5

Periglaciation

'Perennially frozen material lurks beneath at least one-fifth, and perhaps as much as one-fourth, of the Earth's land surface.'

Frederick Nelson, 1999

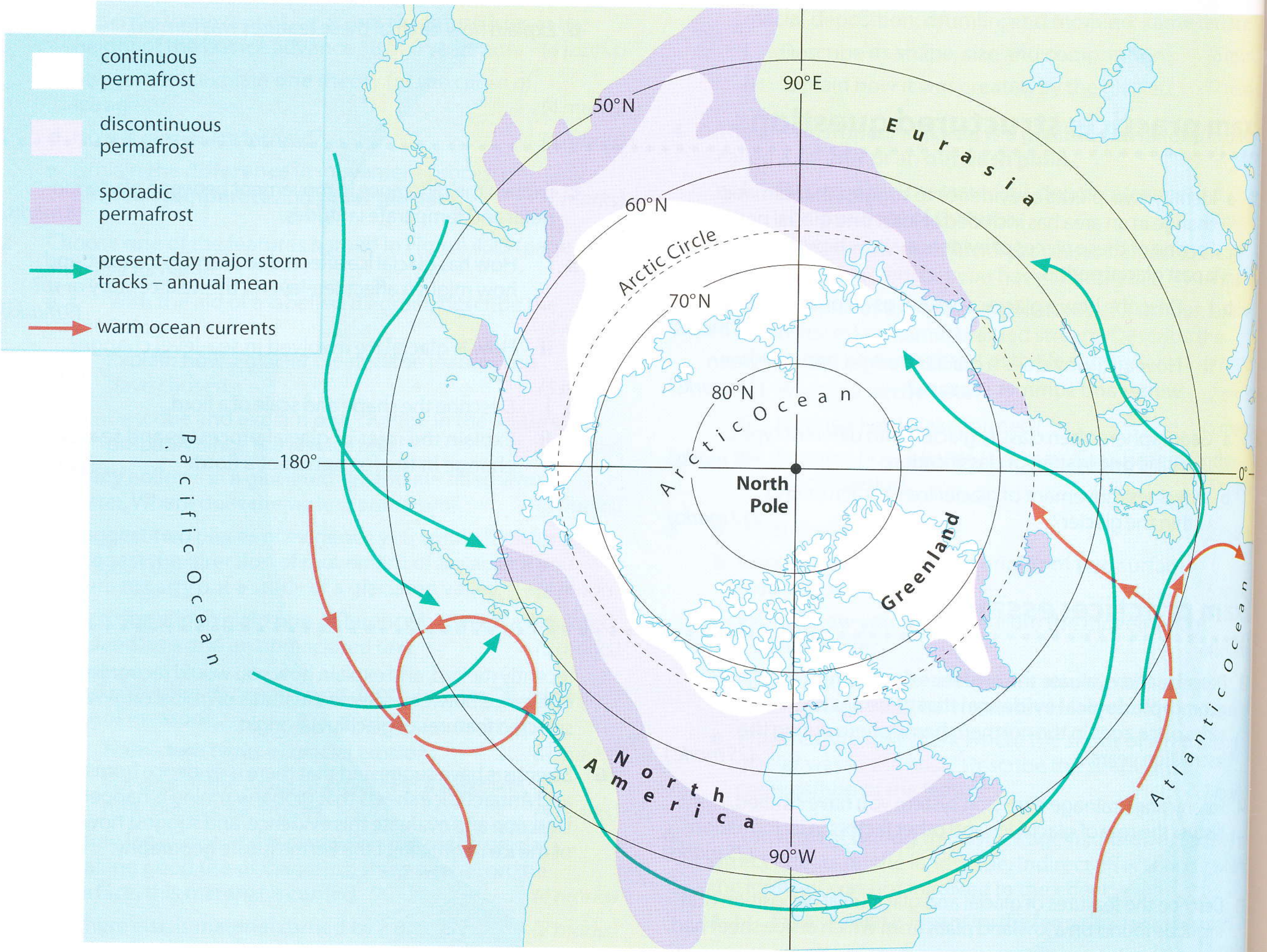
The term **periglacial**, strictly speaking, means 'near to or at the fringe of an ice sheet', where frost and snow have a major impact upon the landscape. However, the term is often more widely used to include any area that has a cold climate – e.g. mountains in temperate latitudes such as the Alps and the Plateau of Tibet – or which has experienced severe frost action in the past – e.g. southern England during the Quaternary ice age (Figure 4.3b). Today, the most extensive periglacial areas lie in the Arctic regions of Canada, Alaska and Russia. These areas, which have a tundra climate, soils and vegetation (pages 333–334), exhibit their own characteristic landforms.

Permafrost

Permafrost is permanently frozen ground. It occurs where soil temperatures remain below 0°C for at least two consecutive years. Permafrost covers almost 25 per cent of the Earth's land surface (Figure 5.1) although its extent changes over periods of time. Its depth and continuity also vary (Figure 5.2).

Figure 5.1

Permafrost zones of the Arctic



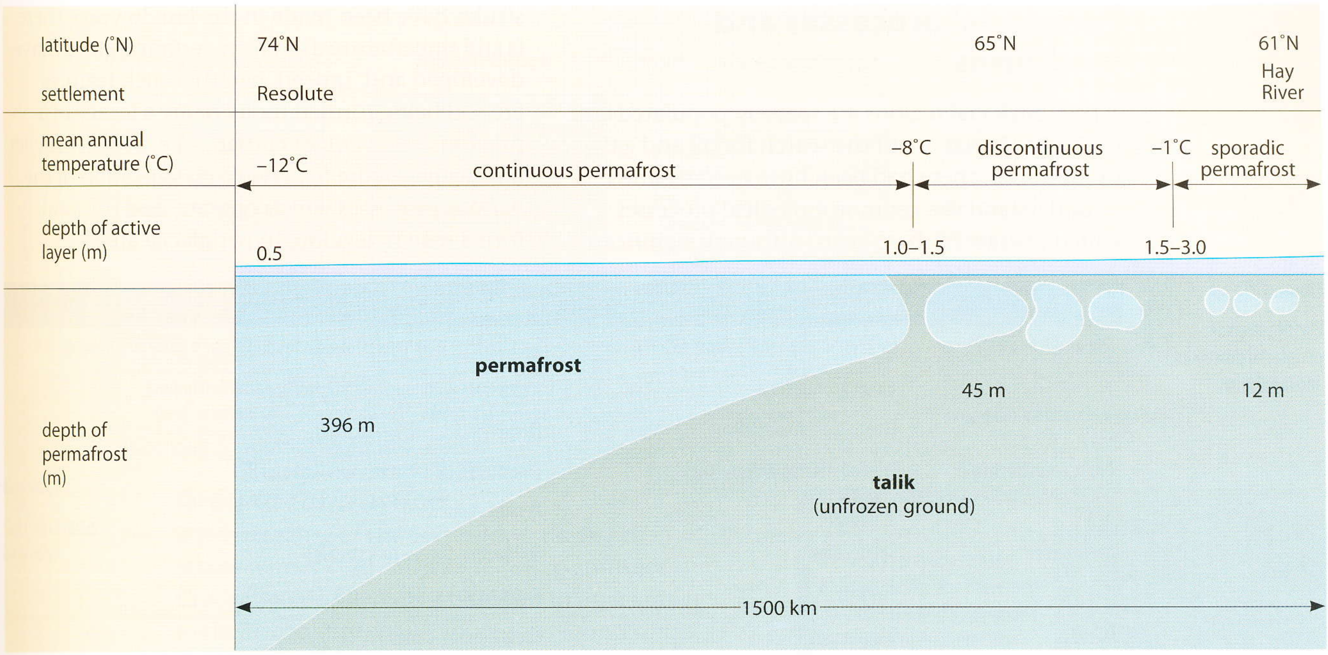


Figure 5.2
Transect through part of the permafrost zone in northern Canada

Continuous permafrost is found mainly within the Arctic Circle where the mean annual air temperature is below –5°C. Here winter temperatures may fall to –50°C and summers are too cold and too short to allow anything but a superficial melting of the ground. The permafrost has been estimated to reach a depth of 700 m in northern Canada and 1500 m in Siberia. As Figure 5.1 shows, continuous permafrost extends further south in continental interiors than in coastal areas which are subject to the warming influence of the sea, e.g. the North Atlantic Drift in north-west Europe.

Discontinuous permafrost lies further south in the northern hemisphere, reaching 50°N in central Russia, and corresponds to those areas with a mean annual temperature of between –1°C and –5°C. As is shown in Figure 5.2, discontinuous permafrost consists of islands of permanently frozen ground, separated by less cold areas which lie near to rivers, lakes and the sea.

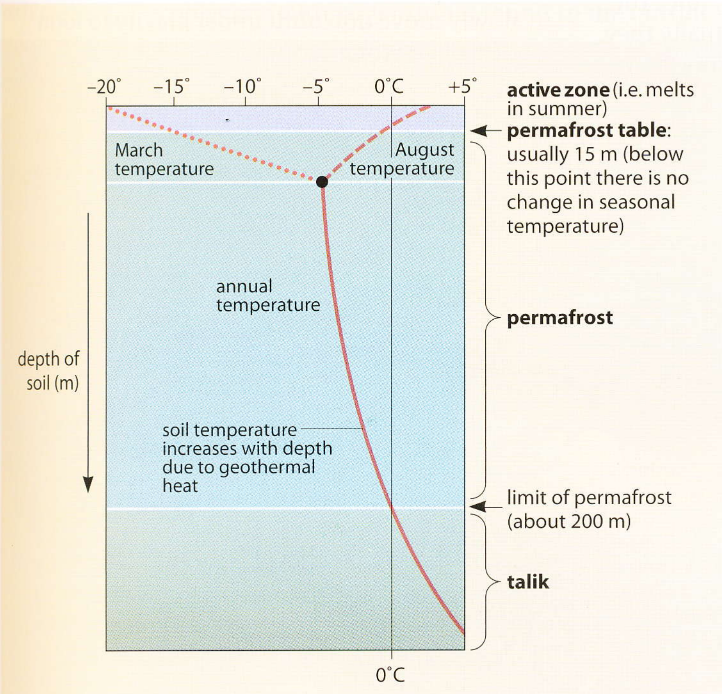
Sporadic permafrost is found where mean annual temperatures are just below freezing point and summers are several degrees above 0°C. This results in isolated areas of frozen ground (Figure 5.2).

In areas where summer temperatures rise above freezing point, the surface layer thaws to form the **active layer**. This zone, which under some local conditions can become very mobile for a few months before freezing again, can vary in depth from a few centimetres (where peat or vegetation cover protects the ground from insolation) to 5 m. The active layer is often saturated because meltwater cannot infiltrate downwards through the impermeable permafrost. Meltwater is unlikely to evaporate in the low summer temperatures or to drain downhill since most of the slopes are very gentle. The result is that permafrost regions contain many of the world's few remaining wetland environments.

The unfrozen layer beneath, or indeed any unfrozen material within, the permafrost is known as talik. The lower limit of the permafrost is determined by geothermal heat which causes temperatures to rise above 0°C (Figure 5.3).

Temperatures taken over a period of years in the discontinuous and continuous permafrost suggest that, in Canada, Alaska and Russia, there is a general thawing of the frozen ground, an event accredited to global warming (Case Study 5).

Figure 5.3
Soil temperatures in permafrost at Yakutsk, Siberia



Periglacial processes and landforms

Most periglacial regions are sparsely populated and underdeveloped. Until the search for oil and gas in the 1960s, there had been little need to study or understand the geomorphological processes which operate in these areas. Although significant strides have been made in the last 30 years, the is still uncertainty as to how certain features ha developed and, indeed, whether such features are still being formed today or are a legacy of a previous, even colder climate – i.e. a fossil or re landscape. Figure 5.4 gives a classification of th various processes which operate, and the land- forms which develop, in periglacial areas.

Figure 5.4

Classification of periglacial processes and landforms

	Processes	Landforms
Ground ice	Ice crystals and lenses (frost-heave)	Sorted stone polygons (stone circles and stripes: patterned ground)
	Ground contraction	Ice wedges with unsorted polygons: patterned ground
	Freezing of groundwater	Pingos
Frost weathering	Frost shattering/Freeze–thaw	Blockfields, talus (scree), tors (Chapter 8)
Snow	Nivation	Nivation hollows
Meltwater	Solifluction	Solifluction sheets, rock streams
	Streams	Braiding, dry valleys in chalk (Chapter 8)
Wind	Windblown	Loess (limon), dunes

Ground ice

Frost-heave: ice crystals and lenses

Frost-heave includes several processes which cause either fine-grained soils such as silts and clays to expand to form small domes, or individual stones within the soil to be moved to the surface (Figure 5.5). It results from the direct formation of ice – either as crystals or as lenses. The **thermal conductivity** of stones is greater than that of soil. As a result, the area under a stone becomes colder than the surrounding soil, and ice crystals form. Further expansion by the ice widens the capillaries in the soil, allowing more moisture to rise and to freeze. The crystals, or the larger ice lenses which form at a greater depth, force the stones above them to rise until eventually they reach the surface. (Ask a gardener in northern Britain to explain why a plot that was left ston less in the autumn has become stone-covered the spring, following a cold winter.)

During periods of thaw, meltwater leaves material under the uplifted stones, preventin them from falling back into their original po tions. In areas of repeated freezing (ideally where temperatures fall to between –4°C and –6°C) and thawing, frost-heave both lifts and sorts material to form **patterned ground** on surface (Figure 5.6). The larger stones, with th extra weight, move outwards to form, on alm flat areas, stone circles or, more accurately, st **polygons**. Where this process occurs on slop with a gradient in excess of 2°, the stones wil slowly move downhill under gravity to form elongated **stone stripes**.

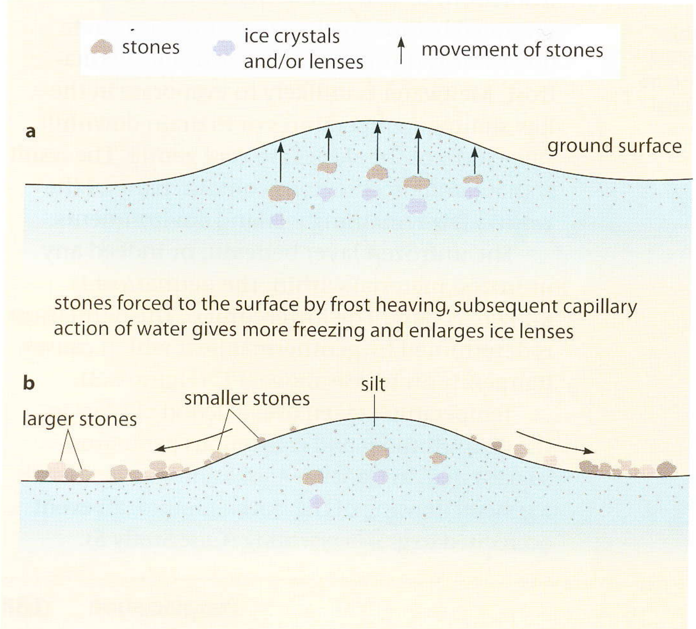


Figure 5.5

Frost-heave and stone-sorting

a doming occurs when the ground freezes in winter but may disappear in summer when the ground thaws – the ground is warmed from above

b stones roll down into the hollows between mounds and material becomes sorted in size, with the finest deposits left in the centre of the polygon and on top of the mound

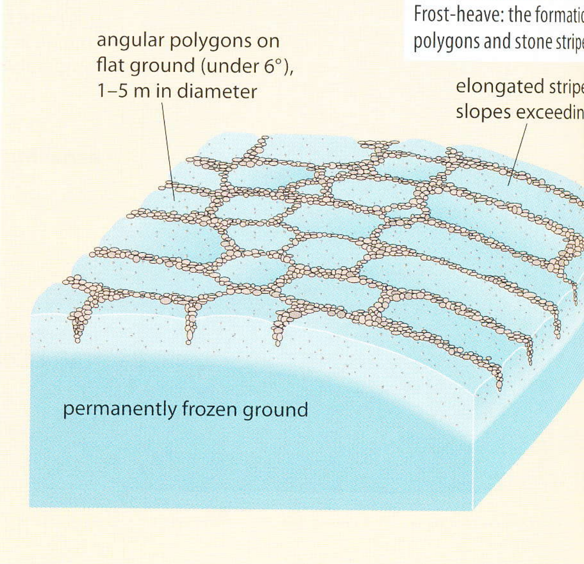


Figure 5.6

Frost-heave: the formatic polygons and stone stripe

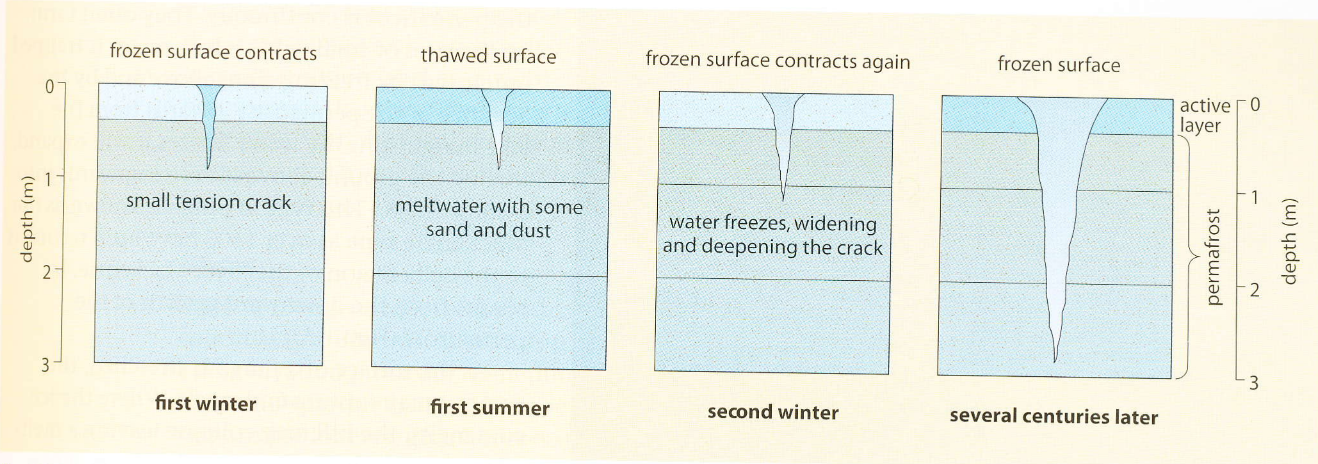


Figure 5.7

The formation of ice wedges

Ground contraction

The refreezing of the active layer during the severe winter cold causes the soil to contract. Cracks open up which are similar in appearance to the irregularly shaped polygons found on the bed of a dried-up lake. During the following summer, these cracks open, close or fill with melt-water and, sometimes, also with water and wind-blown deposits. When the water refreezes, during the following winter the cracks widen and deepen to form **ice wedges** (Figure 5.7). This process is repeated annually until the wedges, which underlie the perimeters of the polygons, grow to as much as 1 m in width and 3 m in depth. **Fossil ice wedges**, i.e. cracks filled with sands and silt left by meltwater, are a sign of earlier periglacial conditions (Figure 5.9).

Patterned ground (Figure 5.8) can, therefore, be produced by two processes: frost-heaving (Figure 5.6) and ground contraction (Figure 5.7). Frost-heaving results in small dome-shaped polygons with larger stones found to the outside of the circles, whereas ice contraction produces larger polygons with the centre of the circles depressed in height and containing the bigger stones. The diameter of an individual polygon can reach over 30 m.

Figure 5.9

Fossil ice wedge

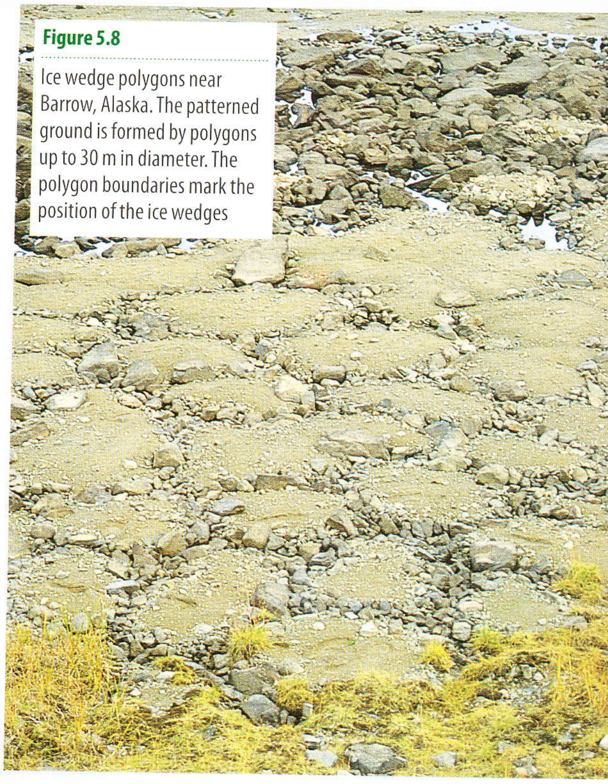


Figure 5.8

Ice wedge polygons near Barrow, Alaska. The patterned ground is formed by polygons up to 30 m in diameter. The polygon boundaries mark the position of the ice wedges

Freezing of groundwater

Pingos are dome-shaped, isolated hills which interrupt the flat tundra plains (Figure 5.10). They can have a diameter of up to 500 m and may rise 50 m in height to a summit that is sometimes ruptured to expose an icy core. As they occur mainly in sand, they are not susceptible to frost-heaving. American geographers recognise two types of pingo (Figure 5.11a and b), although recent investigations have led to the suggestion of a third type: **polygenetic** (or mixed) pingos.

Figure 5.10

A pingo, Mackenzie Delta, Canada

Open-system (hydraulic) pingos occur in valley bottoms and in areas of thin or discontinuous permafrost. Surface water is able to infiltrate into the upper layers of the ground where it can circulate in the unfrozen sediments before freezing. As the water freezes, it expands and forms localised masses of ice. The ice forces any overlying sediment upwards into a dome-shaped feature, in the same way that frozen milk lifts the cap off its bottle. This type of pingo, referred to as the **East Greenland type**, grows from below (Figure 5.11a).

Closed-system (hydrostatic) pingos are more characteristic of flat, low-lying areas where the permafrost is continuous. They often form on the sites of small lakes where water is trapped (**enclosed**) by freezing from above and by the advance of the permafrost inwards from the lake margins. As the water freezes it will expand forcing the ground above it to rise upwards into a dome shape. This type of pingo is known as the **Mackenzie type** as over 1400 have been recorded in the delta region of the River Mackenzie. It results from the downward growth of the permafrost (Figure 5.11b).

As the surface of a pingo is stretched, the summit may rupture and crack. Where the ice-core melts, the hill may collapse leaving a melt-water-filled hollow (Figure 5.11c). Later, a new pingo may form on the same site, and there may be a repeated cycle of formation and collapse.

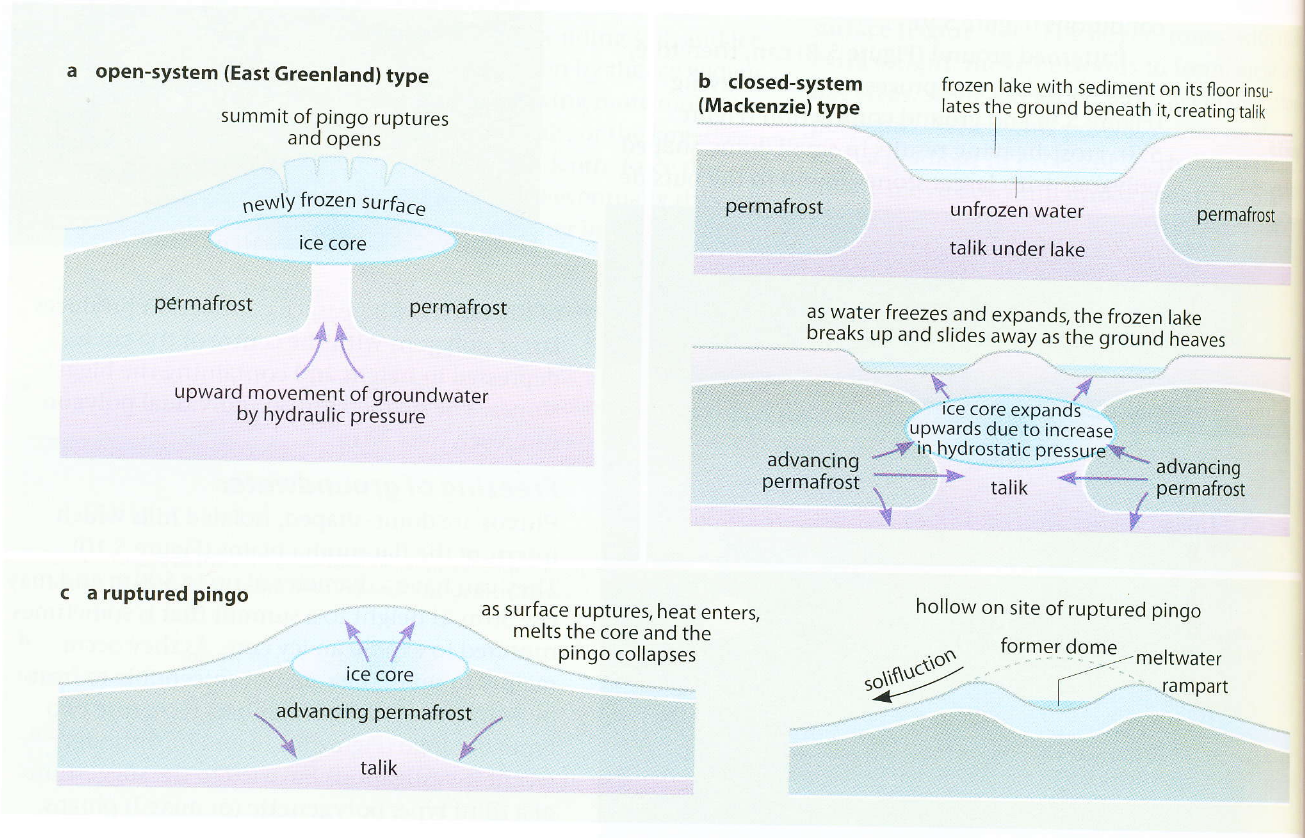
Frost weathering

Mechanical weathering is far more significant in periglacial areas than is chemical weathering, with freeze–thaw being the dominant process (Figure 2.10). On relatively flat upland surfaces, e.g. the Scafell range in the Lake District and the Glyders in Snowdonia, the extensive spreads of large, angular boulders, formed *in situ* by frost action, are known as **blockfields** or **felsenmeer** (literally, a 'rock sea').

Scree, or **talus**, develops at the foot of steep slopes, especially those composed of well-jointed

Figure 5.11

Formation of pingos



rocks prone to frost action. Freeze–thaw may also turn well-jointed rocks, such as granite, into **tors** (page 202). One school of thought on tor formation suggests that these landforms result from frost shattering, with the weathered debris later having been removed by solifluction. If this is the case, tors are therefore a relict (fossil) of periglacial times.

Snow

Snow is the agent of several processes which collectively are known as **nivation** (page 111). These nivation processes, sometimes referred to as 'snowpatch erosion', are believed to be responsible for enlarging hollows on hillsides. Nivation hollows are still actively forming in places like Iceland, but are relict features in southern England (as on the scarp slope of the South Downs behind Eastbourne).

Figure 5.12
Solifluction sheet in the Ogilvie Mountains, Yukon, Canada

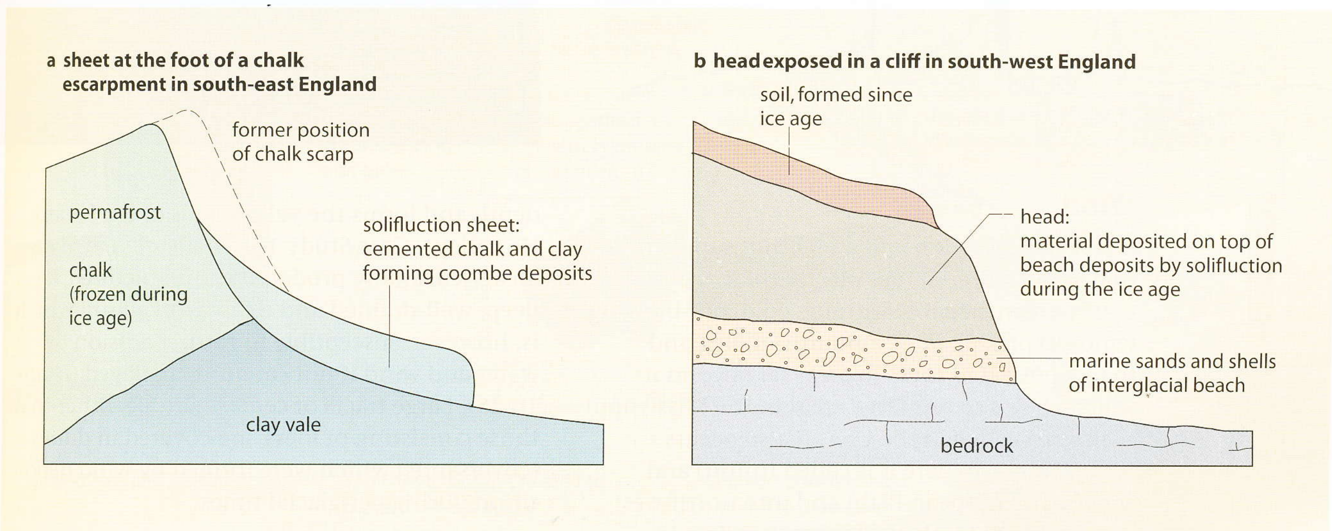
Meltwater

During periods of thaw, the upper zone (active layer) melts, becomes saturated and, if on a slope, begins to move downhill under gravity by the process of solifluction (page 47). Solifluction leads to the infilling of valleys and hollows by sands and clays to form **solifluction sheets** (Figures 5.12 and 5.13a) or, if the source of the flow was a nivation hollow, a rock stream (Figure 5.21). Solifluction deposits, whether they have in-filled valleys or have flowed over cliffs, as in southern England, are also known as **head** or, in chalky areas, **coombe** (Figure 5.13b).

The chalklands of southern England are characterised by numerous dry valleys (Figure 8.11). The most favoured of several hypotheses put forward to explain their origin suggests that the valleys were carved out under periglacial conditions. Any water in the porous chalk at this time would have frozen, to produce permafrost, leaving the surface impermeable. Later, meltwater rivers would have flowed over this frozen ground to form V-shaped valleys (page 200).

Rivers in periglacial areas have a different regime from those flowing in warmer climates. Many may stop flowing altogether during the long and very cold winter (Figure 5.14) and have a peak discharge in late spring or early summer when melting is at its maximum (Places 18). With their high velocity, these rivers are capable of transporting large amounts of material when at their peak flow. Later in the year, when river levels fall rapidly, much of this material will be deposited, leaving a braided channel (Figures 3.32 and 5.16).

Figure 5.13
Formation of solifluction sheet and head



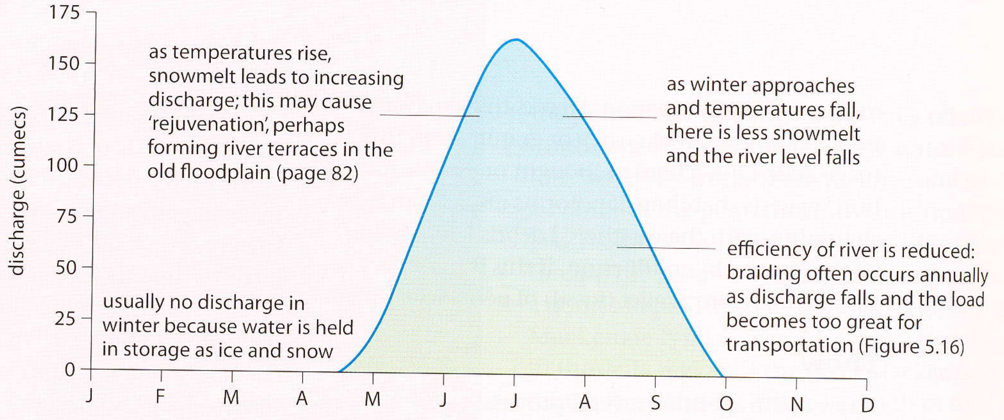


Figure 5.14

Model of a river regime in a periglacial area

Places 18 Alaska: periglacial river regimes

Permafrost also affects the hydrological regimes of subarctic rivers. Figure 5.15 shows the regime of two Alaskan rivers, both of which flow in first order drainage basins (page 65). One river, however, is located in northern Alaska where over 50 per cent of the basin is underlain with continuous permafrost. The other river, in contrast, is located further south where most of the basin consists of discontinuous permafrost and only 3 per cent is continuous permafrost. The northern river, flowing over more impermeable ground (more permafrost giving increased surface runoff and reduced throughflow) responds much more readily to changes in both temperature (increased snowmelt or freezing) and rainfall (amounts and seasonal distribution). It has a more extreme regime showing that it is more likely to flood in summer and to have a higher peak discharge and then to dry up sooner, and for a longer period, in winter or during dry spells. Figure 5.16 was taken on 7 August 1996 in the Dynali National Park. The river level had already fallen (as had the first snow of winter!), and the large load carried by the early summer meltwaters had already been deposited.

Figure 5.15

Contrasting regimes of rivers flowing over continuous and discontinuous permafrost

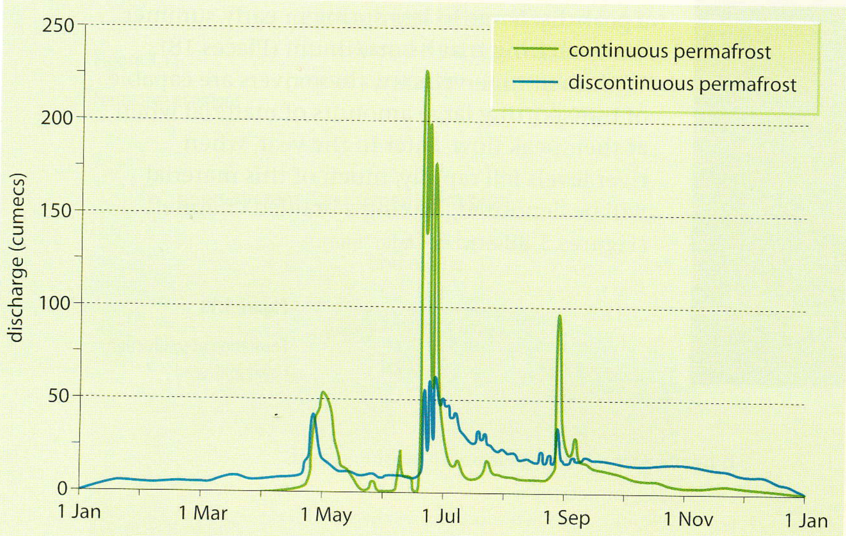


Figure 5.16

A river in the Dynali National Park

Wind

A lack of vegetation and a plentiful supply of fine, loose material (i.e. silt) found in glacial environments enabled strong, cold, out-blowing winds to pick up large amounts of dust and to redeposit it as **loess** in areas far beyond its source. Loess covers large areas in the Mississippi –Missouri valley in the USA. It also occurs across France (where it is called **limon**) and the North European Plain and into north-west China (where in places it exceeds 300 m in depth and forms the yellow soils of the Huang He valley – Case Study 10). In all areas, it gives an agriculturally productive, fine-textured, deep, well-drained and easily worked soil which is, however, susceptible to further erosion by water and wind if not carefully managed (Figure 10.35). Large tracts of central Europe, other than those consisting of loess, are covered in dunes (coversands) which were formed by wind deposition during periglacial times.

The melting permafrost

In 2008, Dr Mike Bentley claimed in *Geography Review* that one of the most important, yet least publicised, effects of global warming is the melting of the permafrost (Figure 5.19). Measurements taken along a north–south transect adjacent to the Alaskan pipeline suggest that the depth of the active layer is increasing and the depth of the permafrost table is getting lower (Figure 5.3).

Causes

- Global warming is causing temperatures to rise more quickly in arctic areas, where the permafrost is located, than in more temperate regions. As the air temperature rises, the frozen ground beneath it warms up. In northern Canada, where there has been an increase in temperature of just over 1°C since 1990, the rate of thaw has trebled. However, although global warming is the main and obvious cause for the melting of the permafrost, there are other contributory reasons.
- The removal of mosses and other tundra vegetation (page 333) for construction purposes means that in summer more heat penetrates the soil, increasing the depth of thaw.
- The construction of centrally heated buildings warms the ground beneath them, while the laying of pipes in the active zone, for heating oil, sewerage and water, increases the rate of thaw (Figure 5.17).
- Heat produced by drilling for oil and natural gas in both Alaska and Russia melts the surrounding permafrost.

Effects

- There is a reduction in the polar extent of the permafrost in arctic areas and an increase in the frequency of landslips and slope failure in more temperate, mountainous regions.
- There is evidence that the tree line (page 331) is beginning to extend further northwards and that the length of the growing season has increased by three days in Canada and Alaska and by one day in Russia.
- There is an increase in the extent of **thermokarst**, which is a landscape that develops where masses of ground ice melts. As the depth of the active layer increases, parts of the land surface subside. Thermokarst is, therefore, the general name given to irregular, hummocky terrain with marshy or lake-filled hollows created by the disruption of the thermal equilibrium of the permafrost (Figures 5.18 and 12.43). This development also increases the risk of local flooding.
- Houses and other buildings tilt as their foundations subside and sink into the ground (Figure 5.20).
- Earth movements can alter the position of the supports for oil pipelines, threatening to fracture the pipes. Roads and railways can lose alignment, and dams and bridges may develop cracks.
- A new railway across the permafrost that makes up much of the Tibetan Plateau has had to be built on crushed rock as this reduces temperatures and consequently the rate of thaw.

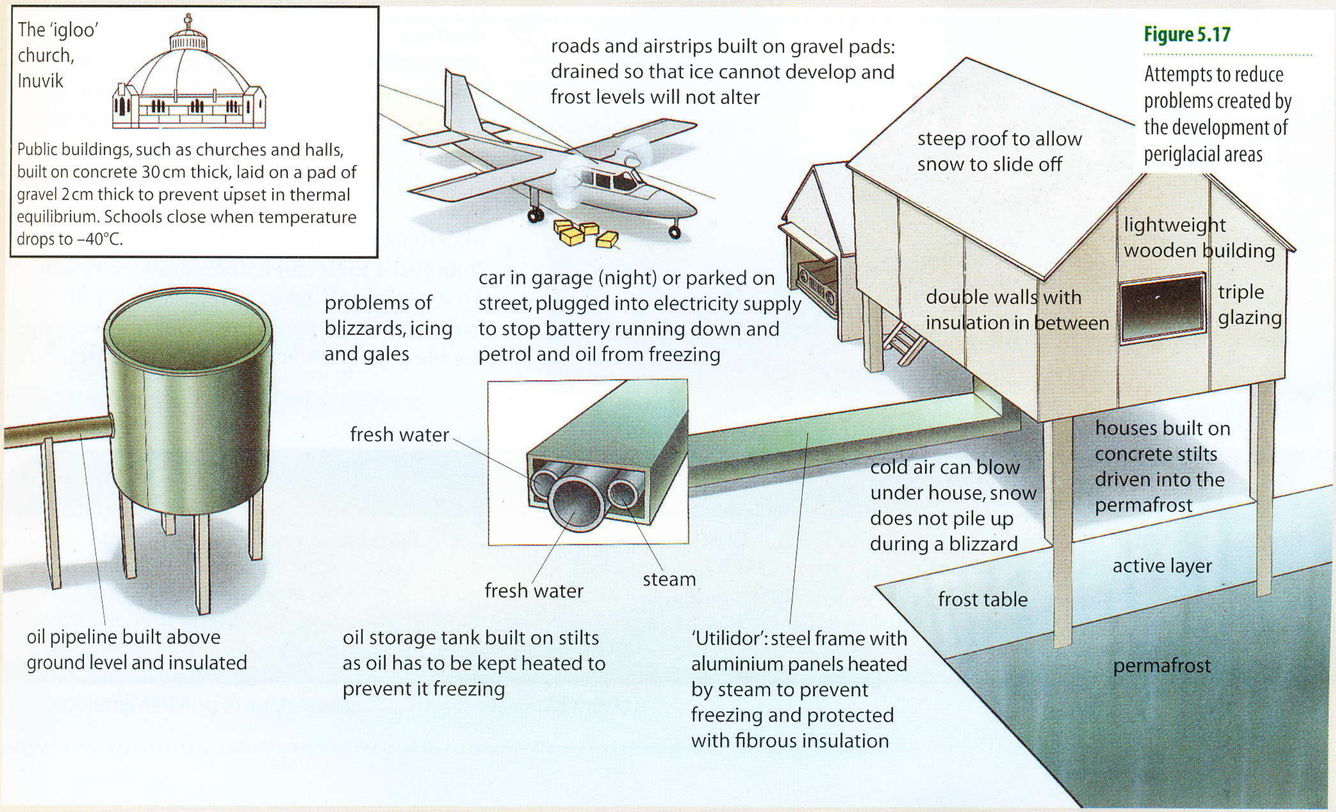


Figure 5.17 Attempts to reduce problems created by the development of periglacial areas

5 Case Study The melting permafrost

- Of all the effects resulting from the melting of the permafrost, it is the release of organic matter from permafrost soils as they thaw that is causing scientists the most concern (Figure 5.19). This organic matter contains large amounts of carbon in storage. As temperatures rise due to global warming, this carbon is released as one of two greenhouse gases – either CO_2 in drier areas or methane in wetter places (Figure 9.78). The release of these gases will increase the speed of global warming which in turn will accelerate the rate of melting in the permafrost, creating a vicious cycle.

Figure 5.18 Thermokarst scenery

Conclusion

Latest estimates suggest that the depth of the active layer could increase by 20 to 30 per cent by 2050, and that between 60 per cent (the most conservative figure) and 90 per cent (the worst-case scenario) of the permafrost could disappear by 2100. As Dr Bentley suggests: 'Permafrost may seem like a remote irrelevance to us in the temperate mid-latitudes, but it has the potential to affect every one of us through its impact on greenhouse gas emissions.'

Figure 5.19 Extract from an article in *Geography Review* February 2008, by Dr Mike Bentley

Normally, the soils of permafrost areas are crammed with undegraded, well-preserved organic matter in the form of leaves, roots, twigs and so on. This is an enormous store of carbon, kept inert by being frozen in the ground. But if that ground begins to melt and the organic material can start rotting, it will release its carbon as carbon dioxide or methane, both greenhouse gases.

In other words, the newly thawed soils may release vast amounts of greenhouse gases into the atmosphere, which will of course give a further 'kick' to global warming. This will melt more permafrost and so on, in a worsening positive feedback cycle. This process is an example of biogeochemical feedback which could influence global climate change. The alarming thing about it is the amount of carbon contained in the Arctic, and the speed at which warming is occurring. The combined effect could be catastrophic.

To illustrate this, consider that the Arctic is estimated to contain about 900 gigatonnes (Gt) of carbon. Humans emit about 9 Gt of carbon from fossil fuels and deforestation every year. So it would only take the release of 1% of carbon in Arctic permafrost soils to effectively double our emissions of greenhouse gases.

Figure 5.20 Buildings in Yukon, Canada, whose footings have sunk into the permafrost

Further reference

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Periglacial processes and landforms:
www.bgrg.org/pages/education/alevel/coldenvirons/Lesson%2019.htm

www.fettes.com/Cairngorms/periglacial.htm

Questions & Activities

Activities

1 Study Figure 5.1 (page 130), which shows where there is permafrost in the northern hemisphere, and Figure 5.2 (page 131).

a i Where is the place closest to the North Pole where there is no permafrost?

ii How close to the North Pole is this place? *(2 marks)*

b i From Figure 5.1 suggest **two** reasons why there is no permafrost in some places while there is in other places. Give examples from the map to support your answer. *(6 marks)*

iii Identify the cause/s of the 'pocket' of permafrost in north-west Scandinavia. *(2 marks)*

c What is the 'active layer' in permafrost like? *(3 marks)*

d i What is meant by the term 'mean annual temperature'? *(3 marks)*

ii How deep is **a** the active layer and **b** the permafrost at Resolute Bay? *(2 marks)*

iii Use data from Figure 5.2 to suggest the relationship between depth of permafrost and latitude. *(2 marks)*

e Why does the permafrost not occur throughout the crustal rocks? *(5 marks)*

2 Study Figure 5.14 (page 136) which shows the flow of a river (its regime) in a periglacial area.

a i When does water not flow in this river? *(2 marks)*

ii Why does water not flow during this time? *(3 marks)*

iii How would you recognise 'river terraces in the old floodplain' cut by such a river? *(5 marks)*

b Using diagrams in your answer, explain the meaning of the term 'braiding' as used in the diagram. *(5 marks)*

c Give **two** reasons why the wind has a greater erosional effect in periglacial environments than in most other areas. *(5 marks)*

d How could you recognise that the wind had:

i removed material from one area and

ii deposited the material elsewhere? *(5 marks)*

Exam practice: basic structured questions

3 **a** Describe the shape and scale of **two** of the following periglacial landforms: ice wedge polygons; scree; nivation hollow; solifluction terracettes. *(6 marks)*

b For **one** of the landforms you have described in **a**, explain how periglacial processes have led to its formation. *(6 marks)*

c Figure 5.10 (page 134) shows a pingo in northern Canada. Write a description of the pingo from the photograph, including the area around it and its scale. *(6 marks)*

d How is a pingo formed? *(7 marks)*

Exam practice: structured questions

4 Study Figure 5.21 which shows a range of periglacial landforms and their locations.

a Choose **one** of the landforms labelled B to H. Describe its size and location in the field and suggest how it has been formed. *(8 marks)*

b Explain the processes that are operating in the snow patch (A). *(5 marks)*

c Explain the role of **i** wind and **ii** meltwater in the formation of landforms in areas of periglacial landscape. *(12 marks)*

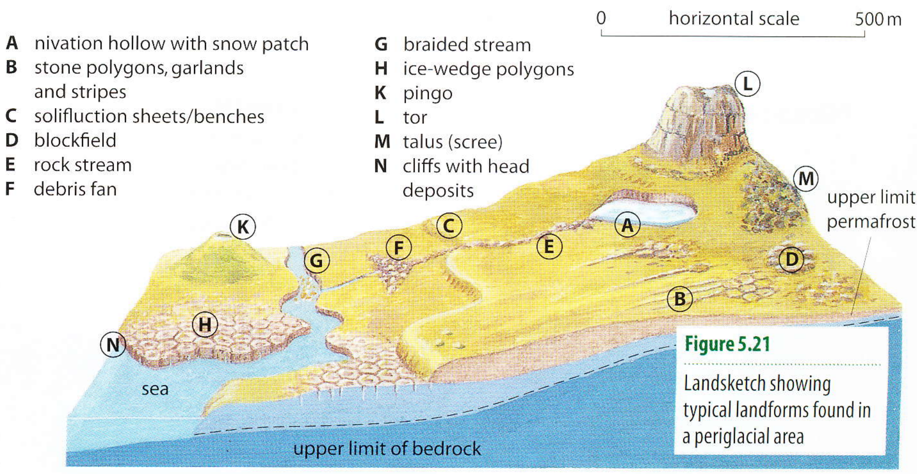

Figure 5.21 Landsketch showing typical landforms found in a periglacial area

Exam practice: essays

5 'Changes to soil stability due to frost are a major problem for development in regions where there is a periglacial climate.'

Using examples you have studied, explain why this could be the case, and describe methods people use to overcome the problems of living in such areas. *(25 marks)*

6 'Permafrost may seem like a remote irrelevance to us in the temperate mid-latitudes, but its destruction could have big implications both locally and globally.'

Discuss this statement. *(25 marks)*