Glaciation, periglaciation and permafrost

GEO-4410
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Glaciation, periglaciation and permafrost

1: Why interest in cold-climate geomorphology ?

2: Glaciation

3: Periglaciation

4: Permafrost

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Increased sedimentation rates and grain sizes 2–4 Myr ago due to the influence of climate change on erosion rates

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Around the globe, and in a variety of settings including active and inactive mountain belts, increases in sedimentation rates as well as in grain sizes of sediments were recorded at ~2–4 Myr ago, implying increased erosion rates. A change in climate represents the only process that is globally synchronous and can potentially account for the widespread increase in erosion and sedimentation, but no single process—like a lowering of sea levels or expanded glaciation—can explain increases in sedimentation in all environments, encompassing continental margins and interiors, and tropical as well as higher latitudes. We suggest that climate affected erosion mainly by the transition from a period of climate stability, in which landscapes had attained equilibrium configurations, to a time of frequent and abrupt changes in temperature, precipitation and vegetation, which prevented fluvial and glacial systems from establishing equilibrium states.

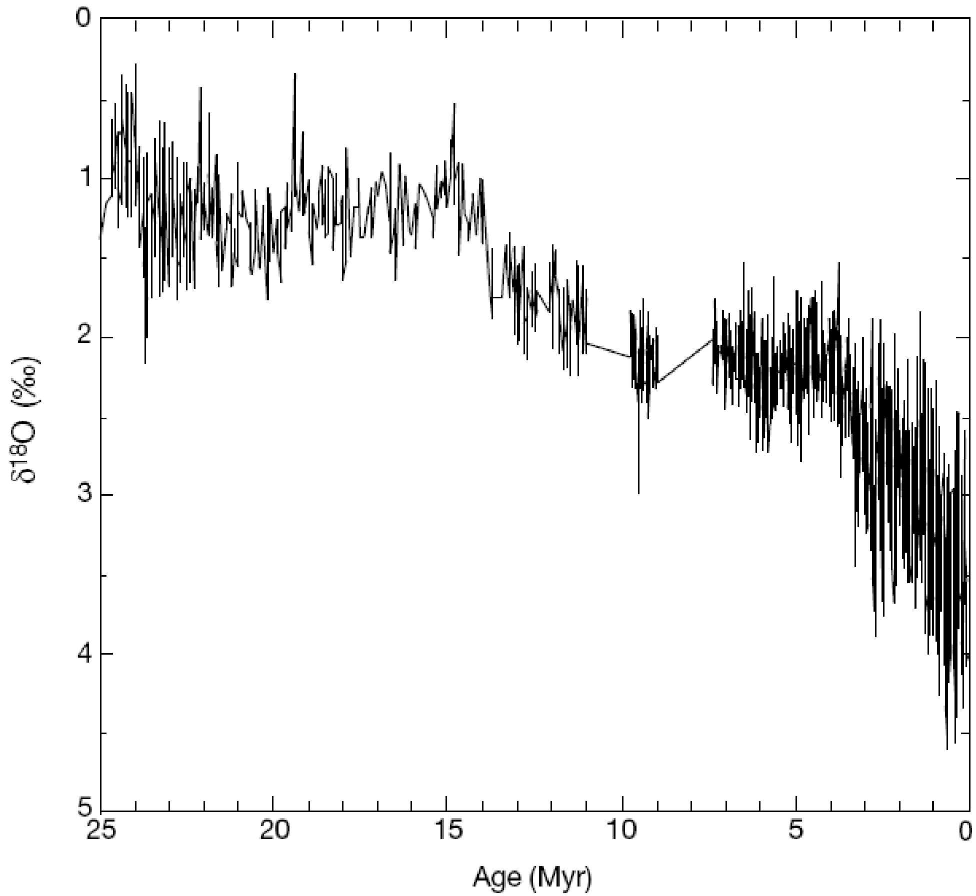
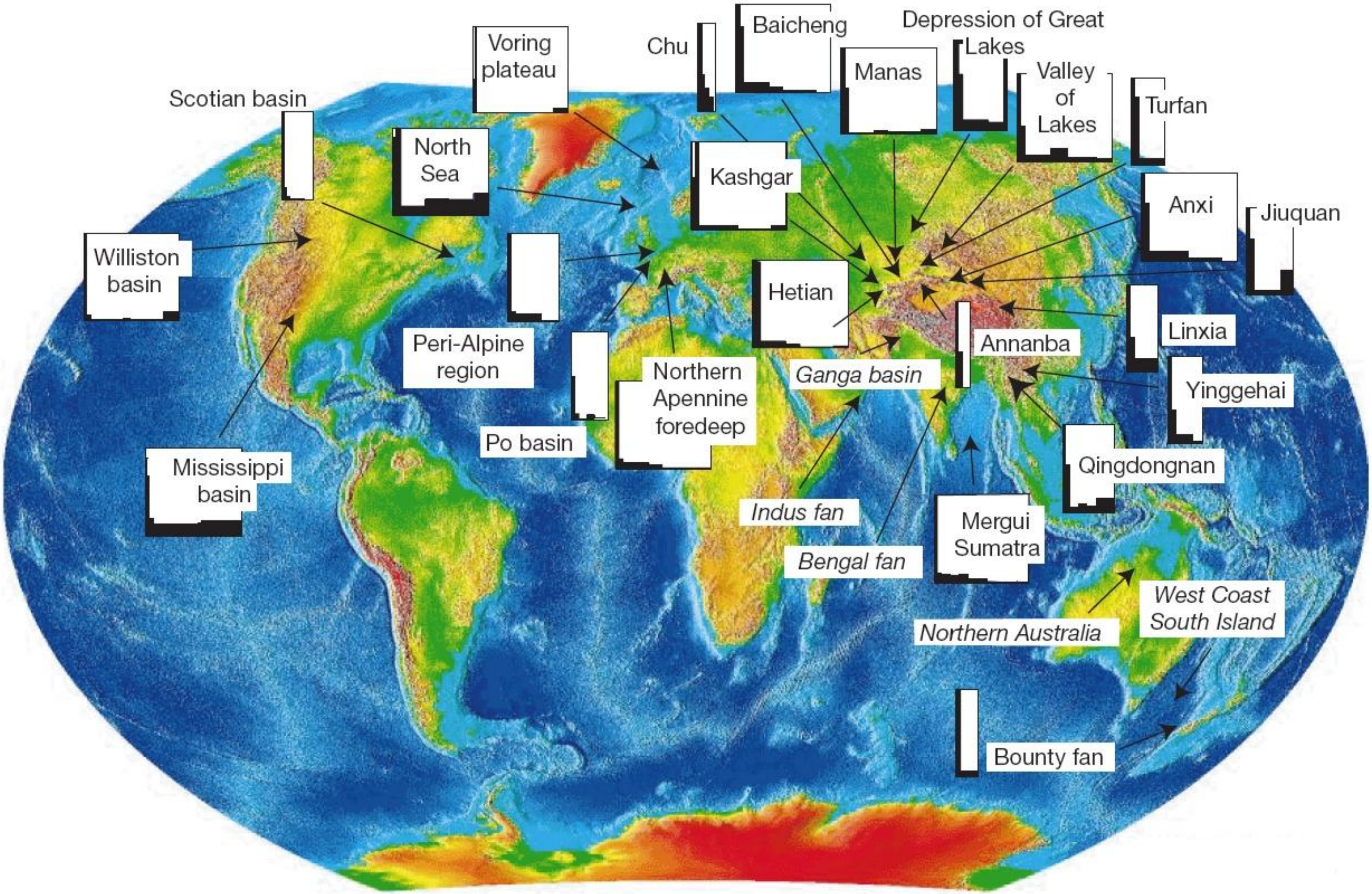


Figure 1 Plot of $\delta^{18}O$ from benthic foraminifers since 25 Myr ago, showing increases in mean values and in variability since ~4 Myr ago. The former increases imply cooling, and the latter increases imply an increasingly variable climate. Values (in ‰) have been measured largely (~95%) from fossil tests of *Cibicoides* spp., or adjusted to be equivalent to those of *Cibicoides* (ref. 63), from the Ceara rise in the eastern equatorial Atlantic Ocean (Ocean Drilling Project sites 925, 926 and 926). Values are plotted increasing downwards to reflect cooling. Data are from refs 62–66, and from T. Bickert and W. B. Curry, personal communication.



Voring plateau
Chu
Baicheng
Depression of Great Lakes
Manas
Valley of Lakes
Turfan
Scotian basin
North Sea
Kashgar
Anxi
Jiuquan
Williston basin
Hetian
Linxia
Peri-Alpine region
Annanba
Northern Apennine foredeep
Ganga basin
Yinggehai
Po basin
Mississippi basin
Qingdongnan
Indus fan
Mergui Sumatra
Bengal fan
West Coast South Island
Northern Australia
Bounty fan

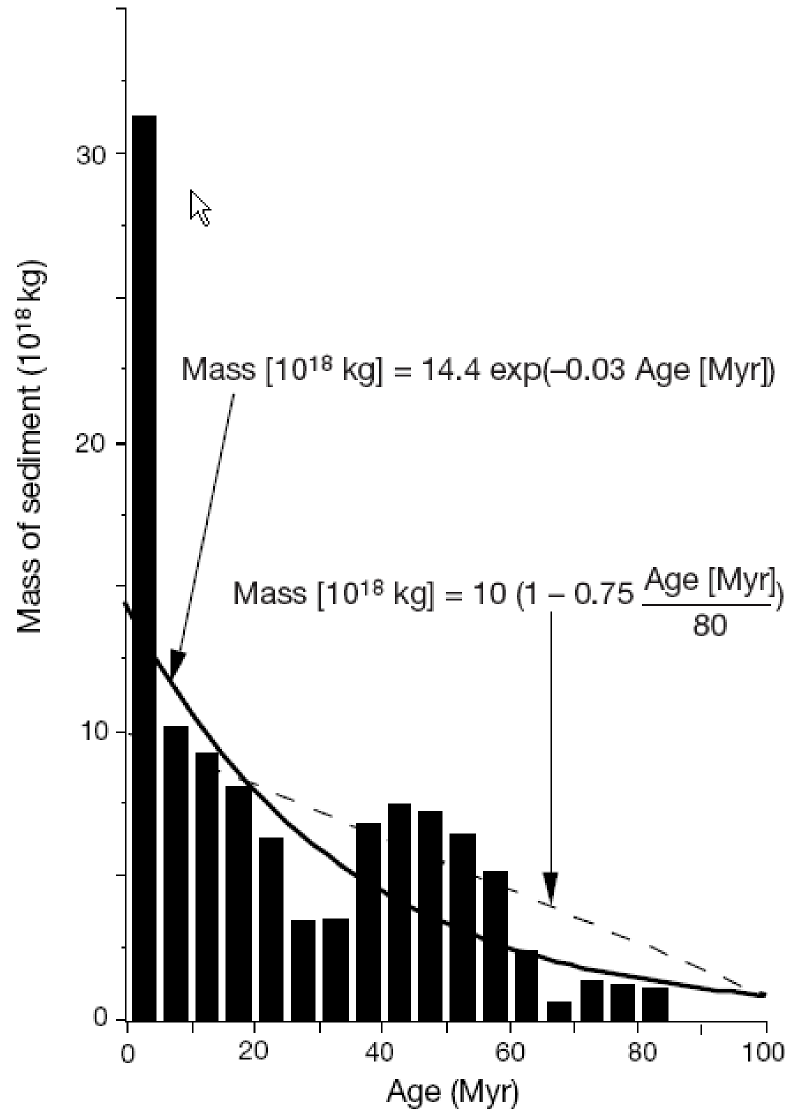
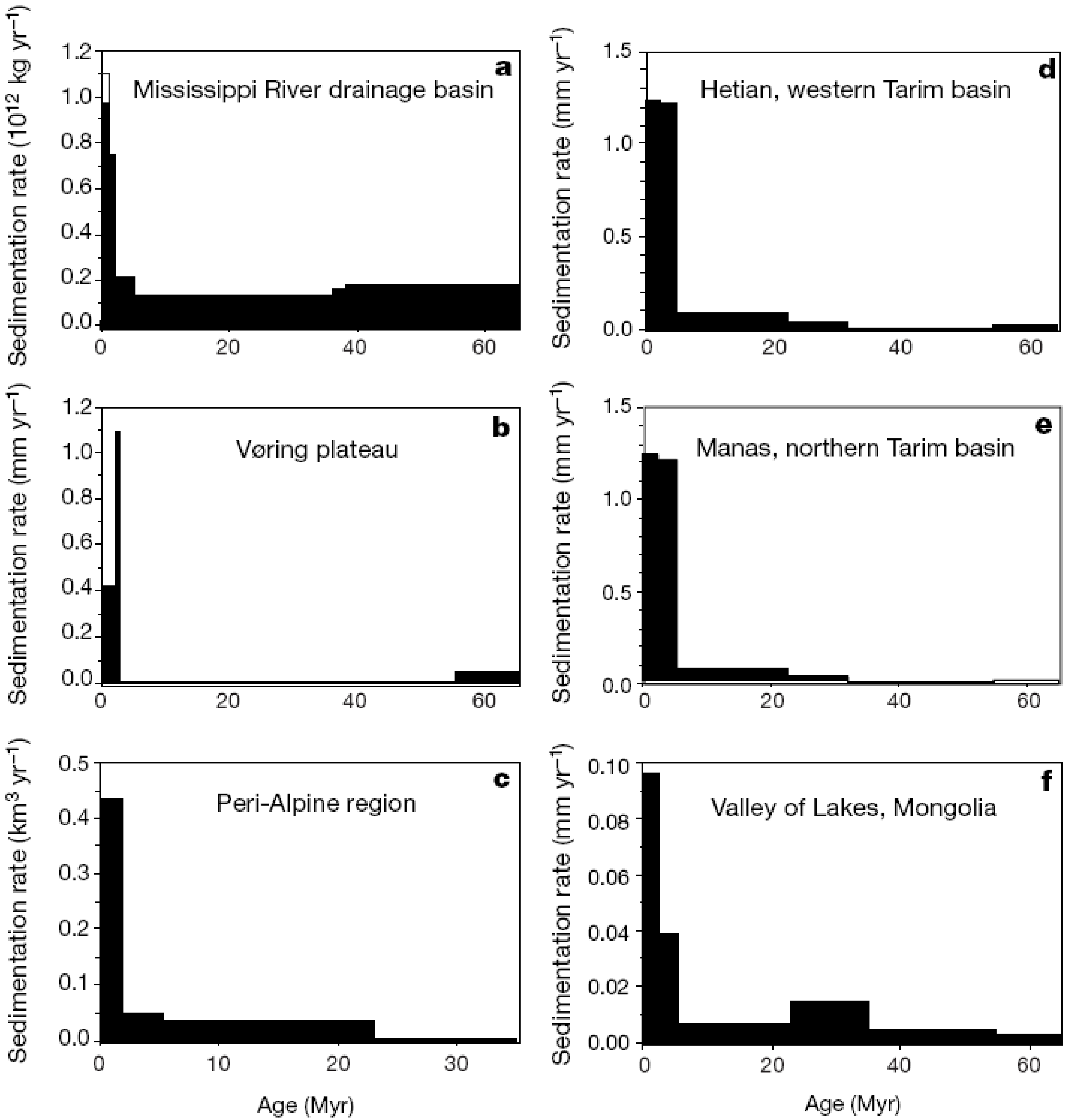


Figure 3 Histogram of terrigenous sediment deposited in the world's oceans, compiled by Hay *et al.*[6]. We note the abrupt increase since ~5 Myr ago. The solid curve is an exponential fit to the data; it deviates markedly from the sedimentation rate since 5 Myr ago. The global sea floor contains nearly all the floor created in the past 5 Myr but only a



a
Mississippi River drainage basin
Sedimentation rate (10^12 kg yr^−1)
b
Vøring plateau
Sedimentation rate (mm yr^−1)
c
Peri-Alpine region
Sedimentation rate (km^3 yr^−1)
d
Hetian, western Tarim basin
Sedimentation rate (mm yr^−1)
e
Manas, northern Tarim basin
Sedimentation rate (mm yr^−1)
f
Valley of Lakes, Mongolia
Sedimentation rate (mm yr^−1)
Age (Myr)
Age (Myr)

may incise and denude surfaces more rapidly than would equable climates climate of any kind alone, even if erosion has occurred during only part of the past few million years. We consider that the increased sedimentation of coarser material since 2–4 Myr ago may have been caused by a climate shift. This shift was from a relatively unvarying climate, to one that oscillated between states that prepared the surface during some periods—by chemical weathering, periglacial fracturing, or other forms of mass wasting—and states that transported material.

Received 5 September 2000; accepted 2 March 2001.

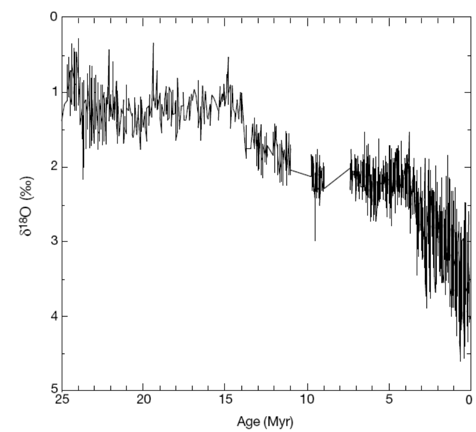
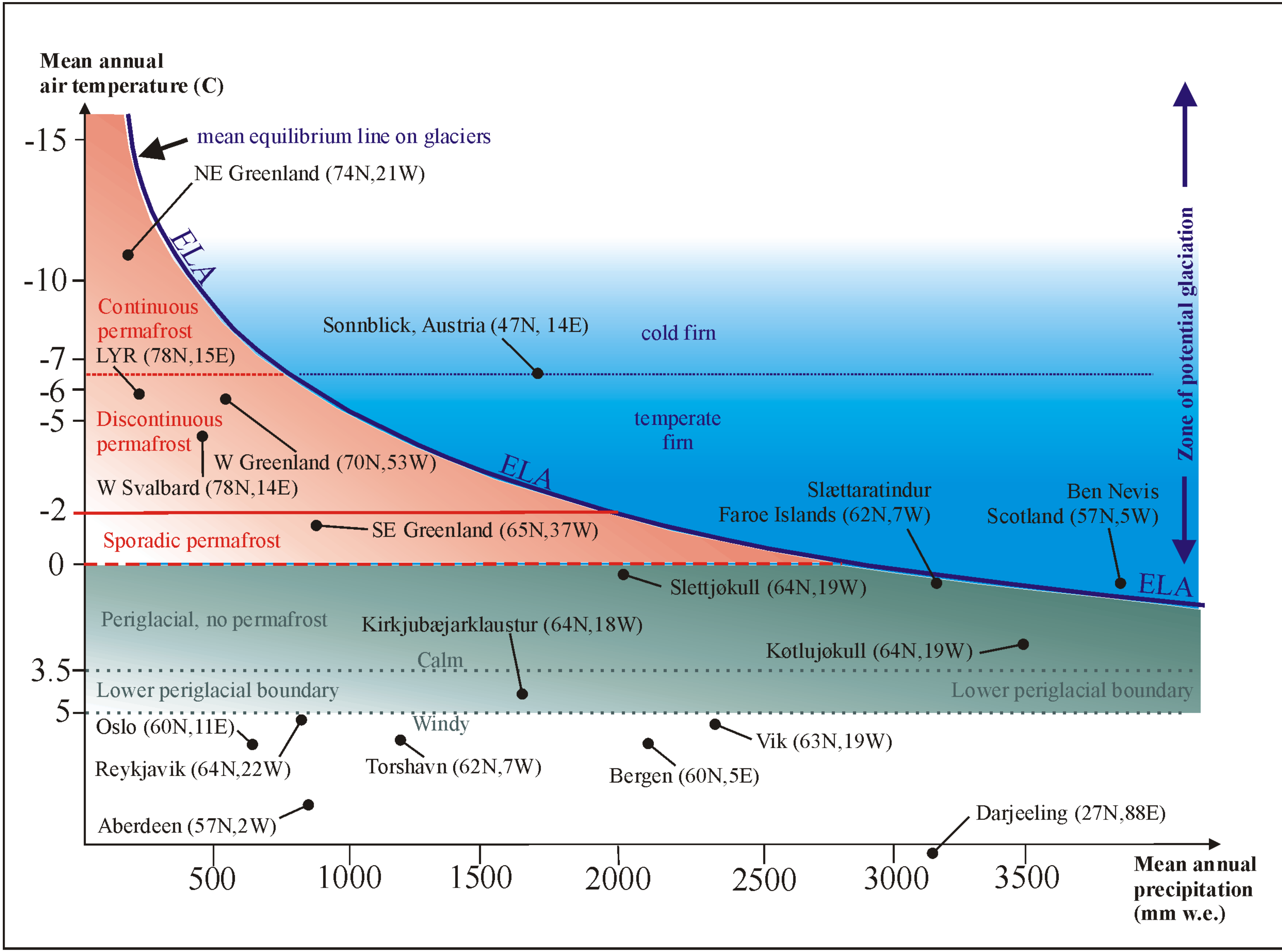


Figure 1 Plot of $\delta^{18}O$ from benthic foraminifers since 25 Myr ago, showing increases in mean values and in variability since ~4 Myr ago. The former increases imply cooling, and the latter increases imply an increasingly variable climate. Values (in ‰) have been measured largely (~95%) from fossil tests of *Cibicoides* spp., or adjusted to be equivalent to those of *Cibicoides* (ref. 63), from the Ceara rise in the eastern equatorial Atlantic Ocean (Ocean Drilling Project sites 925, 926 and 926). Values are plotted increasing downwards to reflect cooling. Data are from refs 62–66, and from T. Bickert and W. B. Curry, personal communication.

Glaciers



Mean annual
air temperature (C)
-15
-10
-7
-6
-5
-2
0
3.5
5
mean equilibrium line on glaciers
NE Greenland (74N,21W)
ELA
Continuous
permafrost
LYR (78N,15E)
Sonnblick, Austria (47N, 14E)
cold firn
temperate
firn
Zone of potential glaciation
Discontinuous
permafrost
W Greenland (70N,53W)
W Svalbard (78N,14E)
ELA
Slættaratindur
Faroe Islands (62N,7W)
Ben Nevis
Scotland (57N,5W)
Sporadic permafrost
SE Greenland (65N,37W)
Slettjøkull (64N,19W)
ELA
Periglacial, no permafrost
Kirkjubæjarklaustur (64N,18W)
Køtlujøkull (64N,19W)
Calm
Lower periglacial boundary
Lower periglacial boundary
Windy
Oslo (60N,11E)
Reykjavik (64N,22W)
Torshavn (62N,7W)
Bergen (60N,5E)
Vik (63N,19W)
Aberdeen (57N,2W)
Darjeeling (27N,88E)
500
1000
1500
2000
2500
3000
3500
Mean annual
precipitation
(mm w.e.)

Ole Humlum

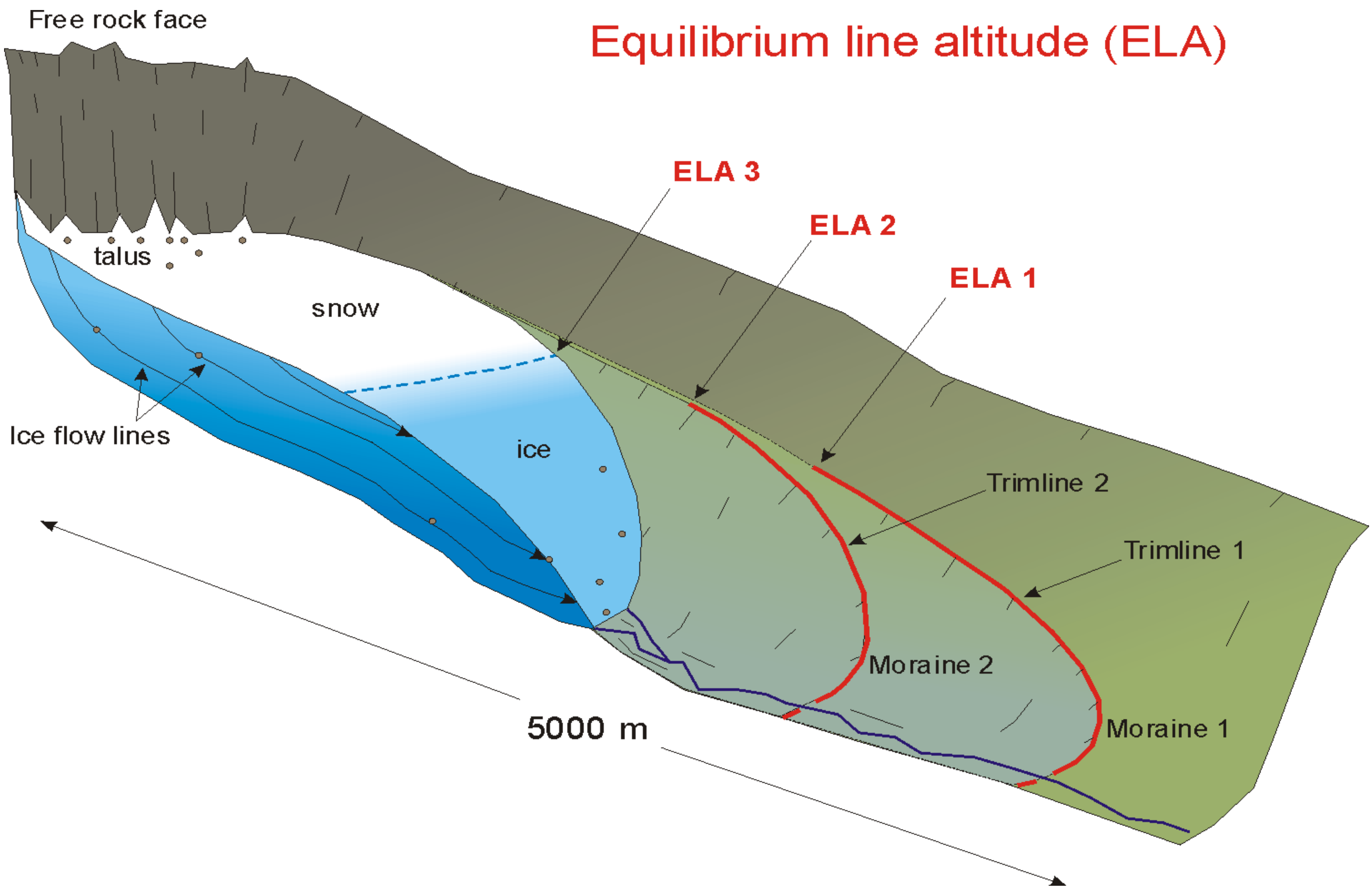
Glaciers

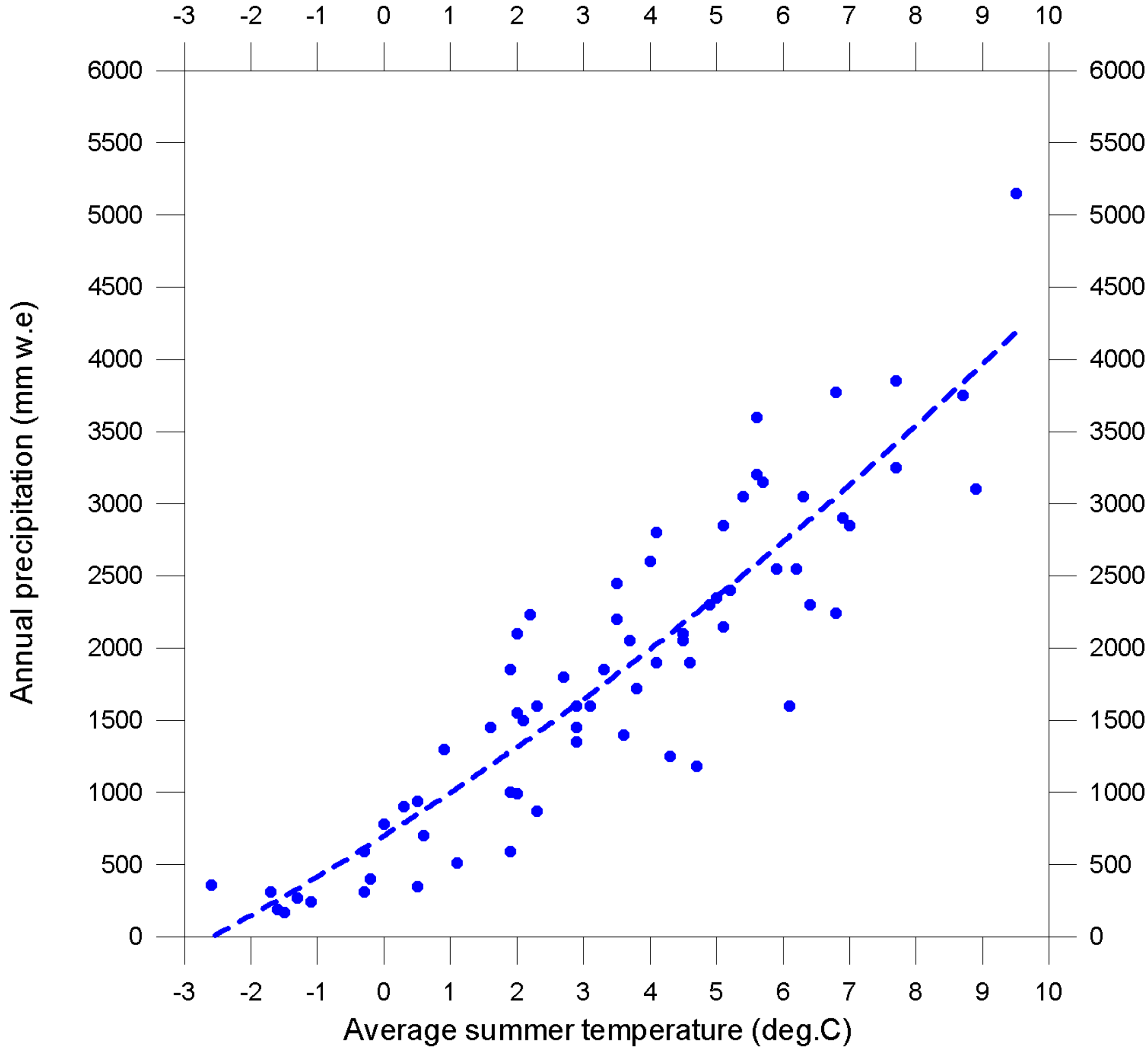
- A glacier is a deforming, superficial, multiyear deposit of snow and ice
- A glacier is a snow-ice accumulation thick enough to deform significantly by its own weight.
- Glaciers therefore usually display crevasses due to internal deformation.
- About 80% of the planets fresh water resources are bound in glaciers, covering about 10% of the total land area.
- Glaciers are highly efficient as rock debris transport agents.

The equilibrium line:

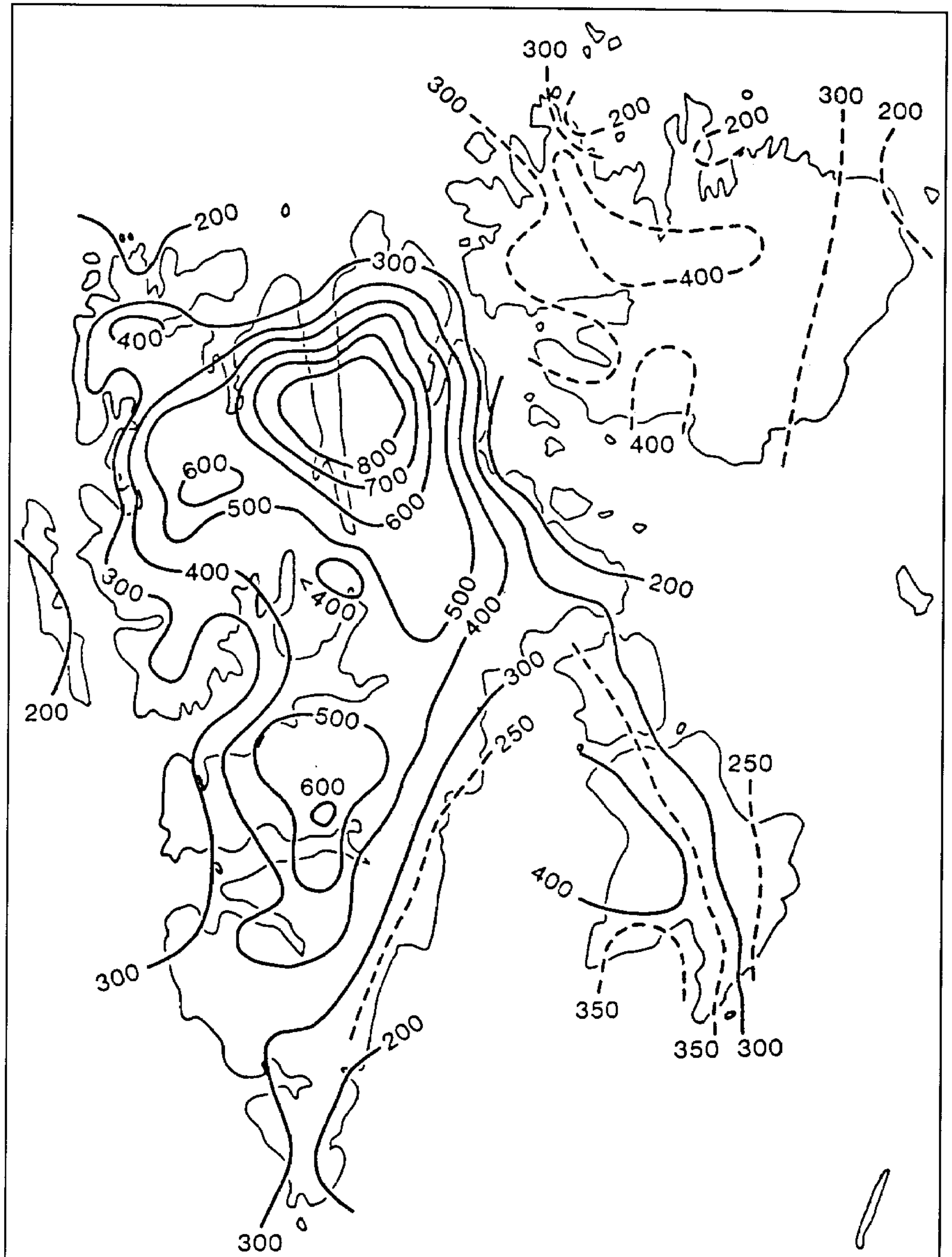
- In general, glaciers can be subdivided into two zones; an upper zone where the annual accumulation exceeds the losses by ablation, and an lower zone where ablation exceeds accumulation.

Equilibrium line altitude (ELA)





Annual precipitation (mm w.e)
Average summer temperature (deg.C)
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000


300
300
200
200
300
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200
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400
400
400
800
700
600
600
500
600
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400
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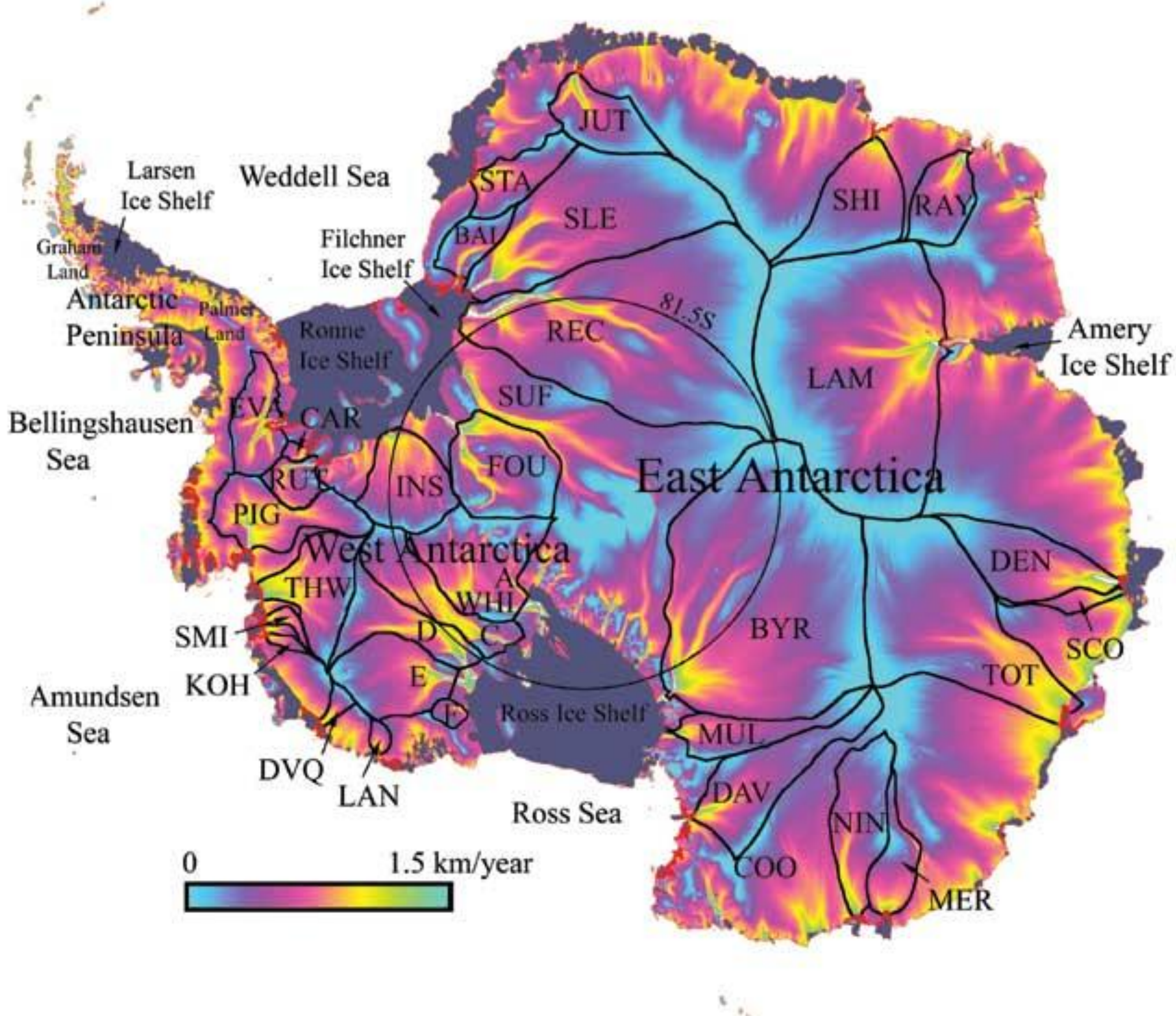
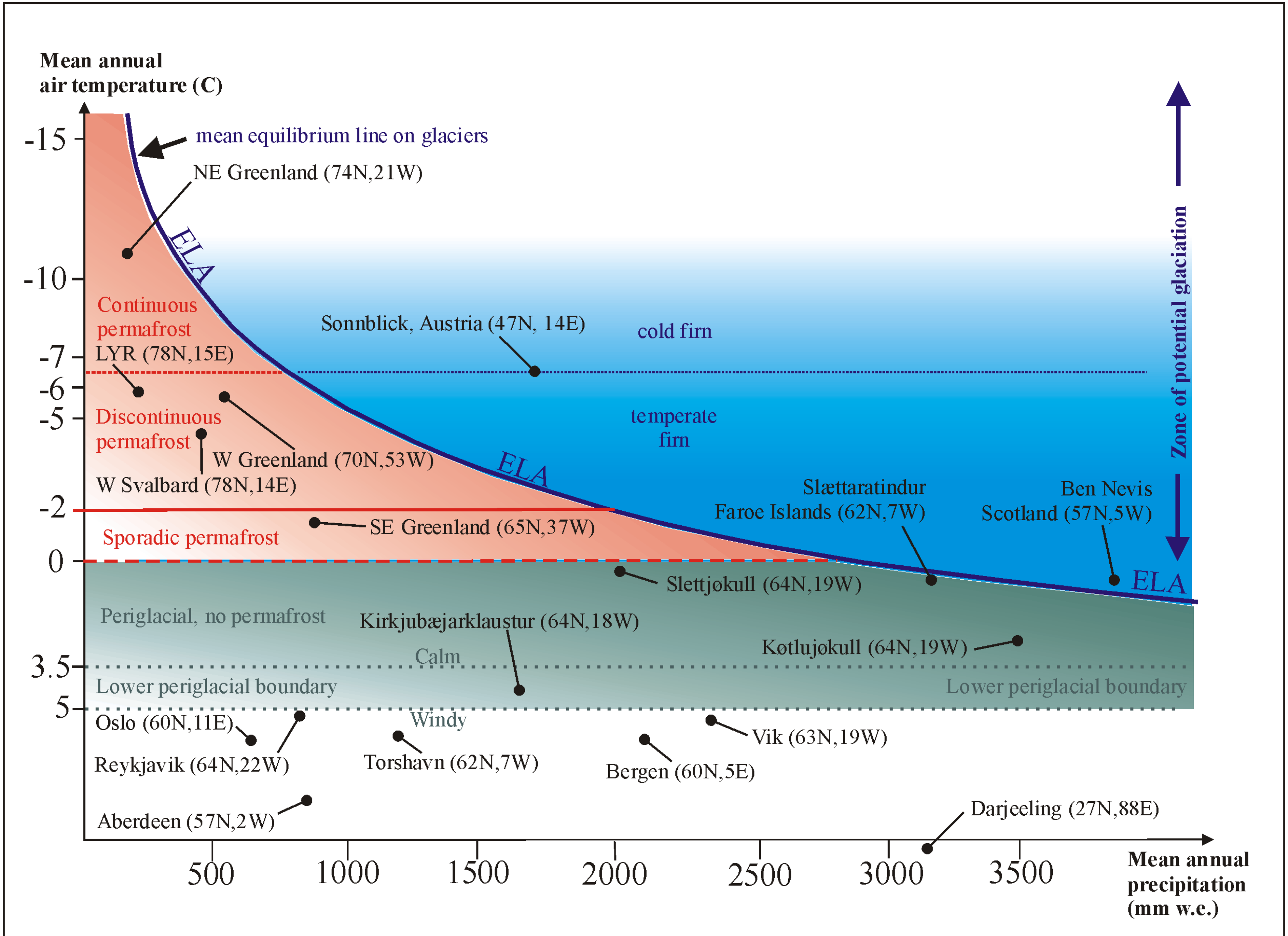
350
350
300
200
300


Larsen Ice Shelf
Weddell Sea
Graham Land
Antarctic Peninsula
Palmer Land
Filchner Ice Shelf
Ronne Ice Shelf
Bellingshausen Sea
Amundsen Sea
Ross Sea
Ross Ice Shelf
Amery Ice Shelf
East Antarctica
West Antarctica
81.5S
JUT
STA
SLE
BAL
SHI
RAY
REC
LAM
SUF
FOU
INS
EVA
CAR
RUT
PIG
THW
A
WHI
D
C
E
F
SMI
KOH
DVQ
LAN
BYR
DEN
SCO
TOT
MUL
DAV
COO
NIN
MER
0
1.5 km/year

Periglacial environments



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Faroe Islands (62N,7W)
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Periglacial, no permafrost
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Lower periglacial boundary
Lower periglacial boundary
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Torshavn (62N,7W)
Bergen (60N,5E)
Vik (63N,19W)
Aberdeen (57N,2W)
Darjeeling (27N,88E)
500
1000
1500
2000
2500
3000
3500
Mean annual
precipitation
(mm w.e.)

Ole Humlum

The periglacial environment

Definition:

Periglacial environments are characterised by frost action and the recurrent presence of a snow cover. If the ground surface consists of sediments, sorted ground phenomena are widespread.

Periglacial environments may have permafrost but many periglacial regions have not.

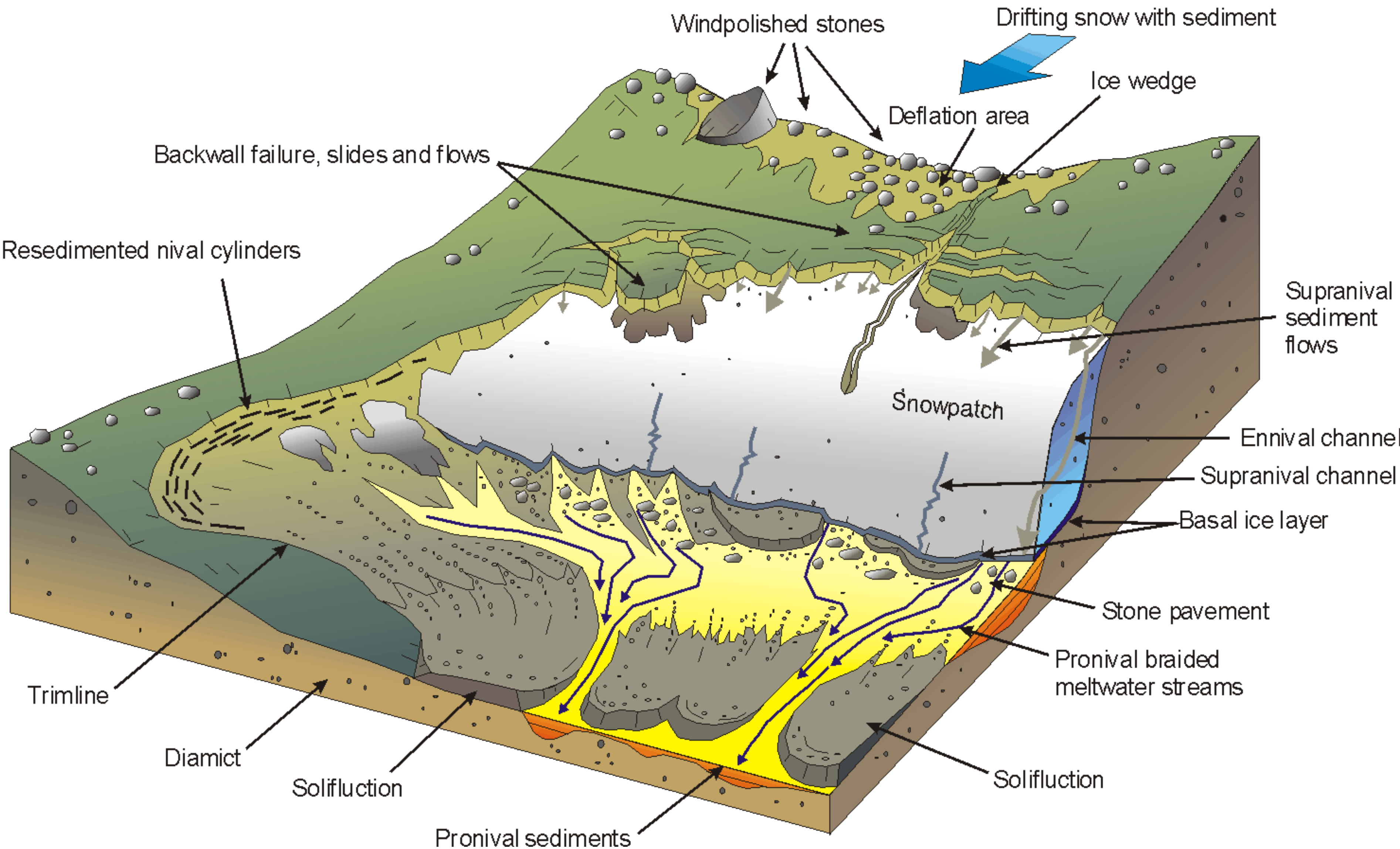
Characteristics of periglacial environments

- Freezing and thawing of the ground
- Permafrost may or may not be present
- Solifluction and patterned ground of a frost-action nature frequent
- Regions with a mean annual air temperature (MAAT) below 3^{o}C (5^{o}C in windy regions) are usually considered periglacial
- The most important ecological boundary associated with the delimitation of periglacial environments is presumably the treeline

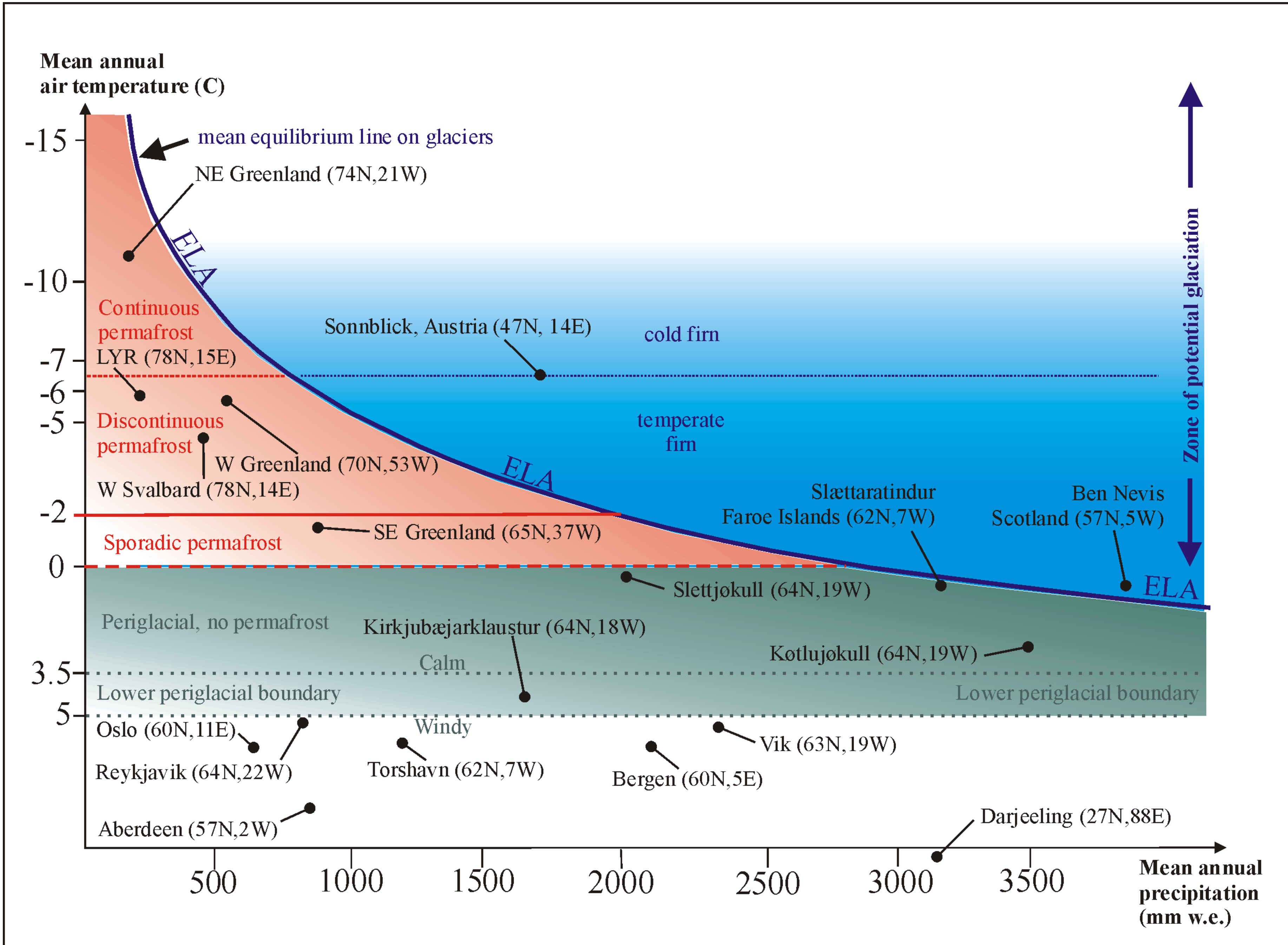
Periglacial environments

Nivation

High Arctic Nivation Process-Form-Sediment Model



Permafrost



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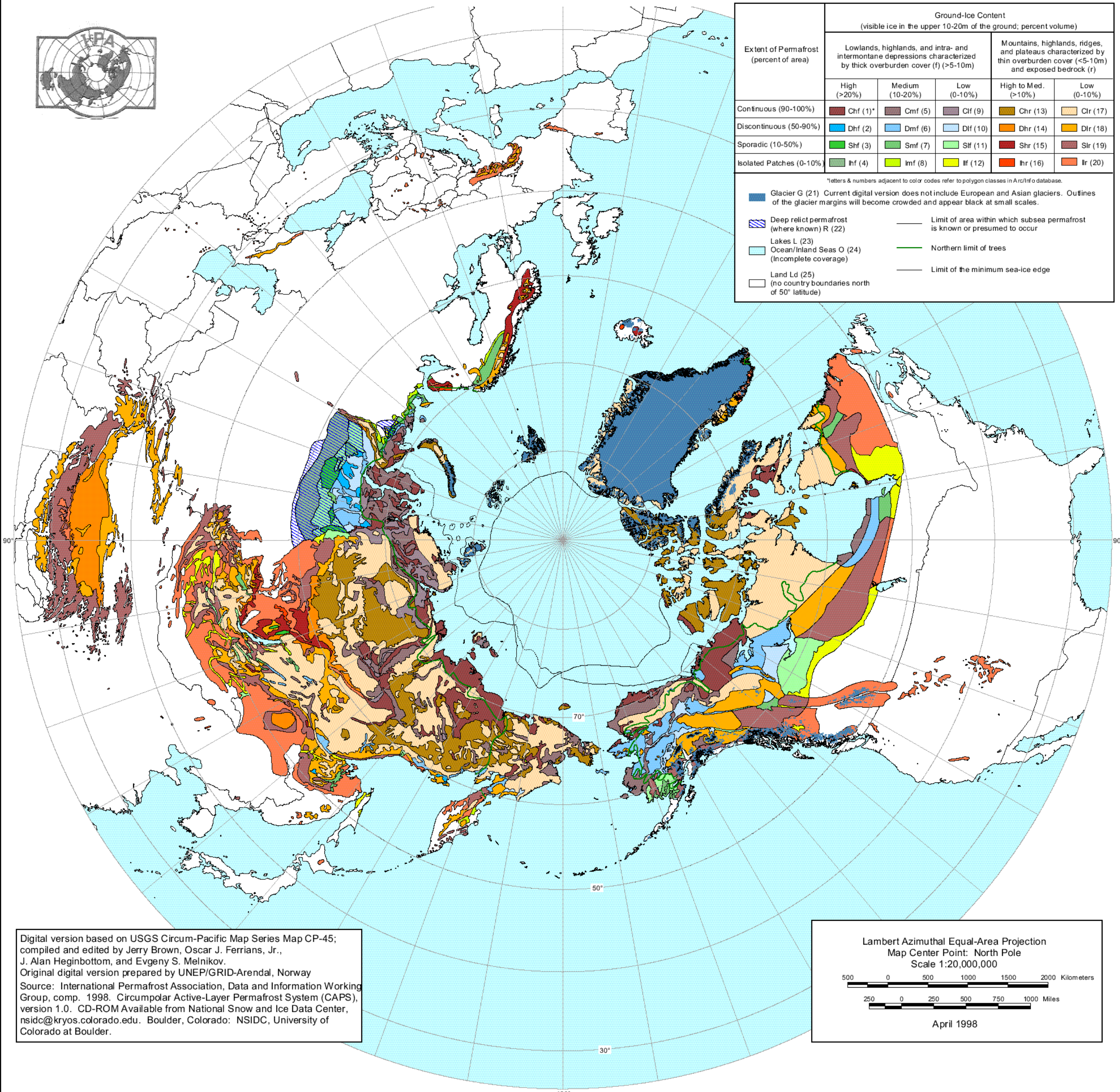
Ole Humlum

Permafrost definition

Permafrost is defined on the basis of **temperature**: that is ground (i.e. soil, sediments, bedrock, etc.) that remains at or below 0^oC (i.e. the pressure melting point for pure ice) for at least two consecutive years. Moisture, in the form of water or ice, may or may not be present in permafrost.

Permafrost may not necessarily be frozen since the freezing point of included water may be depressed several degrees below 0^oC.

CIRCUM-ARCTIC MAP OF PERMAFROST AND GROUND-ICE CONDITIONS



Extent of Permafrost (percent of area)	Ground-Ice Content (visible ice in the upper 10-20m of the ground; percent volume)				
	Lowlands, highlands, and intra- and intermontane depressions characterized by thick overburden cover (f) (>5-10m)			Mountains, highlands, ridges, and plateaus characterized by thin overburden cover (<5-10m) and exposed bedrock (r)	
	High (>20%)	Medium (10-20%)	Low (0-10%)	High to Med. (>10%)	Low (0-10%)
Continuous (90-100%)	Chf (1)*	Cmf (5)	Clf (9)	Chr (13)	Clr (17)
Discontinuous (50-90%)	Dhf (2)	Dmf (6)	Dlf (10)	Dhr (14)	Dlr (18)
Sporadic (10-50%)	Shf (3)	Smf (7)	Slf (11)	Shr (15)	Slr (19)
Isolated Patches (0-10%)	Ihf (4)	Imf (8)	Ilf (12)	Ihr (16)	Ilr (20)

*letters & numbers adjacent to color codes refer to polygon classes in Arc/Info database.

Glacier G (21) Current digital version does not include European and Asian glaciers. Outlines of the glacier margins will become crowded and appear black at small scales.

Deep relict permafrost (where known) R (22)

Lakes L (23)
Ocean/Inland Seas O (24)
(Incomplete coverage)

Land Ld (25)
(no country boundaries north of 50° latitude)

Limit of area within which subsea permafrost is known or presumed to occur

Northern limit of trees

Limit of the minimum sea-ice edge

Digital version based on USGS Circum-Pacific Map Series Map CP-45; compiled and edited by Jerry Brown, Oscar J. Ferrians, Jr., J. Alan Heginbottom, and Evgeny S. Melnikov.
Original digital version prepared by UNEP/GRID-Arendal, Norway

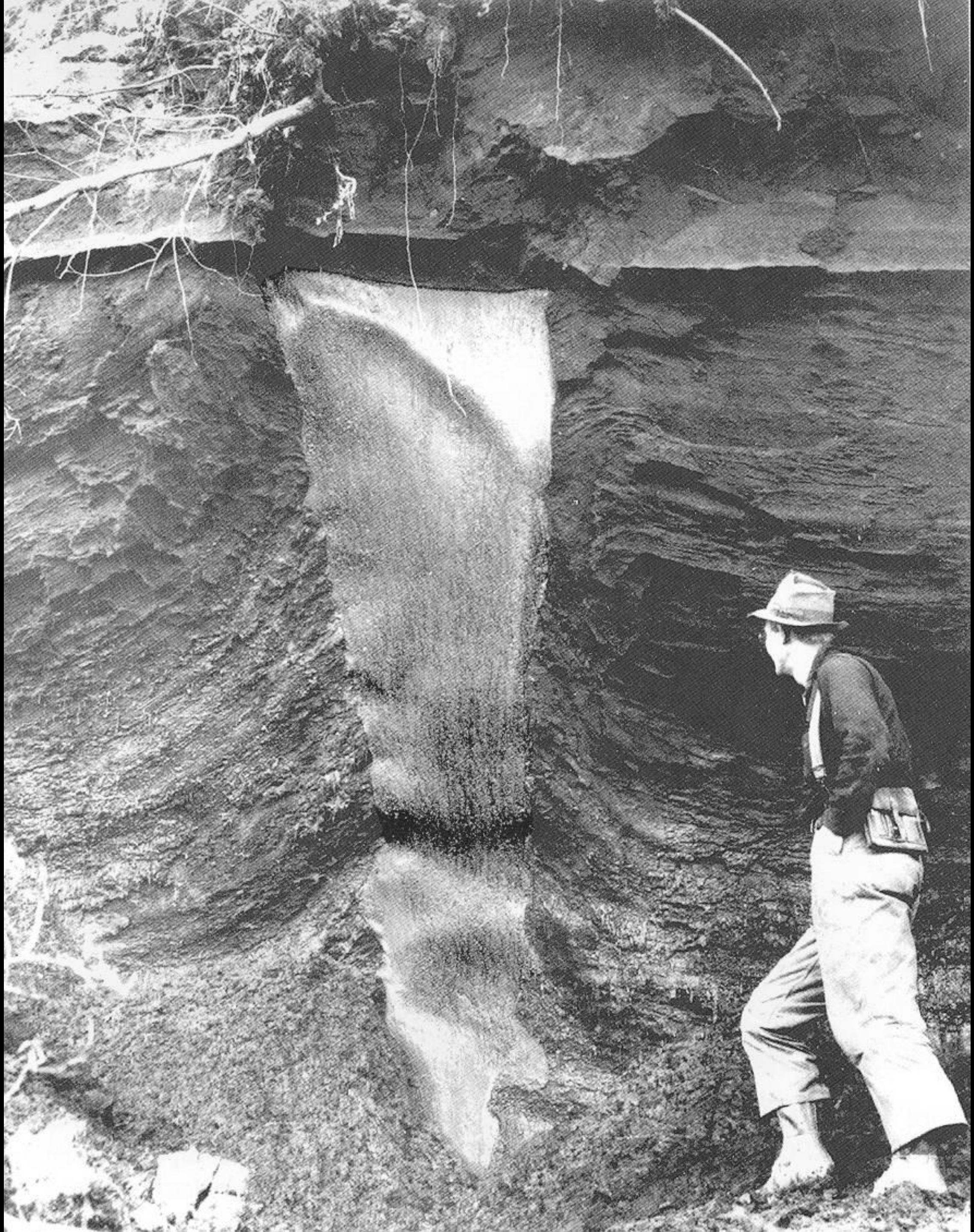
Source: International Permafrost Association, Data and Information Working Group, comp. 1998. Circumpolar Active-Layer Permafrost System (CAPS), version 1.0. CD-ROM Available from National Snow and Ice Data Center, nsidc@kryos.colorado.edu. Boulder, Colorado: NSIDC, University of Colorado at Boulder.

Lambert Azimuthal Equal-Area Projection
Map Center Point: North Pole
Scale 1:20,000,000

500 0 500 1000 1500 2000 Kilometers

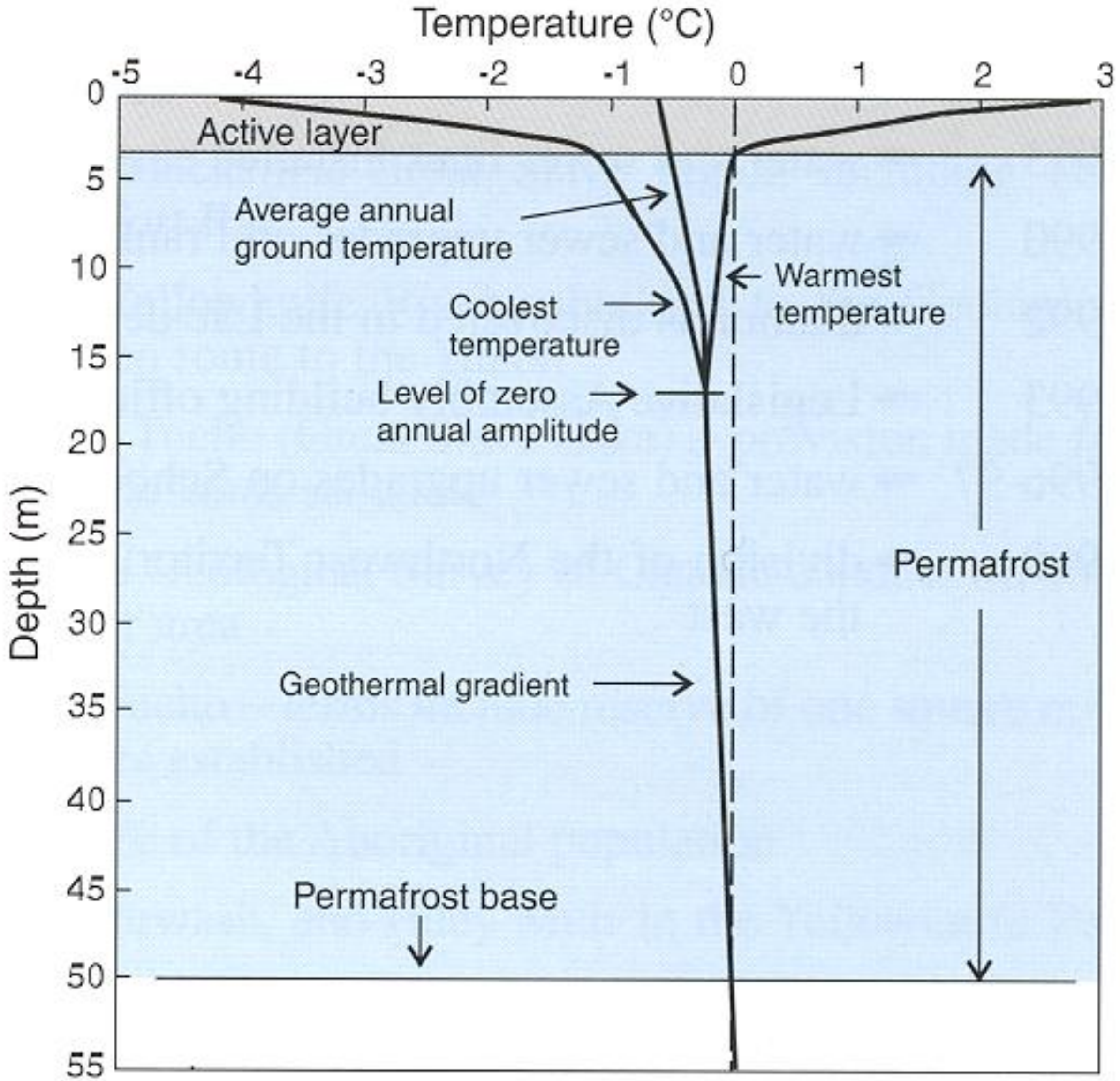
250 0 250 500 750 1000 Miles

April 1998



Ice wedge exposed in river bank, Alaska

Thickness of permafrost ?



Permafrost Regions in the Soviet Union

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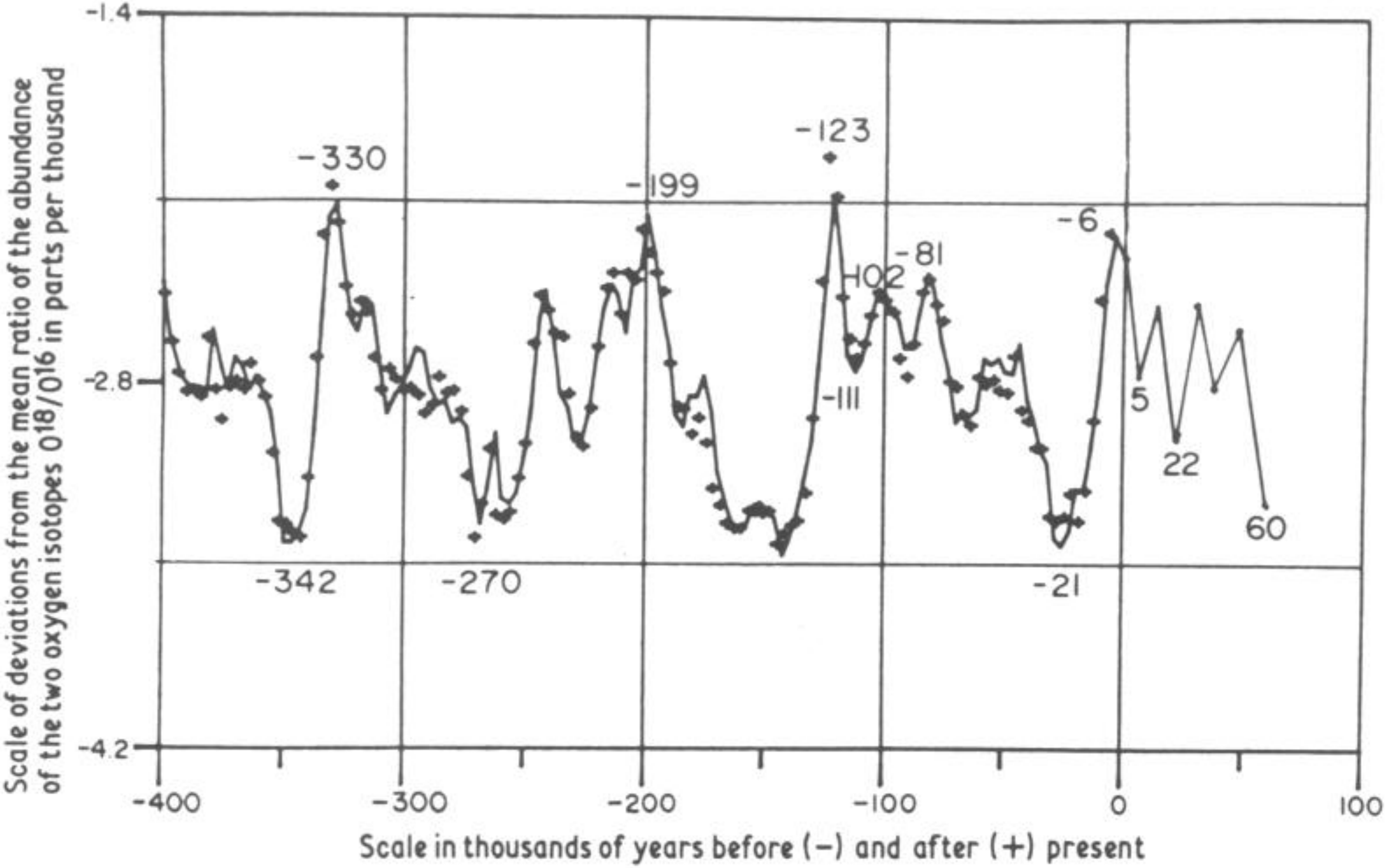
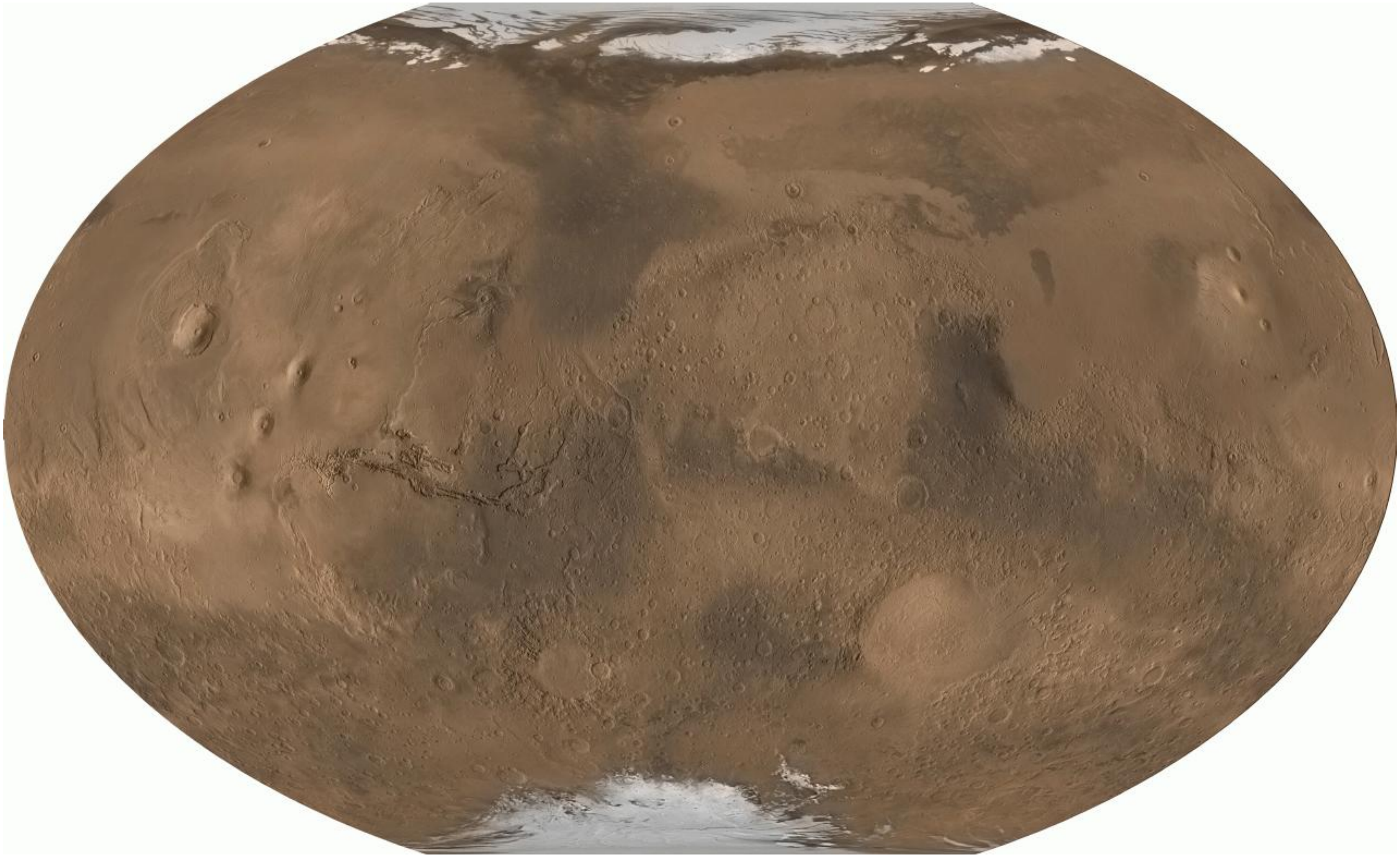


-1.4
-2.8
-4.2
-330
-199
-123
-6
-81
-102
-111
5
22
60
-342
-270
-21
-400
-300
-200
-100
0
100
Scale of deviations from the mean ratio of the abundance of the two oxygen isotopes O18/O16 in parts per thousand
Scale in thousands of years before (–) and after (+) present

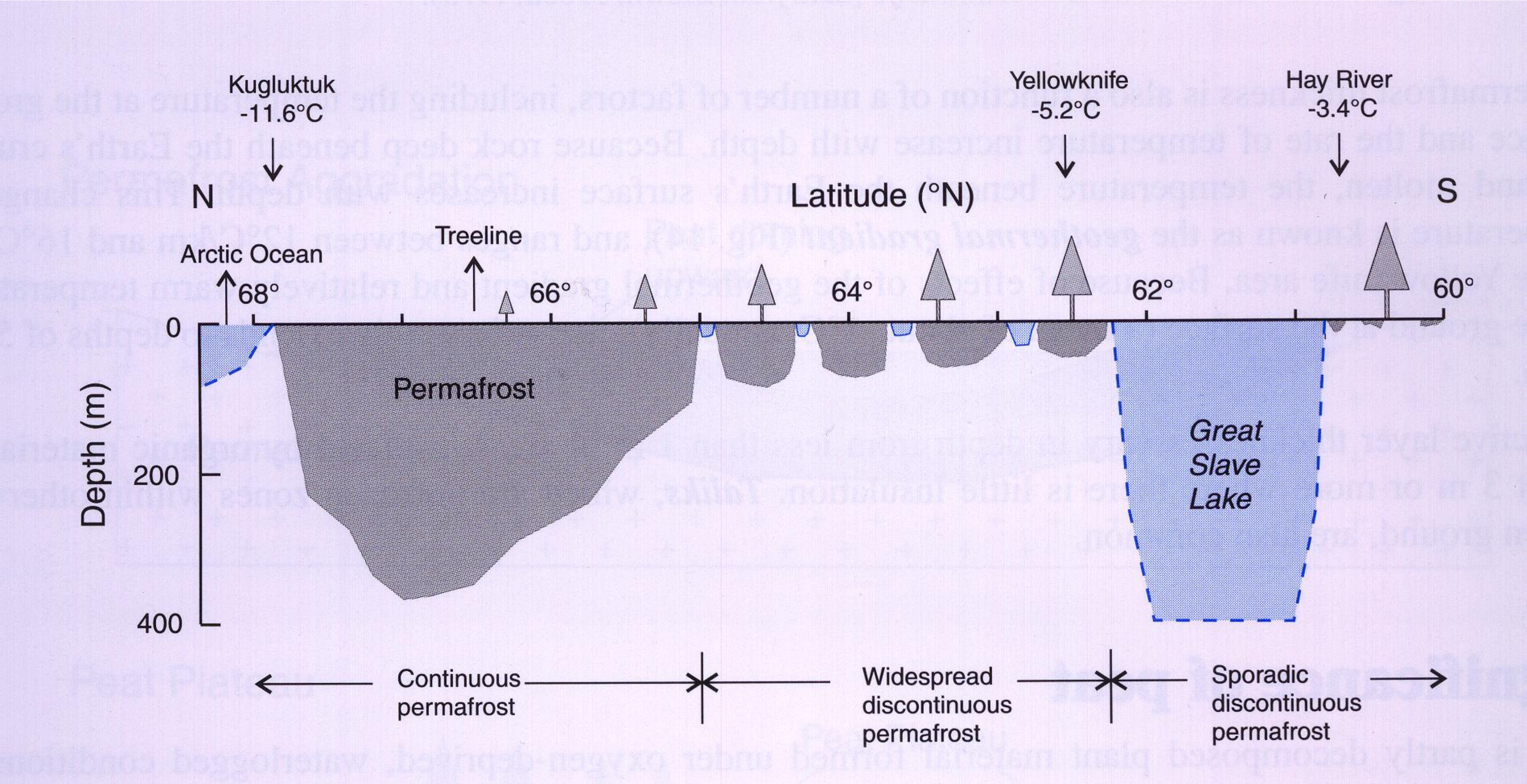
Past distribution of permafrost

During the last glacial period, permafrost covered about 50% of the land surface on planet Earth



Permafrost on other planets !

Permafrost transect north-south in Canada



-6°C -2°C 0°C

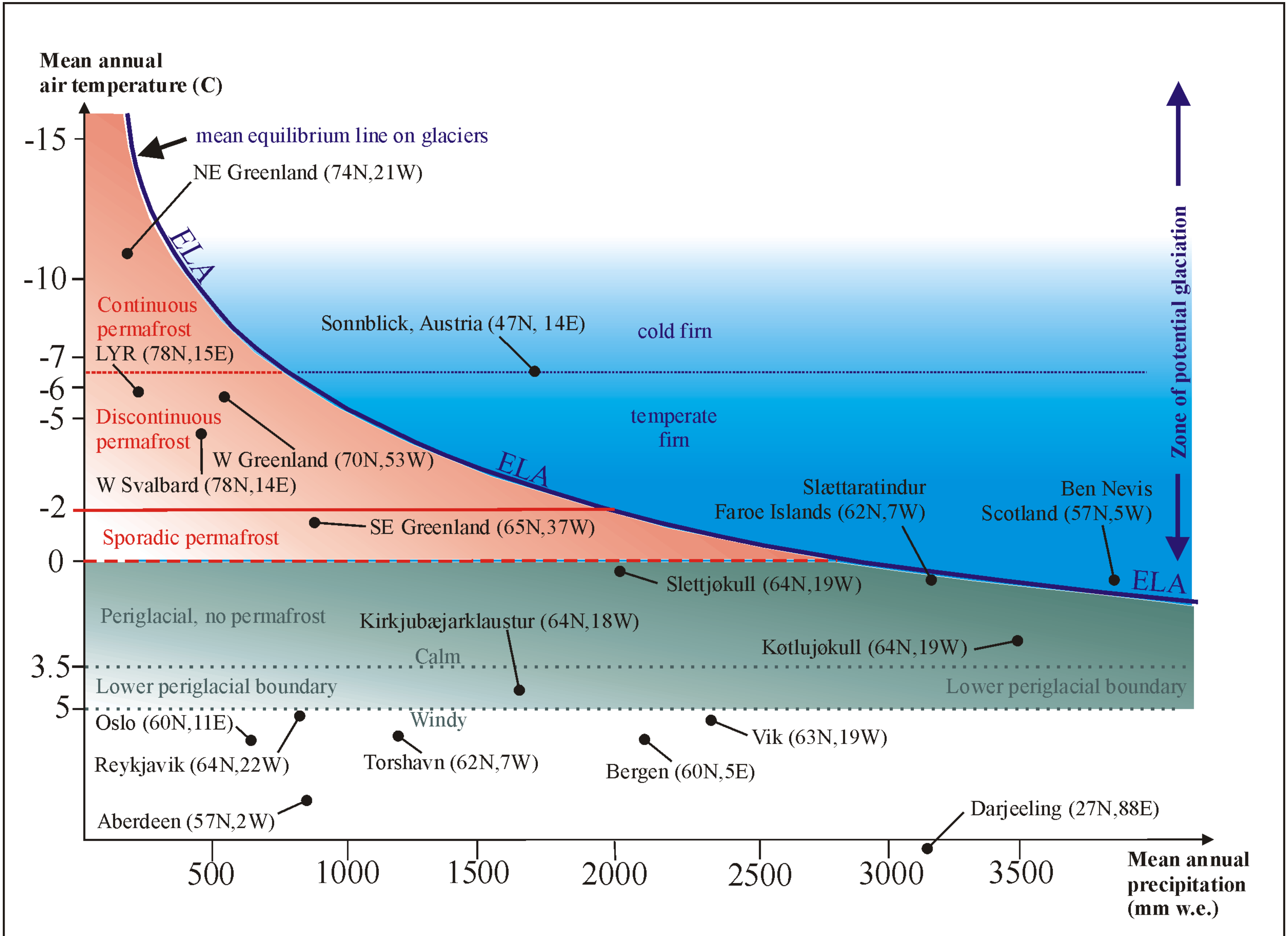
Permafrost significance:

In modern times, permafrost covers about 25% of the non-glaciated land surface

During the Quaternary glacial periods, permafrost covered about 50% of the non-glaciated land surface

Permafrost thickness and distribution varies with climate

A series of specific problems arise during construction work in permafrost regions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