GLACIAL SYSTEMS AND LANDSCAPES: NATURE AND DISTRIBUTION

PLEISTOCENE GLACIATION

During the Pleistocene epoch there were 11 periods of glaciation (between 2.6 million to 11,700 years BP) – interglacials in between.
Glacial periods: Ice expansion and falling sea levels.
Interglacial periods: Glaciers retreat and sea levels rise (happening now).
Last glacial maximum: 21,000 years ago – ice covered 30% of the globe; average global temperature = 6°C (today = to 14-15°C). Water locked in ice meant a drier climate, reduced precipitation, and a drop in sea levels. Most of UK covered in ice (southern Europe periglacial).

CLIMATE

All cold environments experience significant amounts of time below freezing. Snowfall amounts vary significantly depending on the cold environments, freezing winds also add to the wind chill and absorb moisture from plants, severely limiting the effect on the development of soils and vegetation.

SOIL DEVELOPMENT

Soil is a mixture of weathered rock, rotted organic matter, living organisms (biota), gases (particularly oxygen) and water.
In cold environments, weathering is limited due to the lack of liquid water and vegetation, so there is little organic matter and there are few decomposers (as fungi and bacteria thrive in warm and humid conditions).
Soil formation is very slow, and soils are thin, acidic, often waterlogged and mostly frozen.

PRESENT DAY DISTRIBUTION OF ICE SHEETS

Most of the world's current ice sheets are found in the far north, due to the equivalent southern latitudes being ocean rather than land.
There are four types of cold environments:

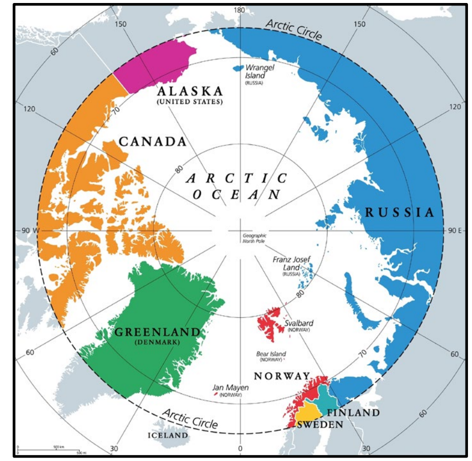
- Polar – areas of permanent ice, e.g. Antarctica
- Periglacial (tundra) – found at the edge of permanent ice, characterised by permanently frozen ground (permafrost)
- Alpine – mountain areas, where altitude allows for permanent ice all year around.
- Glacial – areas found at the edges of ice sheets and in mountainous regions.

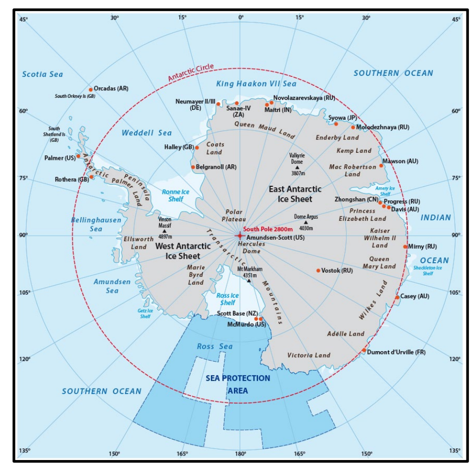
NUTRIENT CYCLING

Nutrient availability is very limited in tundra and polar environments, along with limited transfers. In contrast, alpine environments enjoy warm, wet summers providing conditions for growth and so are home to tremendous biodiversity in the summer months.

VEGETATION DEVELOPMENT

Plants need nutrients, liquid water, and temperatures above 6°C to grow, but many cold environments lack soil and organic matter.
Polar and glacial regions have little vegetation, except lichens on bare rock at the edges.
Periglacial areas support tundra vegetation, including mosses, grasses, and dwarf shrubs, which are adapted to harsh conditions with waxy leaves, rapid summer growth, and Resilience to waterlogged, thin soils.





GLACIAL SYSTEMS AND LANDSCAPES: SYSTEMS APPROACH TO GLACIATION

GLACIERS

Glaciers are 'Large rivers (mass) of ice, moving downhill, under the influence of gravity'.
Glaciers are open systems with inputs and outputs to external systems, including fluvial atmospheric systems.

Classification:
- Status: Active (current) or relict (past)
- Location: Polar, glacial, periglacial, and alpine environments

INPUTS

Energy: Kinetic from wind and moving glacier; thermal from the sun; geothermal heat from the earth.
Atmospheric: Snow from precipitation, avalanche or blown-in, and condensation of water vapour.
Other: Sublimation of vapour directly to ice crystals, and rock debris from weathering and transportation

OUTPUTS

- Meltwater
- Energy through evaporation and sublimation
- Water vapour through sublimation of ice and snow
- Icebergs and ice blocks
- Glacial and fluvio-glacial sediment
- Snow – blown away

STORES

- Accumulated debris from weathering, erosional and depositional processes
- Ice off the glacier itself
- Meltwater – stored on and within the glacier (supraglacial lakes are on top of a glacier)
- Potential energy stored from movement of glacier

FLOWS

- Debris flow through glaciers from surface storage to landforms
- Kinetic energy from movement of glacier
- Meltwater flow
- Glacial movement through gravity

GEOLOGY

Geology plays a key role in shaping these landscapes. Hard, erosion-resistant igneous rock forms steep mountains and hollows; softer sedimentary/metamorphic rocks (found in low-lying areas) erode more easily.

Transportation: As glaciers move, they pluck and transport large amounts of unsorted sand, gravel, and boulders. During the last Ice Age, advancing ice sheets transported materials like chalk and boulder clay to southern and eastern England.
Glacial polish: Trapped sediments grind against bedrock, creating rock flour, which polishes exposed surfaces.
Glacial striations: Larger rocks scrape deep grooves.

TYPES OF GLACIERS

Constrained: Do not have a dome-like structure, so the flow and shape of the glacier influenced by its surrounding.
Unconstrained: The flow and shape of these glaciers are not influenced by its surroundings. They all have the basic shape of a broad, slowly moving, central dome, with channels of faster moving ice that flow to its margins.

CONSTRAINED

Piedmont glaciers: Found at the foot of mountains, where a mass of ice has flowed downslope and fans out, forming lobes of continuous ice
Valley glaciers: Can be single feature or made up of multiple glacial tributaries.
Cirque glaciers: Most common glacier and found in nearly all areas where snow accumulates.

UNCONSTRAINED

Continental glaciers or ice sheets: With no mountains to surround them, they spread out from the centre and cover whole valleys. Sometimes only the tips of mountain peaks show above the ice called nunataks.
Ice caps: Usually centred on a mountain's high point(called a massif),the ice flows flow in multi directions to form a cap
Ice shelves: Thick, floating slabs of ice, permanently attached to a land mass.

GLACIAL SYSTEMS AND LANDSCAPES: GLACIAL SYSTEMS AND PROCESSES

KEY TERMS

Accumulation: The input of snow and ice to a glacier through precipitation, avalanches, or wind-blown snow.
Ablation: The loss of ice from a glacier due to melting, sublimation, or evaporation.
Glacial budget: The balance between accumulation and ablation over a year, determining whether a glacier advances or retreats.
Equilibrium line: The point on a glacier where accumulation equals ablation.
Mass balance: The net gain or loss of ice over a year, indicating whether a glacier has a positive or negative regime.
Dynamic equilibrium: A state where accumulation and ablation are balanced over time, keeping the glacier stable.

GLACIAL CHARACTERISTICS

Distinctive characteristics: Including glaciers, steep mountainsides and deep U-shaped valleys (troughs).
Open system: With inputs and outputs, processes and stores, positive and negative feedbacks and dynamic equilibrium.
Links with other systems: E.g. atmospheric and fluvial systems.
Frozen soils: Limited weathering and lack of vegetation and decomposers – so there are small nutrient stores/transfers.

WARM OR COLD-BASED GLACIERS

Warm-based: Found in temperate regions – pressure lowers the melting point of ice (pressure melting point), so ice melts beneath warm-based glaciers, assisting movement (basal slip).
Cold-based: Found in polar regions – have little, if any, meltwater so remain frozen to the bedrock. Limited movement (internal deformation).

GLACIAL PROCESSES

Erosion: E.g. abrasion, plucking – where ice scours and tears rock.
Weathering: E.g. freeze-thaw, carbonation – weakens rock.
Transportation: Moves debris via ice and meltwater.
Deposition: Occurs when glaciers melt, dropping material as till (unsorted) or outwash (sorted by meltwater).

ADVANCE AND RETREAT

Glaciers advance and retreat in response to the balance between accumulation and ablation (the glacial budget).
Natural cycles: Historically, glaciers have advanced and retreated in response to natural cycles including the Little Ice Age.
Recent retreat: The result of climate change associated with human impact (global warming).
Gulkana Glacier: Used by the USGS to understand glacier dynamics, hydrology and assess glaciers' response to climate change.

WEATHERING IN COLD ENVIRONMENTS

In cold environments, weathering occurs mainly through…
Freeze-thaw: Where water enters cracks, freezes, expands, and fractures rock.
Frost shattering: Breaks exposed rocks due to extreme cold.
Carbonation: Dissolves limestone in acidic meltwater.

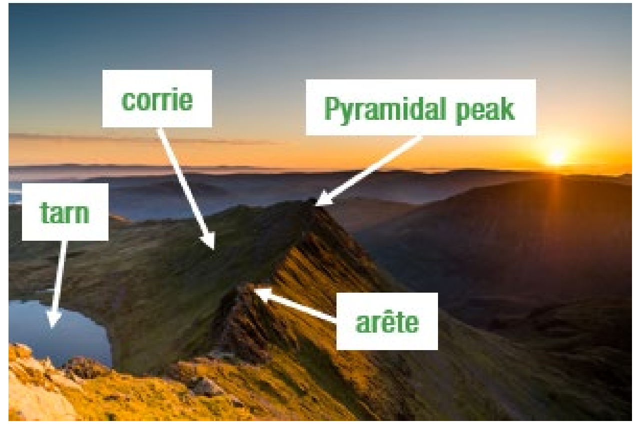
ICE MOVEMENT

Basal sliding: Dominates warm-based glaciers, lubricated by meltwater.
Internal deformation: Occurs in cold-based glaciers, where ice flows slowly under pressure.
Variations in the rate of ice movement:
Ice movement varies due to temperature, gradient, and ice type. Extending and compressing flow respond to slope changes. Surges cause rapid movement due to ice build-up or meltwater increase.

GLACIAL SYSTEMS AND LANDSCAPES: EROSIONAL LANDFORMS AND PROCESSES

FACTORS AFFECTING THE RATE OF EROSION:

Mass of the ice: The thicker the ice, the greater potential energy for erosion.
Gradient: This can affect the rate of flow of the ice, and also its thickness (extensional and compressional flow).
Meltwater: Enables basal sliding to occur, which is likely to be more erosive than internal deformation.
Rock debris: Rocks trapped beneath the ice that scrape and gouge the underlying bedrock.
Underlying geology: Whether the rocks are strong or weak, massive or thinly layered, jointed or unjointed.



ARÊTES

An arête knife-edged ridge formed when two neighbouring corries cut back into a mountainside.

CORRIES

These armchair-like hollows in the sides of mountains are formed by abrasion and plucking. As the glacier moves through rotational slip it will abrade the hollow, making it deeper. Plucking makes the back wall steeper. When the ice melts a lake known as a tarn will form in the corrie.

1. Periglacial processes (nivation, frost action) increase the size of a hollow or depression on the mountainside.
2. As the climate cools, snow turns to ice and a glacier develops. Accumulation increases its mass and rotational sliding 'scoops out' of the hollow by abrasion.
3. As the climate warms, periglacial and then temperate processes (including frost and water action) modify the corrie to create what we see left behind today.

HANGING VALLEYS

A tributary glacier has less mass than a main trunk glacier, meaning it cannot erode as deeply. When the ice melts, the smaller valley is left hanging high above the main valley, often forming waterfalls where streams flow over the edge.

TRUNCATED SPURS

As a glacier moves through a valley, its rigid ice mass cuts off the tips of interlocking spurs through abrasion and plucking, leaving behind steep cliffs known as truncated spurs.

GLACIAL TROUGHS

Steep-sided, U-shaped valleys with broad, flat floors, often several hundred metres deep. They are typically straight due to the immense erosive power and rigidity of glaciers.
Ribbon lakes: Some glacial troughs contain ribbon lakes, formed by localised over deepening caused by:

- Weaker bedrock, which allows greater vertical erosion
- Tributary glaciers merging, increasing ice mass and erosion
- Valley narrowing, causing ice to thicken and intensify vertical erosion

PYRAMIDAL PEAK

Where three or more corries erode back-to-back, the ridge becomes a pyramidal peak.

ROCHE MOUTONNÉES

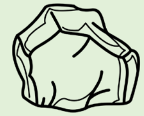
These are rocky outcrops on the valley floor shaped by glacial movement.
Upstream (stoss) side: Increased pressure causes pressure melting – causing basal sliding and abrasion, creating a smooth, striated surface.
Downstream (lee) side: Pressure drops, causing refreezing and plucking – leaving a jagged, rough surface.

GLACIAL SYSTEMS AND LANDSCAPES: DEPOSITIONAL LANDFORMS AND PROCESSES

CHARACTERISTICS:

- Glaciers transport rock debris from eroded mountains and deposit it on valley floors or lowland plains
- Rock debris dumped in situ when the ice melts is angular and poorly sorted (till)
- Meltwater streams can carry sediment many kilometres, depositing it as well-sorted outwash plains

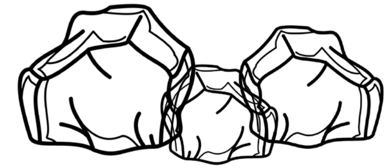
ERRATICS

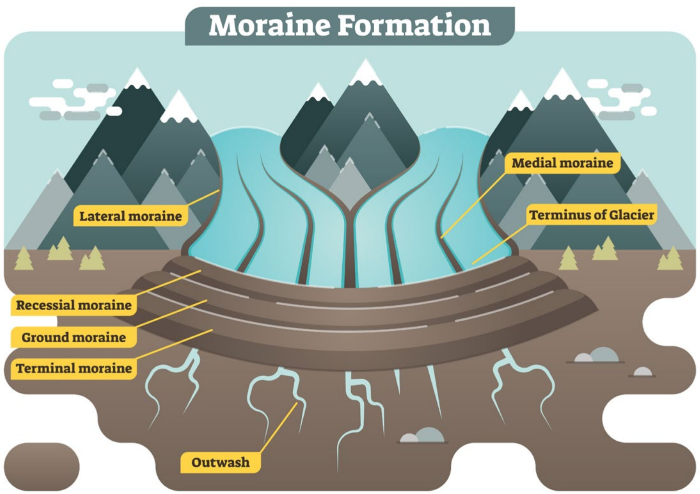


An erratic is a boulder or a smaller rock fragment that has been deposited in a location that is foreign to its origin. They show the direction of ice movement – find where the erratic came from, and you have the direction of ice flow.

TILL PLAIN

A till plain is an extensive plain resulting from the melting of a large sheet of ice that became detached from a glacier. This has the effect of levelling out the existing landscape.





MORAINES

Moraine is a generic term for landforms associated with the deposition of till – it is therefore poorly sorted with predominantly angular sediments. There are several types:

Ground moraine: Sediment transported beneath a glacier that is smeared over the underlying bedrock.

Terminal moraine: A ridge of sediment piled up in front of the glacier. It marks the furthest extent of an advancing glacier.

Recessional moraine: A secondary ridge formed at the snout of a retreating glacier during periods of stability.

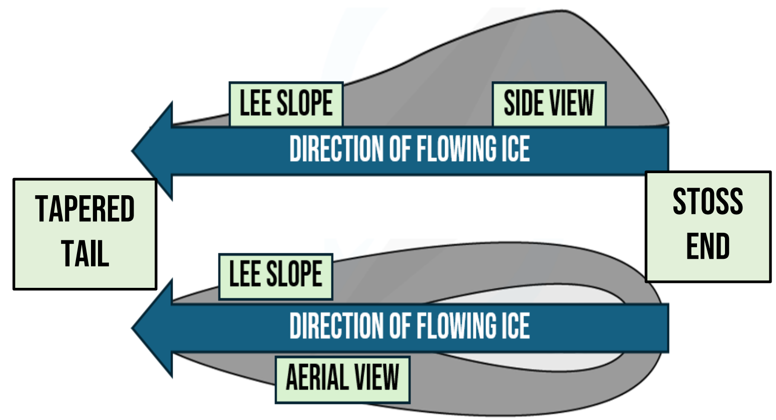
Lateral moraine: A ridge formed alongside a glacier primarily from the build-up of scree slopes.

Medial moraine: When two glaciers merge, lateral moraines at the edges of the two glaciers join to form a medial moraine.

DRUMLINS

An oval or egg-shaped hill composed of glacial till and aligned in the direction of ice flow…

- Tend to be 30–50m in height and up to 1km in length
- Usually occur in clusters or 'swarms' on flat valley floors or lowland plains
- Common in parts of northern England, Scotland and Canada
- Some have a rocky core, almost most do not
- Some consist of fluvial sediment as well as glacial till, which suggests that meltwater plays an important role in their formation, and may be a combination of several processes
- It is hard to determine exactly how they form as they form beneath ice, so cannot be observed



GLACIAL SYSTEMS AND LANDSCAPES: FLUVIOGLACIAL LANDFORMS AND PROCESSES

CHARACTERISTICS:

Associated with flowing water (meltwater) in glacial or periglacial environments.

- Meltwater is seasonally abundant in temperate glacial and periglacial environments
- It is often seen at a glacial snout flowing out from under the ice
- It is much less common in very cold environments, characterised by cold-based glaciers
- Landscape is very dynamic, with river channels constantly changing course

MELTWATER CHANNELS

Meltwater channels are valleys or trenches carved by glacial meltwater flowing beneath, within, or beyond a glacier. They are formed by the erosive power of fast-flowing meltwater, which can carry and deposit large amounts of sediment. There are two main types:

Subglacial channels: Flow beneath glaciers under high pressure, often creating deep, narrow valleys.

Proglacial channels: Found at the glacier's edge, where meltwater drains away, forming wide, shallow valleys.

These channels contribute to the shaping of glaciated landscapes, often leaving behind dry valleys once the glacier retreats.

OUTWASH PLAIN

An outwash plain is an extensive, gently sloping area in front of a glacier resulting from the 'outwash' of sand and gravels carried by meltwater. Some of the most extensive outwash plains are in Iceland and Alaska.

WHAT ARE FLUVIOGLACIAL PROCESSES?

Meltwater plays a crucial role in several glacial and periglacial processes.

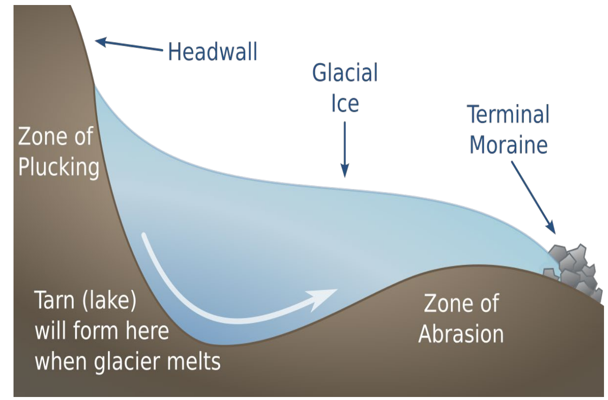
Nivation: Meltwater removes broken rock during the summer when the outer edges of the snow patch melts - also vital for freeze-thaw.

Basal sliding: Meltwater lubricates the base of warm-based glaciers.

Abrasion: Meltwater beneath a glacier provides rocks that are used as 'tools' for erosion by abrasion.

Plucking: Meltwater refreezes to rock fragments, 'plucking' rocks.

Depositional features: Meltwater erodes channels both beneath the ice and in front of it, forming distinctive features characterised by well-sorted, rounded, smoothed deposits.



ESKERS

Eskers are long, sinuous (winding) ridges made of sand and gravel that are often stratified (layered).

- Can be up to 30m high and stretch for several kilometres Usually take the form of meandering hills running roughly parallel to the valley sides
- Formed by subglacial river deposition during the final stages of a glacial period, when the ice is in recession

KAMES

Largely made of sand and gravel, and are deposited on the surface of the ice by streams in the final stages of a glacial period. There are different types of kame:

Kame terrace: Results from the infilling of a marginal glacial lake. When the ice melts, the kame terrace is abandoned as a ridge on the valley side.

Kame delta: Forms when a stream deposits material on entering a marginal lake. They form small, mound-like hills on the valley floor.

Crevasse kame: The result of the fluvial deposition of sediments in surface crevasses. When the ice melts they are deposited on the valley floor to form small hummocks.

GLACIAL SYSTEMS AND LANDSCAPES: PERIGLACIAL LANDFORMS AND PROCESSES

PERIGLACIAL FEATURES AND PROCESSES

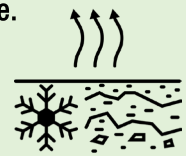
Periglacial environments exhibit distinctive features, such as permafrost and thaw lakes. Many processes in periglacial environments are associated with ice action, such as frost shattering and the formation of ice wedges.

Blockfields: The results of intensive frost shattering.

Mass movement: Active particularly during the summer thaw (e.g. solifluction, frost creep).

PERMAFROST

Soil, rock or sediment that has been frozen for at least two consecutive years. Many landforms owe their formation, at least in part, to the presence of permafrost and the action of ice.



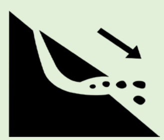
There are three times of permanently frozen ground:

Continuous permafrost: Little thawing even in summer.

Discontinuous permafrost: Breaks in permafrost around water, e.g. lakes.

Sporadic and mountain permafrost: Permafrost only in isolated spots.

SOLIFLUCTION



The slow downslope movement of saturated soil due to gravity, forming tongue-shaped solifluction lobes in summer.

Frost heave: Moves soil particles upwards when frozen and drops them vertically when thawed, gradually shifting material downhill.

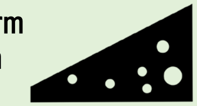
Terracettes: Repeated cycles create step-like features on slopes.

THERMOKARST

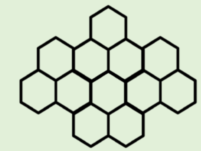
Occurs in periglacial environments when ground ice melts unevenly, creating a landscape of marshy hollows and hummocks, typical of Arctic lowland plains.

ICE WEDGES

In extremely low temperatures, the ground contracts and cracks develop. During the summer, meltwater fills these cracks and then freezes in the winter to form ice wedges, which increase in size through repeated cycles of freezing and thawing



PATTERNED GROUND



As ice wedges become more extensive, a polygonal pattern may be formed on flat ground, with the ice wedges marking the sides of the polygons.

Frost heave causes expansion of the ground and lifts soil particles upwards.

Smaller particles are removed by wind or meltwater, leaving larger stones lying on top of the ice wedges marking out the polygonal pattern.

Sloping ground causes stones to move downhill under gravity, leading to the formation of elongated stone stripes rather than polygons.

PINGOS

Dome-shaped hills formed in a permafrost area when the pressure of freezing groundwater pushes up a layer of frozen ground. Can be closed- or open-system…

Closed system pingo:

1. The shallow lake increases the size of the active layer as it acts as an insulator reducing the effect of permafrost in winter. Lake retains heat in summer.
2. Eventually the lake becomes infilled with sediment lake filled in with sediment freezes. Permafrost begins to advance because there is no lake to insulate.
3. The surface has been heaved outwards. The ice core grows over many years causing the ground to heave up and form a small hill (pingo). The cracks get bigger and during the summer the sun will melt the ice core, leaving just the ramparts behind.

Open-system pingo: Form at the foot of a slope. The water from the active layer of the slope moves downwards and collects at the base. Formed from water moving ahead of the freezing front (surface) and down a slope under gravity. Open-system because the water comes from elsewhere.

GLACIAL SYSTEMS AND LANDSCAPES: HUMAN IMPACT ON GLACIAL LANDSCAPES

FRAGILITY

Cold environments are fragile because they have harsh climates, slow recovery rates, and highly specialised ecosystems, making them vulnerable to disruption.

Extreme climate: Low temperatures and short growing seasons limit plant growth and biodiversity, making ecosystems sensitive to change.

Slow recovery: Soil formation and plant regrowth take centuries due to permafrost and low nutrient availability, meaning damage lasts for a long time.

Sensitive ecosystems: Arctic and alpine species are highly adapted to the cold, so even small changes in temperature, ice cover, or food supply can threaten survival.

Permafrost dependency: Many landscapes rely on frozen ground stability, and melting permafrost due to climate change or human activity leads to land collapse and carbon release.

Human impact: Pollution, tourism, and resource extraction cause long-term damage, as cold environments lack the resilience to recover quickly.

This fragility makes conservation crucial to prevent irreversible damage from climate change and human activity.

HUMAN IMPACT

Climate change: Rising global temperatures are accelerating glacial retreat, permafrost thawing, and sea ice loss, disrupting ecosystems and indigenous communities.

Resource extraction: Mining, oil, and gas drilling (e.g. in Alaska and Siberia) cause landscape destruction, oil spills, and pollution, damaging fragile tundra ecosystems.

Tourism: Increasing visitors to areas like Antarctica and the Alps lead to pollution, habitat disturbance, and glacier erosion from foot traffic and infrastructure.

Infrastructure and urbanisation: Roads, pipelines, and settlements disturb permafrost, causing thermokarst landscapes, land subsidence, and altering natural drainage.

PRINCIPLES OF ENVIRONMENTAL MANAGEMENT

Prevention: Attempting to prevent a harmful event occurring, e.g. deforestation.

Reaction: Responding to an event once it has occurred, e.g. clearing an oil spill.

Adaptation: Learning to live with change, e.g. climate change.

EXAMPLE: OIL EXPLORATION IN ALASKA

The Prudhoe Bay oilfield is the largest in North America, supplying a significant portion of the USA's energy and enhancing national energy security.

Trans-Alaska pipeline: 1,287 km insulated structure, transports oil from Prudhoe Bay to Valdez while minimising environmental impact by being raised on stilts to protect permafrost and allow wildlife migration.

EXAMPLE: ADAPTING TO CLIMATE CHANGE IN THE EUROPEAN ALPS

A report funded by the European Union, 'Climate Change and its Impacts on Tourism in the Alps' (2011), identified opportunities and threats associated with climate change.

- Summer tourism could benefit from climate change – hotter summers (as in 2003) would bring more people to the mountains and the tourism season could be extended
- Winter tourism faces serious challenges due to the expected decrease in snow and ice cover – already, 57 of the main ski resorts in the European Alps are considered not to be snow-reliable
- Many resorts use artificial snow, which not only use huge amounts of water and energy, but also may have detrimental impacts on ecosystems
- Droughts may become more frequent in the summer

GLACIAL SYSTEMS AND LANDSCAPES: CASE STUDY - SVALBARD

LOCATION

Svalbard (Norway) is in the Arctic Ocean and is the most northerly permanently inhabited island group in the World. Mixture of polar and tundra – around 60% is covered in glaciers so would be described as a polar region, and the rest is tundra (but most of that land is also permanently frozen). The environment is too harsh for trees or crops to grow.

MINERAL EXTRACTION

Vast reserves of coal – mining is vital for economy (the main economic activity), employing over 300 people in the mines and in a range of other supporting roles.
New mine (2014): This development faced criticism as a new access road had to be constructed over a glacier.
Phasing out: Coal mining is declined and being phased out in Svalbard in favour of tourism and scientific research

FISHING

The Barents Sea lies south of Svalbard and is abundant with fish stocks, making these cold waters one of the richest fishing areas in the world (150+ species) - but stormy seas and sea ice make it hazardous.
Issues with ownership: Norway and Russia jointly control and monitor fishing in the Barents Sea to ensure that the marine ecosystem is not polluted, and that overfishing doesn't occur, so fish stocks can be naturally replenished.

POLAR RESEARCH

Scientists study climate change, ecosystems, and glaciers, with major research stations and the SVALSAT satellite facility supporting global data collection.

POPULATION:

Five major islands form part of Svalbard - Spitzbergen is the largest and is home to 2,700 people, who mostly live in the main town of Longyearbyen. Svalbard is known for having fewer people than polar bears and snowmobiles!

TOURISM

Svalbard has lots of offer tourists – spectacular scenery (e.g. glaciers, ice caves and fjords), wildlife (e.g. tours to see polar bears and whales) and adventure tourism (e.g. snow mobile safaris, dog sledding, kayaking).
Visitor numbers: Around 30,000 visit Longyearbyen every year, with another 30,000 visiting as cruise ship passengers - the harbour at Longyearbyen was extended in the 2010s to cope with an increase in cruise ship traffic.
Employment: Tourism relatively small industry in Svalbard and provides jobs for around 300 people, although this is often low-paid, part-time and seasonal.

CHALLENGES IN SVALBARD

Extreme cold: Temperatures fall below -30°C during winter in Longyearbyen (much colder in northern glacial regions). Dangerous to work outside – need properly insulated clothes to reduce risk of frostbite.
Building on permafrost: When the ground is frozen it provides a stable foundation for buildings, but if the top layer starts to melt it can cause serious subsidence issues, with roads and buildings cracking or collapsing. Permafrost has to be protected which makes building more expensive.
Inaccessibility: Remote island group – only reached by sea and air (small airport in Longyearbyen). Very limited road network – people tend to rely on snowmobiles.

LIVING IN A HARSH CLIMATE

Resilience: Locals endure extreme cold, long winter darkness, and snowstorms.
Mitigation: Well-insulated homes, warm clothing, and above-ground utilities prevent damage from permafrost thawing.
Adaptation: Medical care is limited, so residents often travel to Norway for treatment. The coal-fired power station ensures energy security in severe winters.