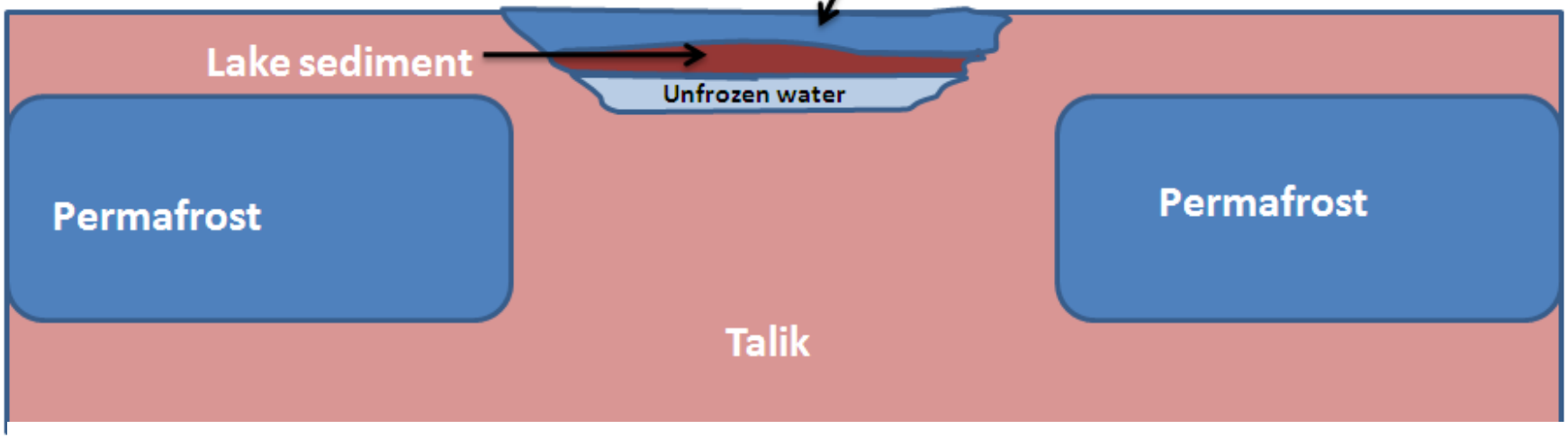
http://home.online.no/~alice/Alice/svalbard1.htm

Minature pingos (frost boils) at Ditlovtoppen, observed in a bed of coaly shale

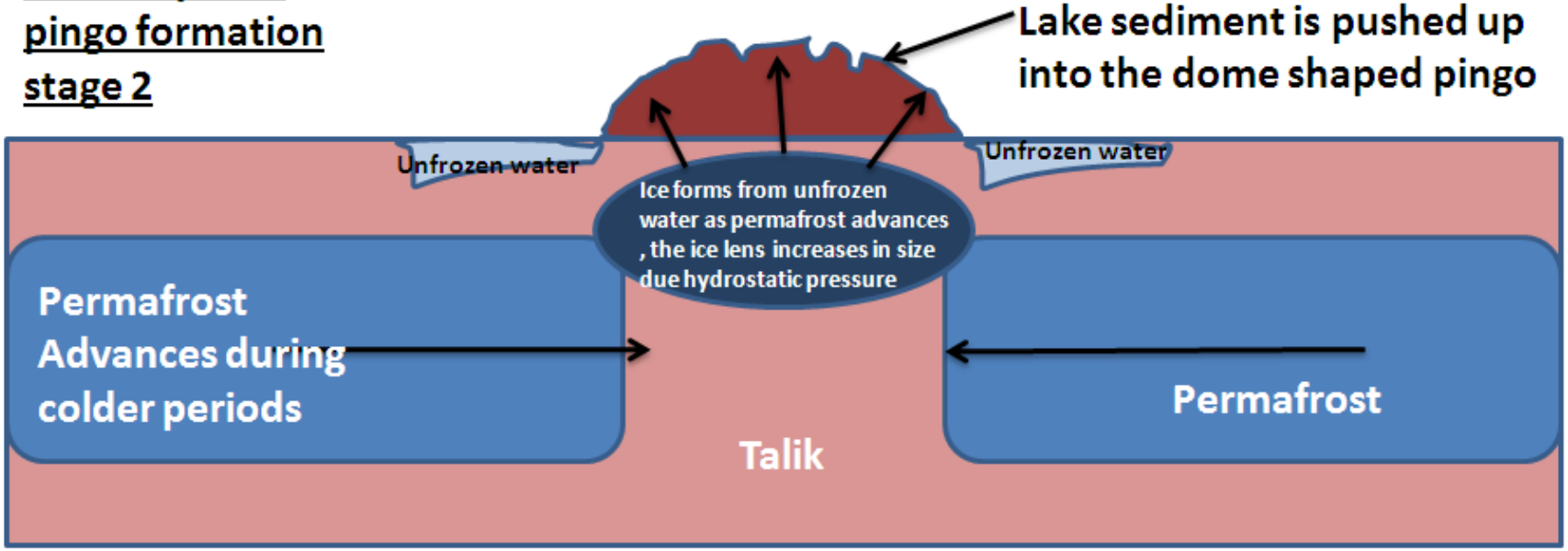
Pingos

Closed system pingo formation stage 1

A frozen lake with sediment on the floor insulates the ground beneath against the cold – this allows talik to exist



Closed system pingo formation stage 2



Permafrost is a major C-reservoir for planet Earth

Organic carbon content of permafrost is assessed as:

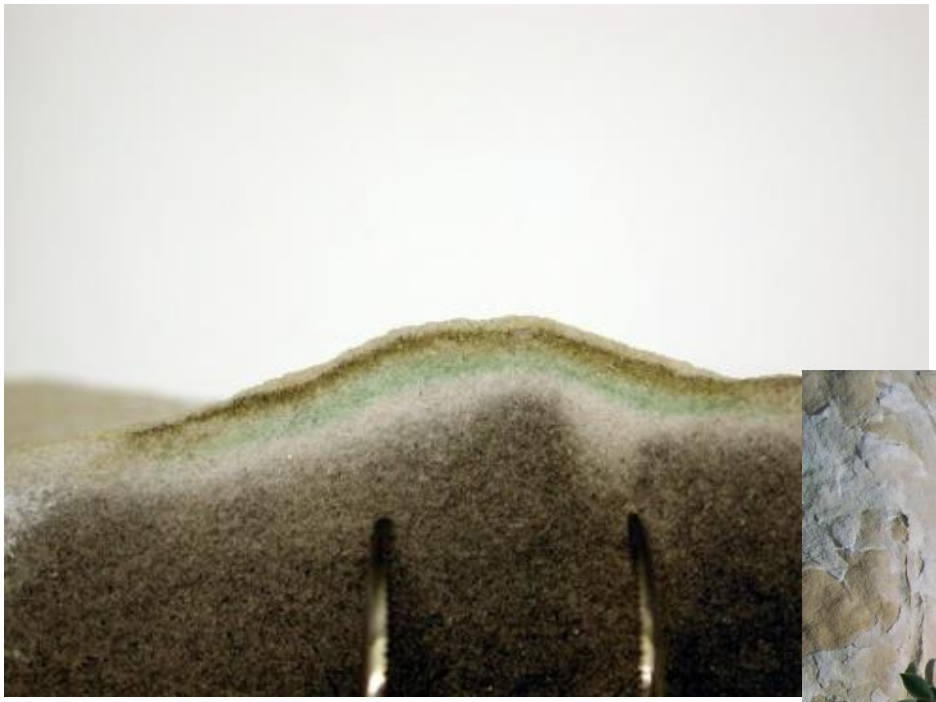
1672 x 10^{15} g (Pg) C

Today's atmospheric content of CO_2:

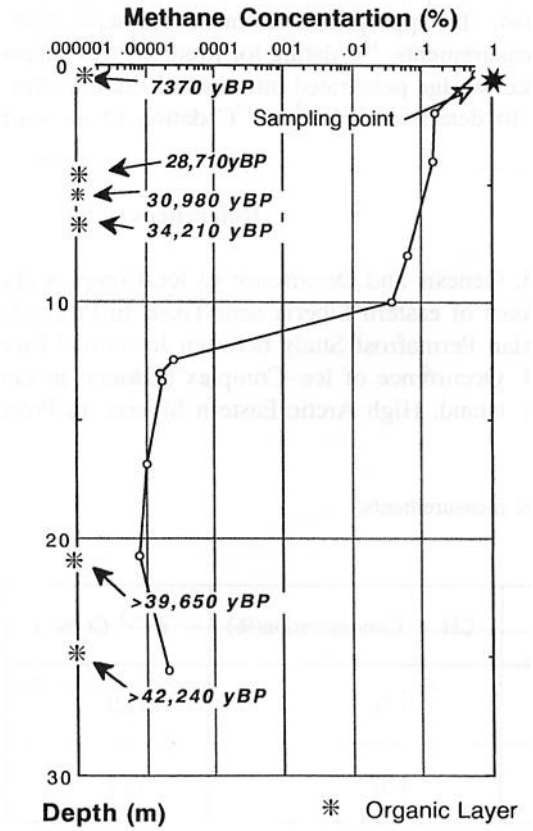
780 x 10^{15} g (Pg) C

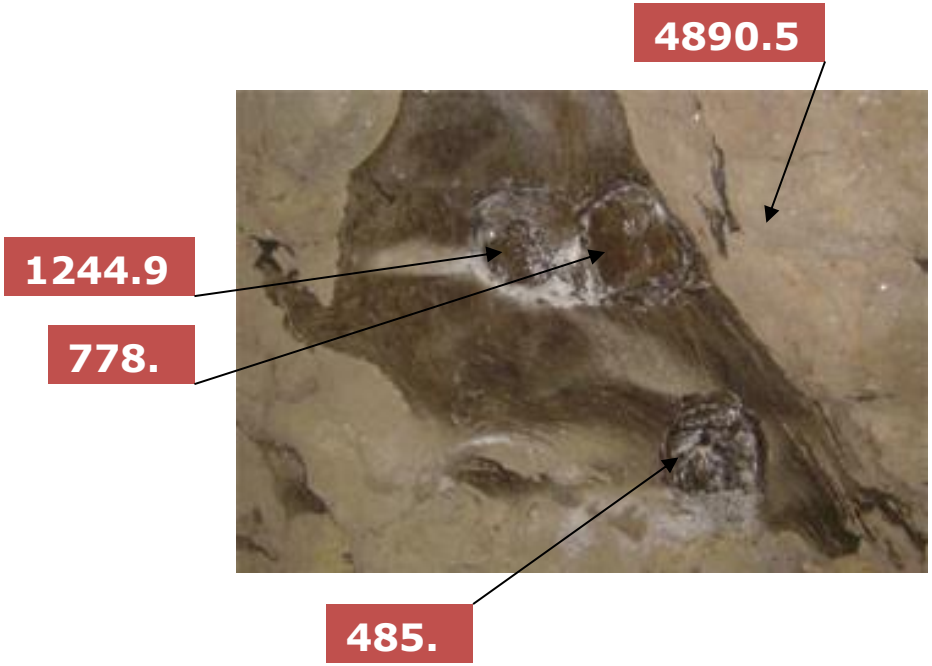
(Tarnocai et al. 2009. GBC 23, GB2023)

Cryptoendoliths in the Arctic

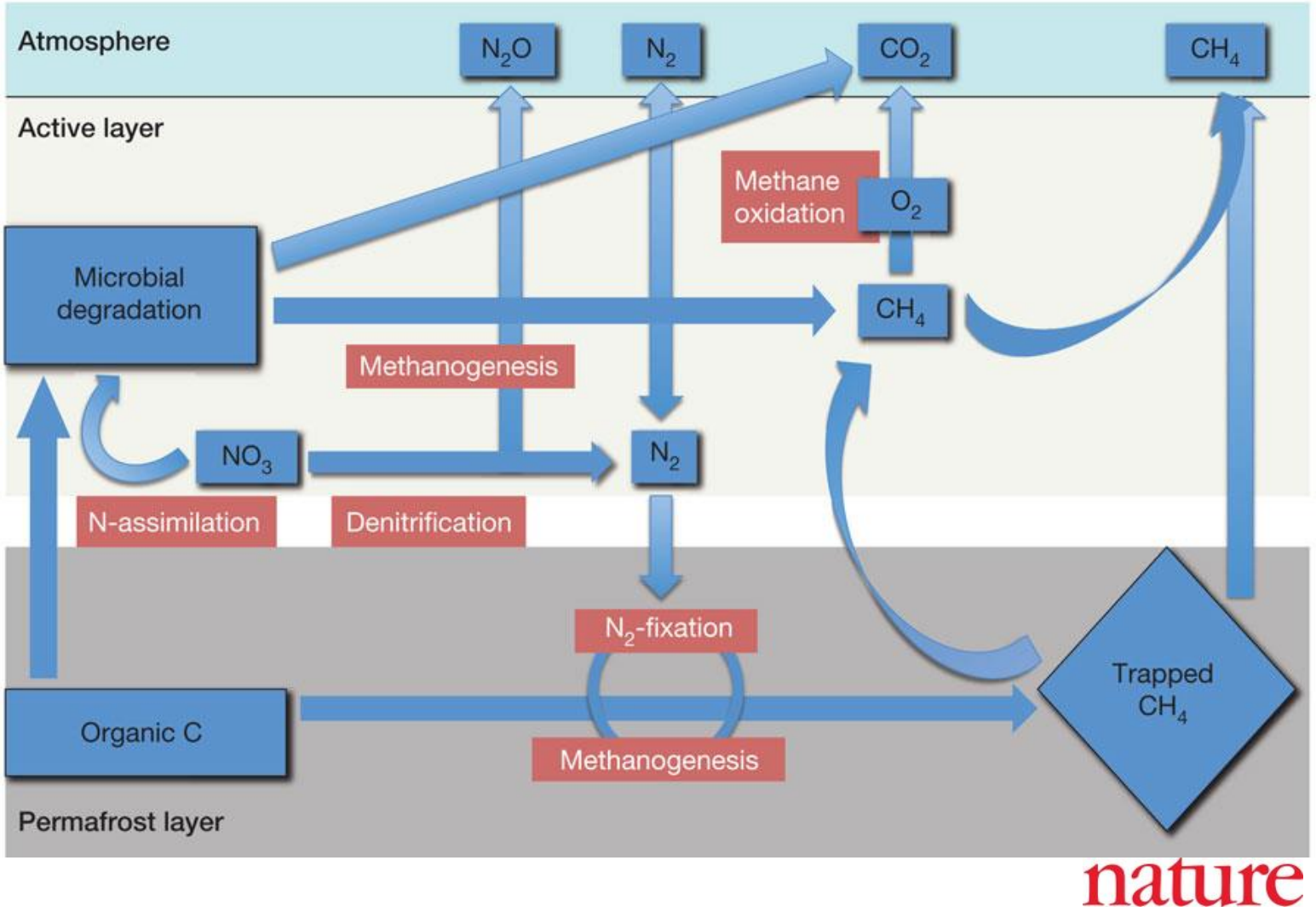


Methane and Permafrost





Conceptual model of C and N cycling
in Arctic soils based on metagenome data.

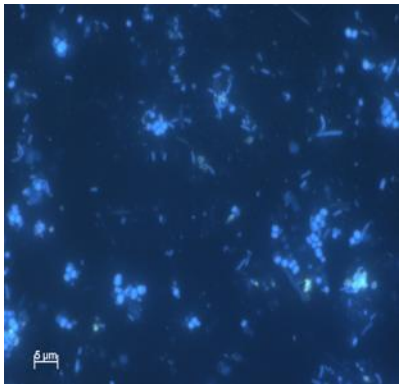


R Mackelprang *et al*. *Nature* **000**, 1-4 (2011) doi:10.1038/nature10576

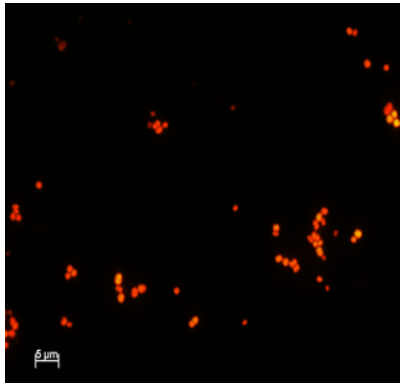
Types	Locations [ref.]
23 genera, mostly similar to spore-forming *Bacilli or Actinobacteria*	Glacial ice from various locations[16]
Deinococcus, Thermus, Alcaligenes, Cytophaga, Bacteriodes (all psychrophiles)	South Pole snow[11]
Serratia, Enterobacter, Klebsiella, Yersinia (all psychrotrophs)	Ellesmere Island ice[21]
Viable fungi (*Penicillium, Cladosporium, Ulocladium, Pleurotus,…*)	Greenland ice cores; age ≤ 140,000 yr [34]
>57 taxa of eukaryotes (fungi, plants, algae, and protists)	Hans Tausen ice core, northern Greenland[100]
Bacillus and other soil bacteria	At base of Guliya (Tibet) ice core in 1 My-old ice (J. Reeve, personal comm.)
Yeasts, fungi, microalgae, bacteria (including vegetative cells of spore-formers); below 1500 m, only spore- forming bacteria	Vostok ice core[1,2]
Non-spore formers (*Pseudomonas…*); spore-formers (mesophiles to psychrophiles); actinomycetes (psychrotolerant)	Vostok ice core[1]
Caolobacter, an aquatic oligotroph, probably indigenous to Lake Vostok	Accretion ice at bottom of Vostok core (R. Sambrotto, personal comm.)
Aerobic bacteria, mostly psychrotolerant oligotrophic non-sporeformers	Kolyma permafrost[94]
14 diverse genera, dominantly corynebacteria, psychrotrophs, not true psychrophiles †	Kolyma lowland permafrost[87]
11 groups of bacteria including *Proteobacteria and Fibrobacter*; SSU rDNA clones suggest novel genera or families	Kolyma lowland permafrost[104]
>30 genera of great diversity, aerobic and anaerobic, including archaea	Kolyma lowland permafrost[34,95]
Bacillus, Arthrobacter, Streptomyces, inter alia	Antarctic permafrost[95]
Methanococcoides burtonii, Methanogenium frigidum, Halorubrum lacusprofundii	Psychrophilic archaea in Antarctic lakes[28-30]

† Shi et al. (87) concluded that the majority of true psychrophiles are found in the ocean. They are rare in Antarctic rocks and soils and permafrost.

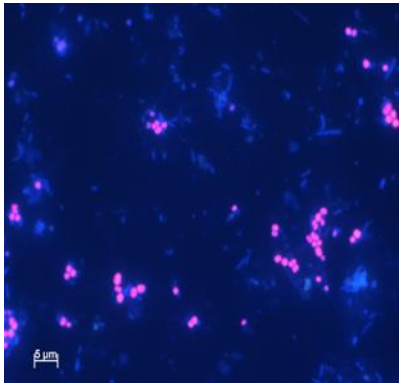
Life in Solid Ice on Earth and Other Planetary Bodies
P. Buford Price
Physics Department, University of California, Berkeley, CA 94720



All organisms in the sample are marked in blue by using DAPI (4',6-Diamidino-2-phenylindole), a fluorescent dye which bounds to all DNA.

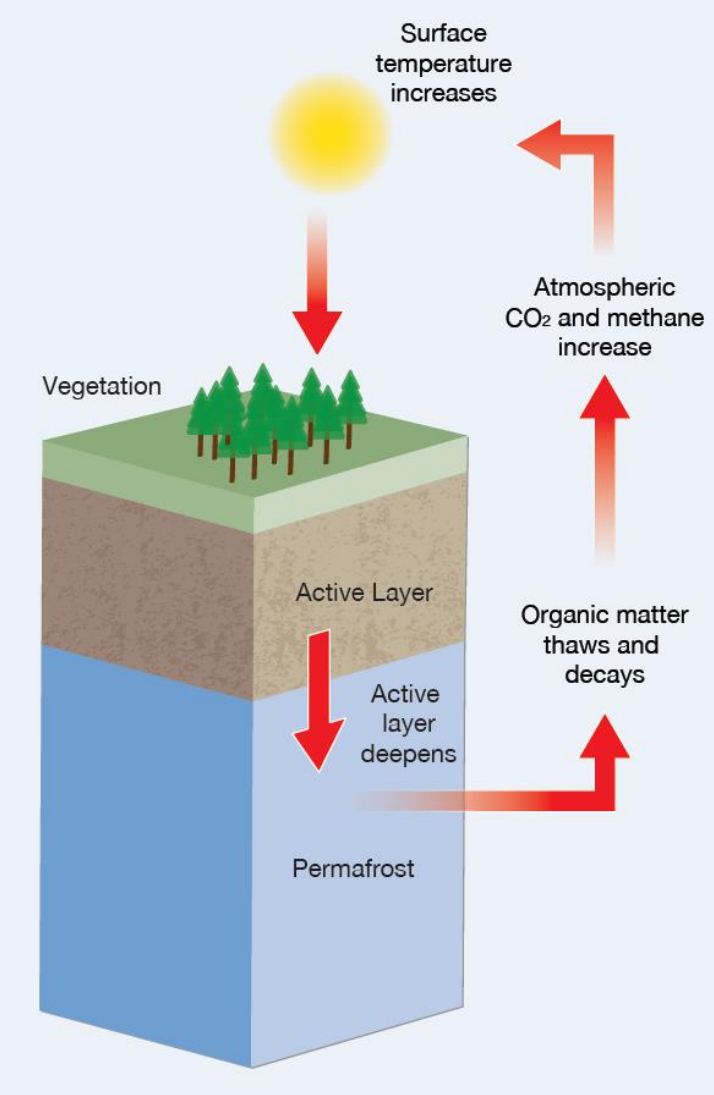


Methane producing microorganisms of the order Methanomicrobiales are marked in red by hybridisation with a specific oligonucleotide probe (MG1200)



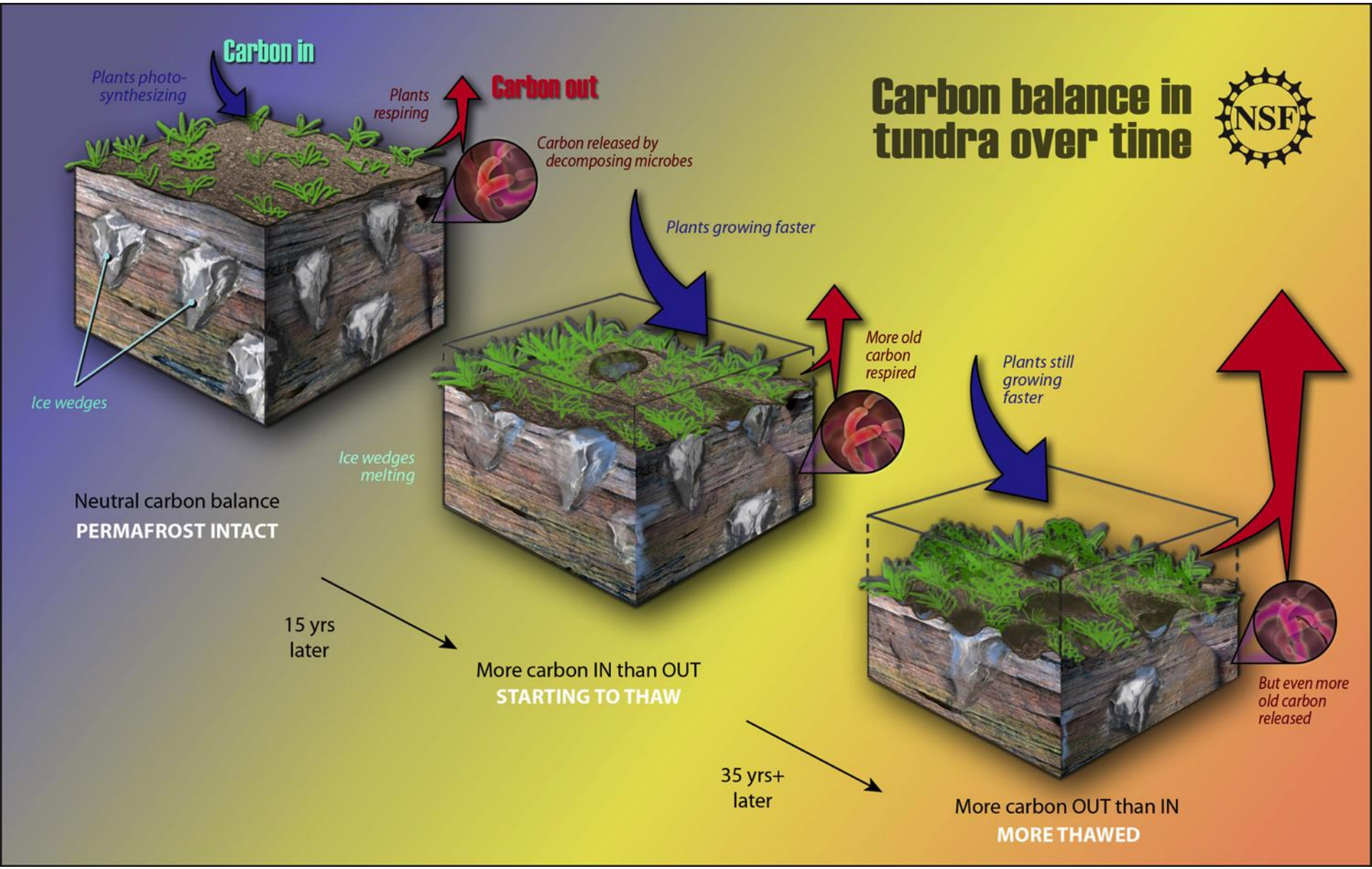
By overlaying the pictures the fraction of Methanomicrobiales cells per DAPI-detected cells can be visualised.

Permafrost Carbon Feedback



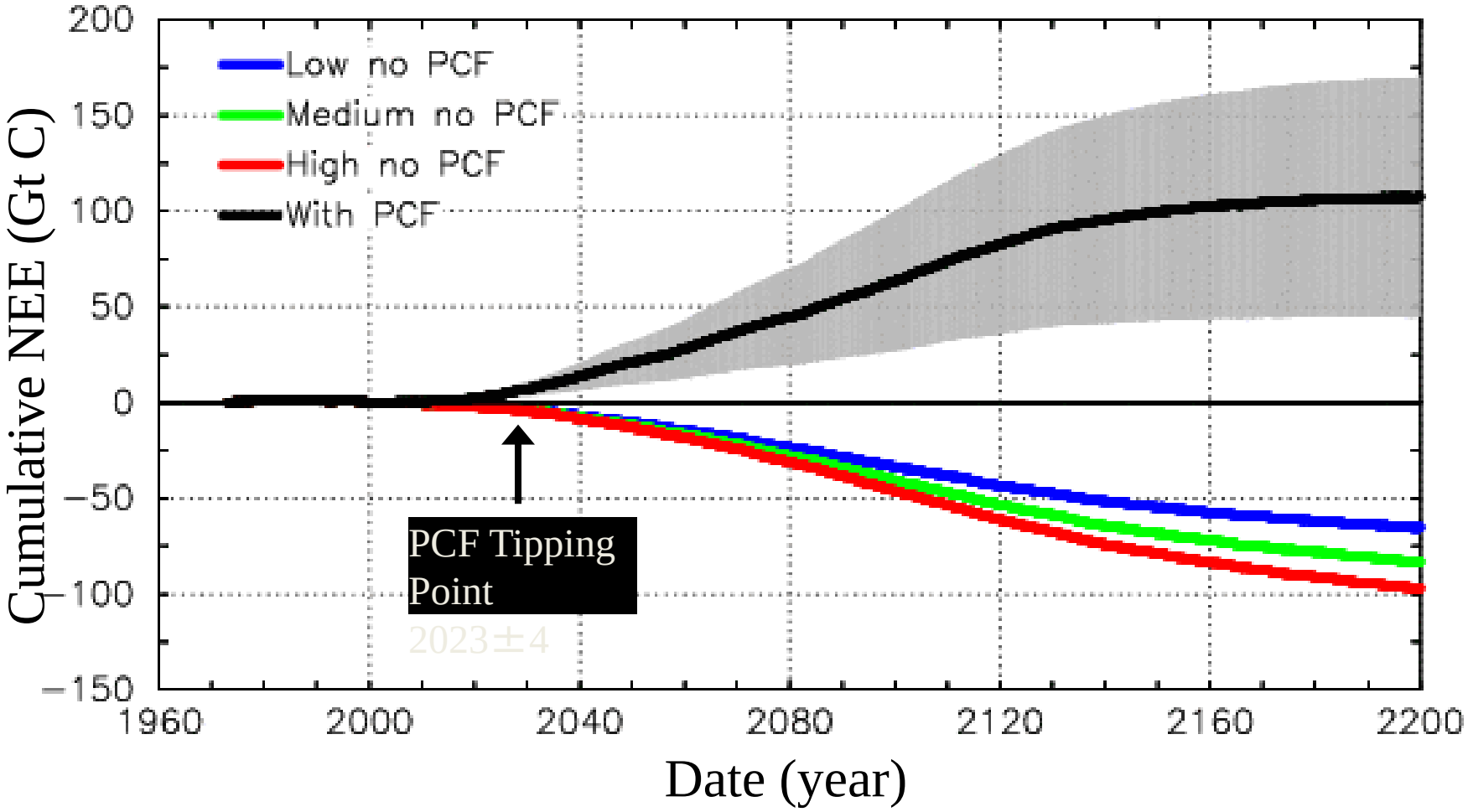
Amplification of warming due to release of CO_2 and CH_4 from thawing permafrost

University of Alaska Fairbanks



Zina Deretsky, National Science Foundation

Permafrost Carbon Tipping Point

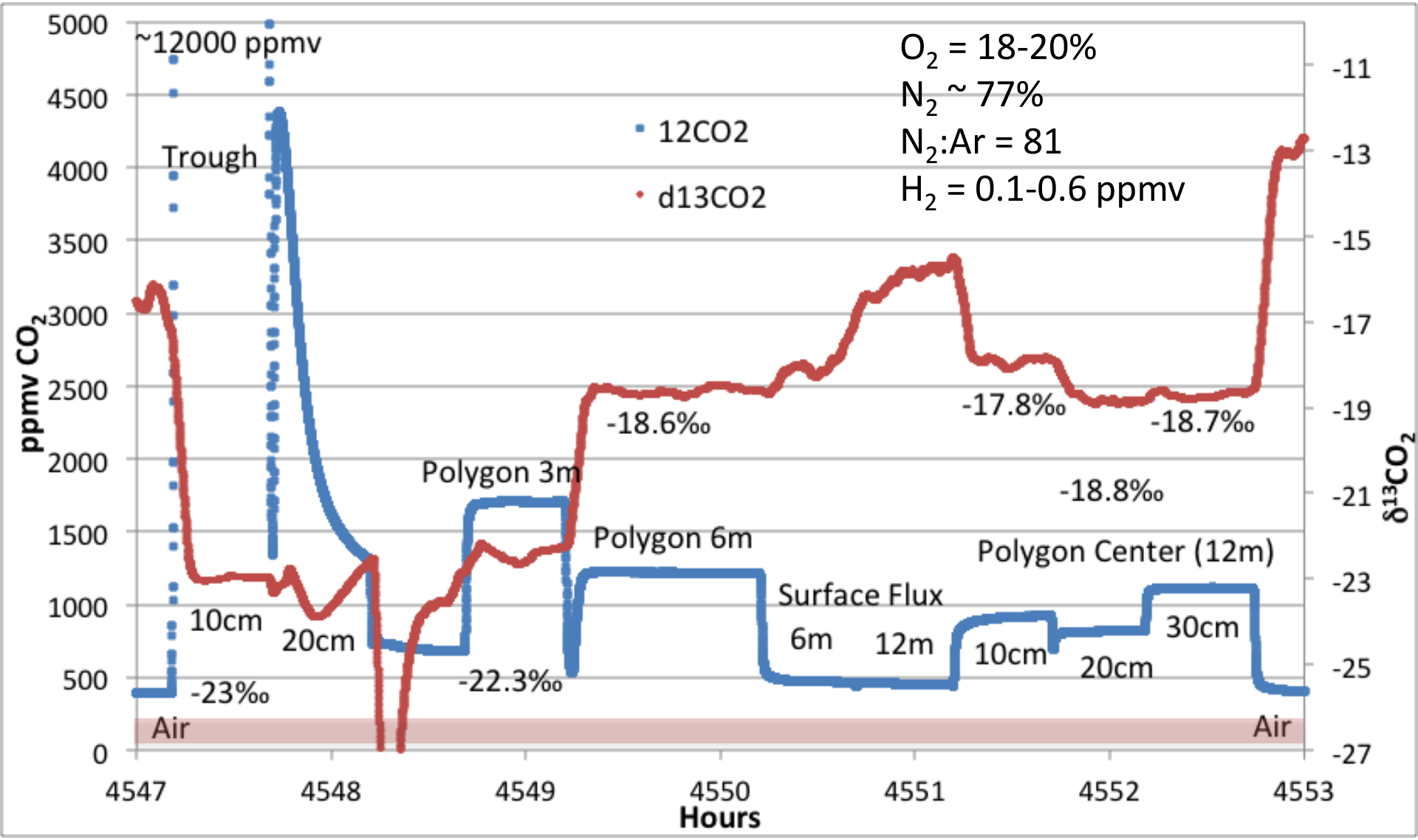


Kevin Schaefer

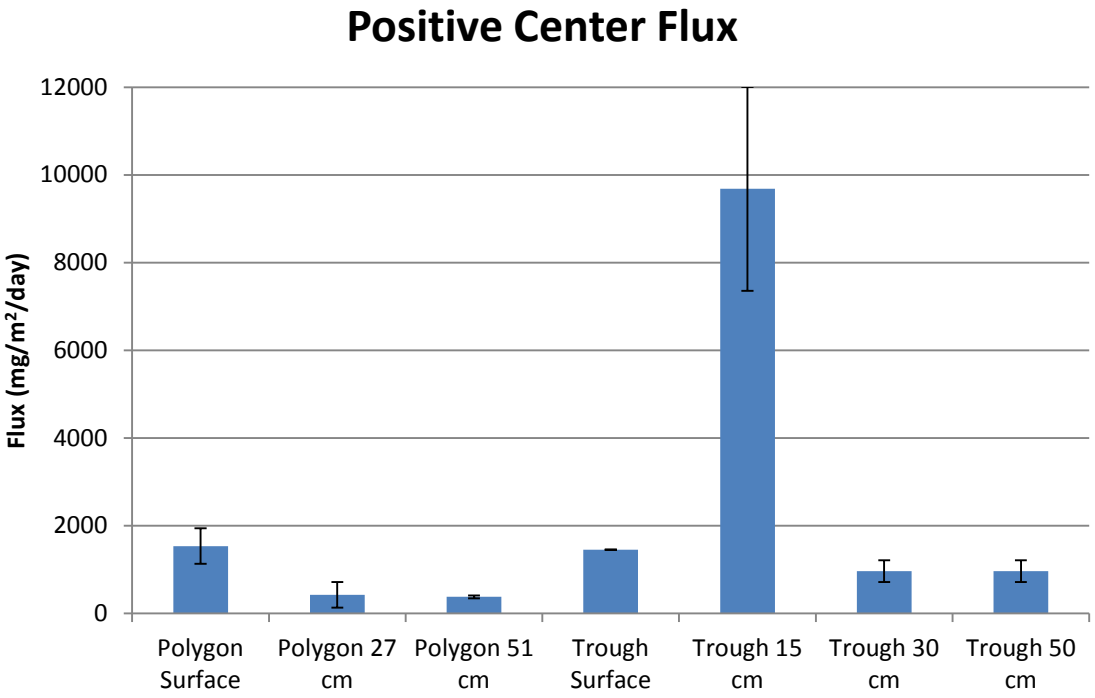
Recent Permafrost Temperature Trends

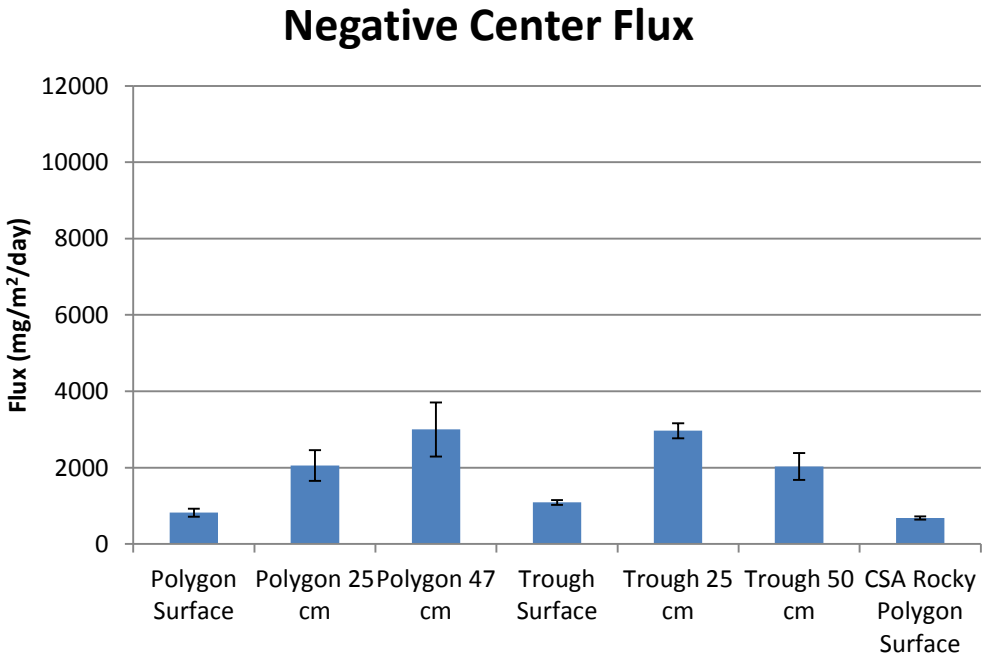
Country	Region	Permafrost Temp. Trend	Reference
USA	Trans-Alaska pipeline route (20 m), 1983-2003	+0.6 to +1.5° C	Romanovsky and Osterkamp, 2001; Osterkamp 2003
USA	Barrow Permafrost Observatory (15 m), 1950-2003	+1° C	Brewer 1958; Romanovsky et al., 2002
Russia	Northwest Siberia (10 m), 1980-1990	+0.3 to +0.7° C	Pavlov, 1994
Russia	European North of Russia (6 m), 1973-1992	+1.6 to +2.8° C	Pavlov, 1994
Canada	Alert (15 m), 1995-2000	+0.15° C yr^{-1}	Smith et al., 2003
Canada	Northern Quebec (10 m), late 1980s - mid 1990s	–0.1°C yr^{-1}	Allard et al., 1995
Norway	Janssonhaugen, Svalbard	+1° to +2° C	Isaksen et al., 2001
Kazakhstan	Northern Tien Shan (1973-2003)	+0.2° to +0.6° C	Marchenko, 1999 and 2002
Tibet	Qinghai-Tibet Plateau (1970s-90s)	+0.1 to +0.3° C	Huijin et al., 2000

Positive Center Polygon: CO_2

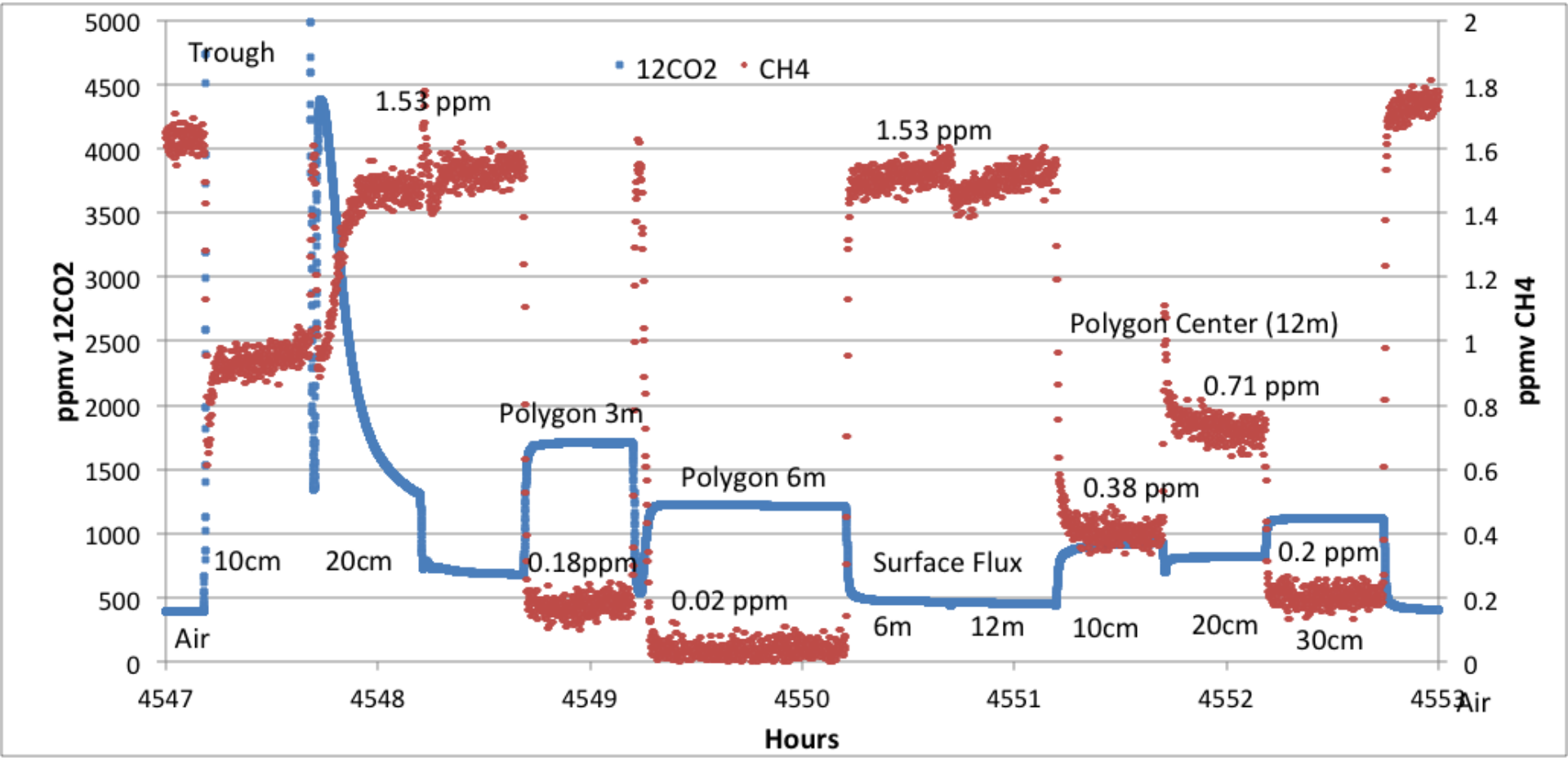


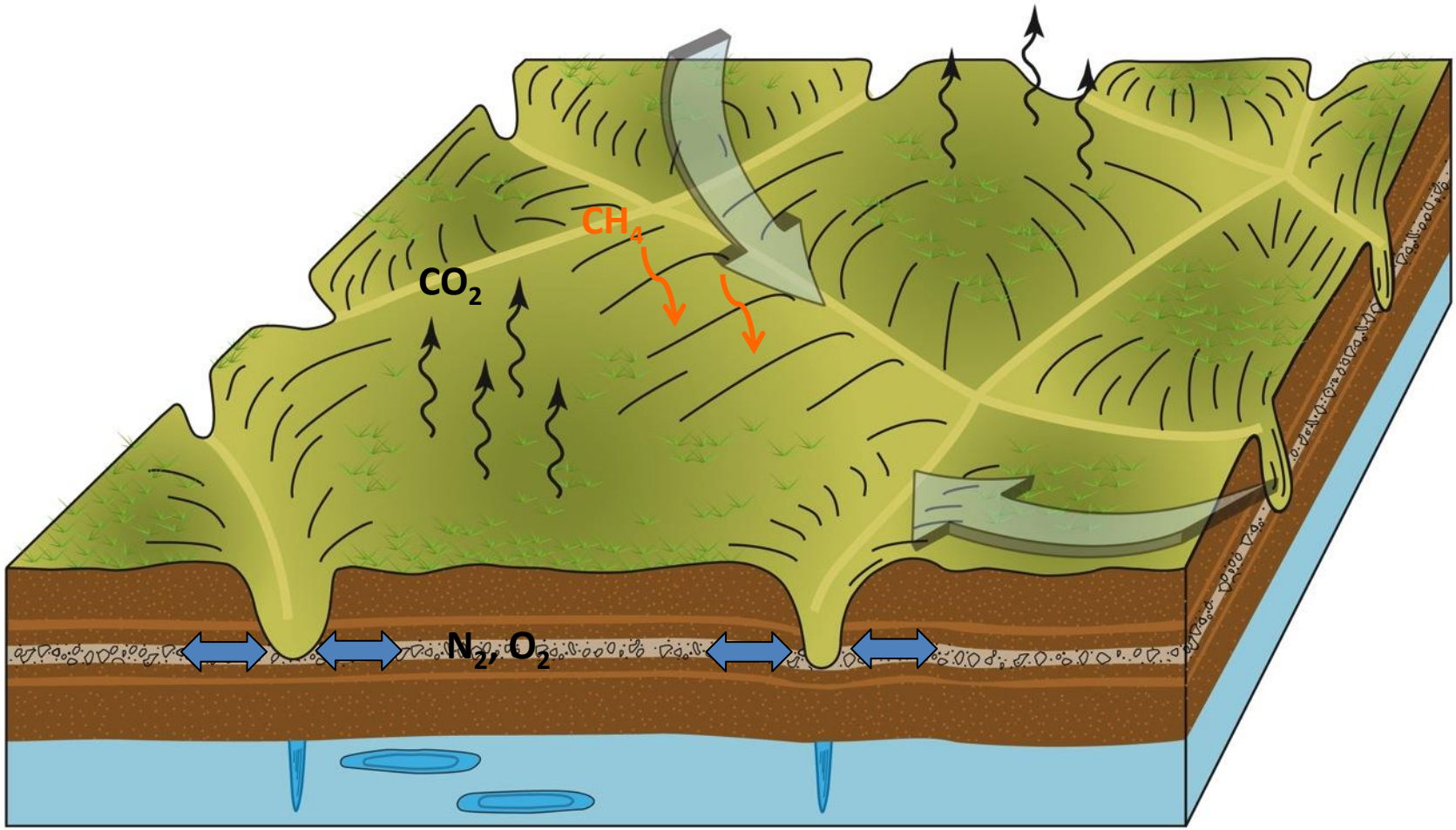
GasFlux


Positive Center Flux
Flux (mg/m²/day)
12000
10000
8000
6000
4000
2000
0
Polygon Surface
Polygon 27 cm
Polygon 51 cm
Trough Surface
Trough 15 cm
Trough 30 cm
Trough 50 cm


Negative Center Flux
Flux (mg/m²/day)
12000
10000
8000
6000
4000
2000
0
Polygon Surface
Polygon 25 cm
Polygon 47 cm
Trough Surface
Trough 25 cm
Trough 50 cm
CSA Rocky Polygon Surface

Positive Center Polygon: CH_4




CH_4
CO_2
N_2, O_2