Periglacial geomorphology

GEG 2130

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Periglacial

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.

Please note:
Periglacial environments may have permafrost but many periglacial regions have not.
Periglacial climate types

![Diagram of periglacial climate types with various locations and data points.](image)

Figure 3.2 Freezing and thawing conditions in various periglacial environments of the world: (a) Yakutsk (lat. 62°01'N, long. 129°43'E, altitude 108 m); (b) Tuktoyaktuk (lat. 69°27'N, long. 133°02'W, altitude -10 m); Mackenzie Delta (c) Svalbard (lat. 78°02'N, long. 14°14'E, altitude 7 m); (d) Fenghuo Shan Qinghai-Khong (Tibet) Plateau, China (lat. 34°20'N, long. 92°52'E, altitude 4800 m); (e) El Misti (Mont Blanc Station), South Peru (lat. 16°16'S, long. 71°25'W, altitude 4760 m); (f) El Misti (Summit Station), South Peru (lat. 16°16'S, long. 71°25'W, altitude 5850 m); (g) Sonnblick, Austrian Alps (lat. 47°05'N, long. 12°57'E, altitude 3060 m); (h) Kerguelen Island (lat. 49°30'S, long. 69°30'E, altitude sea level). (Sources: (a), (c), (e) and (f) from Troll, 1944; (b) from AES records, Canada; (d) constructed from monthly means of air temperatures recorded at Fenghuo Shan by Northwest Railway Institute personnel).
Further notes about 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

• The most important ecological boundary associated with the delimitation of periglacial environments is presumably the treeline

• Regions with a mean annual air temperature (MAAT) below 3°C (5°C in windy regions) should be considered periglacial
The Arctic

(Greek: Arktos = Bear)
Sornfelli meteorological station
Planned and designed: spring 1999
Established: May-Nov 1999
Operation since Nov 1999
Data analysis: Year 2000
MAAT: 1.71°C
MAWS: 6.5 m/s N, SV, SØ
MALapse rate: -0.0077°C/m

High arctic (WM 5°C)  

5.5°C WM  1.2°C MAAT (856 m asl)

**ET polar climate – arctic climate**

Low arctic (WM 10°C, at 200 m asl)

6.6°C MAAT (33 m asl) **subarctic climate**  WM 10.4°C

Potential permafrost zone 150-200 m above highest tops

Modern altitudinal climate zonation
The Polar zone
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°C (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.

However:

Permafrost may not necessarily be frozen since the freezing point of included water may be depressed several degrees below 0°C.
Distribution on Northern hemisphere

Permafrost alpine and arctic

Asymmetrical distribution

Zonation:
Continuous
Discontinuous
Sporadic
Patchy
Submarine
Permafrost importance:

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.
Permafrost temperature profile

Figure 4.5 (a) Illustration of a step change model for climatic change. (b) Sequence of geothermal response to a surface temperature step change (from Molochuskin, 1973).
Figure 6.6  A genetic classification of ground ice (after Mackay, 1972b).
Ice content in the permafrost influence seal capacities and melting rates
Permafrost thickness

Svalbard permafrost thickness
Janssonhaugen permafrost observatory:

Fig. 3. Seasonal temperature profiles for the uppermost 20 m of the Janssonhaugen borehole during the first year after drilling. The year is divided into five readings with equal intervals (73 days). Dates are in dd.mm.yy. The dotted line represents the mean annual temperatures.
‘Significant warming is detectable down to at least 60m depth, and present decadal warming rates at the permafrost surface are on the order of 0.04–0.07°C/yr’

(Isaksen et al., 2007)
Permafrost Observatory Project: A contribution to the Thermal State of Permafrost in Norway and in Svalbard

Project focus:
1) Permafrost temperatures in boreholes - snapshot
2) Permafrost landform activity
3) Permafrost observatories in Troms and in Svalbard
4) National permafrost database
5) Permafrost modelling – first permafrost map of Norway
6) Permafrost Int. University Course in Svalbard and Greenland

TSP Norway 8 new and 2 existing boreholes Longyearbyen - Adventdalen
Permafrost boreholes drilled during winter 2008
Now online permafrost temperatures in Svalbard from www.unis.no
UNIS students drilling to 3 m – ice content & temperature
<table>
<thead>
<tr>
<th>Borehole name</th>
<th>Depth (m)</th>
<th>Present instrumentation</th>
<th>Best instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kapp Linne 1</td>
<td>30</td>
<td>2 * Geoprecision (0, 0.25, 0.5, 1, 2, 3, 4, 5, 7, 10, 10.25, 10.5, 11, 12, 13, 14, 15, 17, 20m)</td>
<td>Termistorstreng (+/- 0.01 degC)</td>
</tr>
<tr>
<td>Kapp Linne 2</td>
<td>38.8</td>
<td>-</td>
<td>Termistorstreng (+/- 0.01 degC)</td>
</tr>
<tr>
<td>Kapp Linne 3</td>
<td>4</td>
<td>-</td>
<td>Miniloggere/ 1 * Geoprecision</td>
</tr>
<tr>
<td>Longyearbyen skole</td>
<td>9.8</td>
<td>1 * Geoprecision (0, 0.25, 0.50, 1, 2, 3, 4, 5, 7, 9m)</td>
<td>1 * Geoprecision</td>
</tr>
<tr>
<td>Gruvefjellet</td>
<td>5</td>
<td>Koblet til online værstasjon (0, 1, 2, 3, 4, 5m)</td>
<td>Koblet til online værstasjon</td>
</tr>
<tr>
<td>Larsbre-steinbreen</td>
<td>11.5</td>
<td>1 * Geoprecision (1, 2, 3, 4, 5, 6, 7, 8, 9, 11m)</td>
<td>1 * Geoprecision</td>
</tr>
<tr>
<td>Pingo</td>
<td>19.1</td>
<td>2 * Geoprecision (0, 0.25, 0.5, 1, 2, 3, 4, 5, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19m)</td>
<td>2 * Geoprecision</td>
</tr>
<tr>
<td>Endalen</td>
<td>19.7</td>
<td>-</td>
<td>Termistorstreng (+/- 0.01 degC)</td>
</tr>
<tr>
<td>Snøleie 1</td>
<td>5.4</td>
<td>-</td>
<td>1 * Geoprecision</td>
</tr>
<tr>
<td>Snøleie 2</td>
<td>10</td>
<td>-</td>
<td>1 * Geoprecision</td>
</tr>
<tr>
<td>Gml. Nordlysst.</td>
<td>9.9</td>
<td>-</td>
<td>1 * Geoprecision</td>
</tr>
<tr>
<td>Ny-Ålesund</td>
<td>10</td>
<td>-</td>
<td>1 * Geoprecision</td>
</tr>
<tr>
<td>Colesbukta 1</td>
<td>6</td>
<td>-</td>
<td>1-2 * Geoprecision</td>
</tr>
<tr>
<td>Colesbukta 2</td>
<td>28</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**Permafrost database NORPERM**

[NGU logo]
Active layer definition

The active layer is defined as the top layer of ground subject to annual thawing and freezing in areas underlain by permafrost (Glossary of Permafrost and Related Ground-Ice Terms, 1988)

Figure 1. Selected terms used by the Glossary to describe the states of water and ground temperature in permafrost (after ACGR, 1988, Figure 2). Note that the active layer, as defined by Muller (1947), is described here as “seasonally cryotic” ground.
Seasonal changes in the active layer

(a) Late summer

- Permafrost table
- Permafrost
- Permafrost base

- Active layer (seasonally thawed)
- Seasonally active permafrost
- Perennially frozen
- Basal cryopeg (perennially unfrozen cryotic)

(c) Late winter

- Active layer (seasonally frozen)
- Permafrost
- Perennially frozen
- Basal cryopeg

(b) Autumn and winter (freezing)

- Cryofronts
- Freezing fronts
- Permafrost
- Basal cryopeg

(d) Spring and summer (thawing)

- Cryofront
- Thawing front
- Seasonally thawed
- Perennially frozen
- Basal cryopeg

Figure 8.2 Seasonal changes (a–d) in the active layer. The temperature relative to 0 °C and the state of water are also indicated (source: ACGR, 1988).
Temperature measurements

Ground temperature at H1 in 1998-1999

- Winter snow cover starts at 25.10
- Isolating snow cover accumulated at 20.01
- Snow melt at 03.06
- Active layer development

Depth (cm):
- Partly frozen
- Active layer at 47 cm (20.08)
- Active layer at 49 cm (09.08)

Degrees C:
- 20
- 18
- 16
- 14
- 12
- 10
- 8
- 6
- 4
- 2
- 0
- -2
- -4
- -6
- -8
- -10
- -12
- -14
- -16
- -18
Active layer thickness

Calculation:

- Active layer thickness = \( E \sqrt{TDD} \)
  \( (E = \text{edaphic factor}) \)

- Active layer thickness = \( \sqrt{\alpha \frac{P}{\pi} \log e \left| \frac{A_o}{T_o} \right|} \)
  \( (\alpha = \text{soil thermal diffusivity, } P = \text{period of temperature cycle} \)
  \( A_o = \text{surface temperature amplitude, } T_o = \text{mean annual surface temperature} \)

Monitoring:

- Mechanical probing
- Temperature measurements
- Visual observations
UNISCALM: 100 x 100 m = 121 points, 10 gridsize

Flat and silt dominated loess deposits on fluvial terrace
Svalbard – a very maritime high arctic setting – Longyearbyen met. station

UNISCALM period
MAAT: -1.7°C to -6.1 °C
Thaw progression in the UNISCALM
Probed from 8 to 15 times annually

Active layer average: 94 cm, min: 74 cm, max: 105 cm
Meteorological control on active layer thickness
Interannual spatial variation in active layer thickness in the UNISCALM

Interannual grid node variability (INV) based on normalized variability index for each grid node over the 8 year measuring period.
The Surface/Nival and Thermal Offsets

Figure 3 Schematic mean annual temperature profile through the surface boundary layer, showing the relation between air temperature and permafrost temperature.
Temperature of the active layer in UNISCALM in the sediment by 5 miniature temp. dataloggers

Large interannual variation of mean ground temperatures

**Nival offset** (Ground surface to 20 cm above ground): Max: 2.0°C, Min: 0.4°C, Mean: 1.0°C

**Thermal offset** (Ground surface to 110 cm top PF): Max: 2.0 °C, Min: 0.1°C, Mean: 0.8°C
Summing up:

- Upper 40 cm thawing until mid June, winter and spring controlled, while the lower thawing is summer controlled.

- Interannual active layer variation (0.3 m) as large in sediments as in sandstone rock – no large transient layer influence, as less ice in permafrost top.

- Interannual active layer variation mainly controlled by meteorology - mainly cloud cover (radiation) and air temperature.

- Large interannual spatial variability in active layer thickness (INV) for UNISCALM data, but not in ground thermal data profile, so local variability, need to be careful with direct climatic causes only.

- Clear nival and thermal offsets even with only 20-30 cm snow and hardly any vegetation.

- Fairly warm permafrost top, 0°C to -2°C in summer, and no significant two-sided freezing.

- UNISCALM is very susceptible to meteorological variations like over the last 8 years.
Permafrost as a seal:

- No permafrost generally below the glaciers
- Not a lot of permafrost in the sea
- Melting rate of permafrost of app. 300 m during a glaciation 30000 yr
<table>
<thead>
<tr>
<th>Factor</th>
<th>Slow</th>
<th>Intermediate</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral resistance to chemical weathering</td>
<td>High (e.g., quartz)</td>
<td>Intermediate (e.g., mica, feldspar)</td>
<td>Low (e.g., calcite, olivine)</td>
</tr>
<tr>
<td>Frequency of joints</td>
<td>Few joints (meters apart)</td>
<td>Intermediate (0.5-1.0 meters apart)</td>
<td>Many (centimeters apart)</td>
</tr>
<tr>
<td>Depth of regolith</td>
<td>Zero</td>
<td>Shallow</td>
<td>Deep</td>
</tr>
<tr>
<td>Steepness of slope</td>
<td>Steep</td>
<td>Moderate</td>
<td>Gentle</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Sparse</td>
<td>Moderate</td>
<td>Dense</td>
</tr>
<tr>
<td>Temperature</td>
<td>Cold (average about 5°C)</td>
<td>Temperate (average about 15°C)</td>
<td>Warm (average about 25°C)</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Low (&lt;40 cm/y)</td>
<td>Intermediate (40-130 cm/y)</td>
<td>High (&gt;130 cm/y)</td>
</tr>
<tr>
<td>Burrowing animals</td>
<td>Rare</td>
<td>Frequent</td>
<td>Abundant</td>
</tr>
</tbody>
</table>
A. Wet ——— Rainfall ——— Dry

Mean annual temperature (°C)

Cold ——— Hot

Annual rainfall (cm)

Strong chemical

Moderate chemical with frost action

Moderate mechanical

Strong mechanical

Slight mechanical

Very slight weathering of any kind

Svalbard

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’Cryogenic weathering is the combination of mechanico-chemical processes which cause the in situ breakdown of rock under cold-climate conditions’. (French, 1996)

Frost weathering is controlled by geology:

• Rocks with high porosity are frost sensitive
• Very permeable rocks are not frost sensitive
• Poorly consolidated rocks are frost sensitive
• Rock fracturing improve weathering

& by climate:

• Moisture is needed, a critical saturation level is needed
• Temperature (fast cooling but nature is slow 2 to 4°C/hour max, no minimum most occur from 0 to -6°C, freeze/thaw cycles increase weathering)
Surface disturbance leading to subsidence - Thermokarst
Controlling factors:
- Sediment type (ice content)
- Increased continentality
- Tree cutting/fires
- Lateral water course erosion

2 types of processes:

Thermal erosion
(horisontal)

Termokarst subsidence
(vertical)

Thermokarst landforms:
- Closed depressions
- Hilly irregular terrain
- Thaw lakes (oriented)
What are the controlling factors on thermokarst development?

Figure 7.2 Diagram illustrating how geomorphic, vegetational and climatic changes may lead to permafrost degradation (modified from French, 1987c).
How can climatic changes affect permafrost?
Suggestions for readings: