

CHAPTER 24

Polar and Alpine Environments

Introduction

This chapter analyses the polar and alpine regions of the Earth. Polar regions are remote and have low populations but they are not immune from the impacts of human activities. Literally, arctic and antarctic regions extend north and south of the 66° 30' latitude respectively, but the natural boundaries are defined by climate and tree line. The boundaries of Antarctica are defined by ocean limits rather than land. An analysis of polar ecosystems in terms of climate, vegetation and soils is presented. The overriding importance of permafrost is emphasized. Plant adaptations to cold are described, though the environmental limitations on ecological productivity include factors other than low temperatures. An examination of a marine arctic ecosystem emphasizes how fragile polar ecosystems are. Problems associated with the construction of residential and industrial buildings, transport networks and oil and gas developments are discussed, together with a description of how the adverse impacts are mitigated. Levels of pollution in the Arctic are reviewed, and the impacts of polar tourism described.

Mountains present something of an environmental paradox. Shunned as a permanent home by 90 per cent of global human population because of their hostile environment, they are popularized by 25 per cent of global tourism for the very same reason. Their generally high-energy environments provide specialized physical and recreational resources and are a major influence on weather, climates and hydrological resources for human societies well beyond their boundaries. The paradox continues with their rugged nature, which should not disguise their instability and sensitivity to environmental processes and change, particularly in terms of mountain geocology. For all these reasons, mountain environments have recently received timely international attention through UN and other agencies. Mountain scenery, the awesome power of its formative processes and the disadvantaged status of most indigenous mountain peoples make appealing subjects of environmental study and fieldwork. To all this should be added the realization that mountain environments are now under stress and are prime areas of environmental concern, in need of sustainable management.

The physical geography of mountains starts with an outline of the physical geology of most of Earth's principal mountain systems. The mountains are not simple 'there' but are in most cases the most recent and often actively forming orogens. This helps to explain their dynamic influence on global and regional climate, their geomorphically active alpine landsystems and a role in plant evolution which is developed in later sections. The simulation of high latitude conditions by high altitude over very steep climatic gradients is well known but some of its more localized effects on microclimate, ecology and - cryonival processes are also outlined in these sections. The chapter concludes by reviewing a model active and mobile alpine landsystem.

Chapter summary

Distribution of polar landscapes

- About 20 million km² of treeless tundra is found on Earth in the two polar zones and in alpine regions.
- Polar climates occur poleward of the 10° C isotherm for the warmest month, and the summer position of the arctic/antarctic Front separating Arctic/Antarctic air masses from polar air masses.
- Some ecologists prefer to use the Nordenskjöld line, an isopleth of the mean temperature of the warmest month equalling $(9 - 0.1K)$, K being the mean temperature of the coldest month in degrees celsius.
- Although the 10° C January temperature works quite well in the Antarctic, many prefer the marine Antarctic Convergence which separates cold antarctic water from cool subantarctic water.
- The details of climates in polar regions are much affected by the incursion of ocean currents from warmer latitudes.

Vegetation and soils in high latitudes

- American, Canadian and Russian ecologists define arctic and subarctic zones in contrasting ways.
- The soil catena is the fundamental unit of study in polar regions, as it encompasses local variations in topography, permafrost depth, hydrology, soils and plant communities.
- Arctic Brown soils occur on well drained sites, Tundra Gleys on poorly drained sites, and Peaty Tundra Gleys on very poorly drained sites in the Low Arctic.
- Polar Desert soils, Lithosols and Regosols dominate the High Arctic.
- The nutrient content of polar soils is very low, and undoubtedly restricts the productivity of polar ecosystems.

Plant adaptations in polar regions

- Low temperatures are but one of the factors of environmental stress to overcome which polar plants species have had to evolve adaptations.
- Low soil nutrient contents, windiness, waterlogging and unweathered regoliths are additional limits on vegetation survival and growth.
- Polar plants show a great variety of adaptations to cold by growth, habitat, ecophysiological characteristics and biochemical metabolism.
- Waterlogging of the 'active layer' of soils means that many polar plants show hydrophytic characteristics.
- Areas where snow lingers in early summer usually show a distinctive 'snow loving' vegetation.

Energy and ecological productivity

- Polar ecosystems are simple in structure, but often have long food chains which link both terrestrial and marine ecosystems.

- In terrestrial ecosystems 90 per cent of energy flow is accounted for by plant production, 8 per cent by decomposition and 2 per cent by flow through herbivores and carnivores.
- Primary production shows a very large range of values, from $3 \text{ g}^{-1}\text{m}^{-2}\text{day}^{-1}$ in polar deserts to $225 \text{ g}^{-1}\text{m}^{-2}\text{day}^{-1}$ in productive meadows during the growing season.
- Productivity studies of the Lancaster Sound ecosystem, Canada, illustrate the dominance of one or two species, in this case Arctic cod, in energy flow.
- Marine ecosystems have variable productivities, depending upon the thickness, and length of time, of the pack-ice cover.
- Population cycles in mammal populations have long been recognized, though there remains considerable debate on their causes.

Construction problems

- The removal of surface vegetation removes an important insulating effect, usually leading to melting of the permafrost.
- Melting of permafrost usually leads to subsidence, flooding and the development of thermokarst terrain.
- Construction techniques involve putting buildings on piles and/or building on thick pads.
- The problem of municipal water, waste and heating systems can be solved by 'high-tech' above-ground systems.
- 'Low-tech' solutions involve building on thick gravel pads or wooden blocks.

Impacts of oil and gas fields

- The transport of oil and gas in polar regions by tanker and pipeline poses severe problems of environmental impact.
- Major spills of oil in Alaska and Russia are exacerbated by the fact that at 5°C oil degrades ten to twenty-five times more slowly than at 25°C .
- The problems of cleaning up oil spills are compounded by the remoteness of polar regions, and the huge expense of mounting clean-up operations.
- The impacts of oil and gas industries in polar regions cover a wide range of activities – production fields, transportation corridors, seismic trails, materials sites and living camps.
- Oil is transported at high temperatures (about 65°C), whereas natural gas is transported at low temperatures (below 0°C).

Arctic pollution

- The discovery of DDT in Antarctic penguins is a reminder that polar regions are affected by pollution from the chemicals used in mid-latitudes.

- The long food chains and high body-fat contents of Arctic mammals mean that ‘biomagnification’ of pollutants is a very serious matter.
- The four main elements of Arctic pollution are chlorinated organics, heavy metals, radionuclides and acid precipitation.
- The effects of pollutants on marine mammals, land mammals and birds can reach lethal levels.
- Radioactive pollution by radionuclides is of particular concern following the Chernobyl accident of 1986 and the widespread use of nuclear reactors in marine vessels and power stations in the arctic.

Environmental impacts of polar tourism

- Tourism can destroy the wilderness and wildlife aspects of a region which initially attract it.
- Overflights disturb birds and mammals and distribute kerosene residues on ecosystems.
- Cruise tourism disturbs wildlife, pollutes waters and can introduce alien species.
- Land-based tourism has the potential for the greatest damage owing to the permanent facilities for transport and accommodation which it requires.
- Tourism can have potentially harmful results, though good planning can go a long way in mitigating them, and it is possible to overstress the danger.

Physical geology of principal mountain systems

- The great extent of Earth’s two newest continental orogens is noted and attributed to recent and continuing tectonic activity.
- American Cenozoic orogens include the type-cordilleran Andes, Rocky Mountain and Coast Range subsystems. They began to form in pre-Cenozoic times, at and behind the B-subduction zone of Pacific and adjacent plates, at the leading edge of the American continental plates.
- The North and South American continents contain not one but many cordilleran elements and the relative simplicity of the Andes compression contrasts with more complex ranges and displaced terranes in North America, including large areas of crustal extension related to continental override of ocean plate.
- Many parts of the cordilleran system are still tectonically active, promote vigorous geomorphic processes and are dotted throughout their length by active stratovolcanoes, earthquakes, alpine glaciers and small icefields.
- They barrier zonal climatic and oceanic circulation and are high enough to stimulate migrating waves in mid–upper troposphere circulation.
- Quasi-continuous Eurasian orogens extend from the Pyrenees through the Alps to the Himalayas and beyond. They also comprise a complex assemblage of terranes

and ages but generally represent subduction and intercontinental suturing, marking closure of the Tethys Sea.

- More complex Africa–Europe collision began earlier although it is still incomplete but the Karakoram–Himalaya–Tibetan Plateau region is the most extensively active orogen, uplifted where India not only collided with but continues to indent Asia.
- Mediterranean B-subduction feeds stratovolcanoes on Europe’s southern fringe but they are absent from the A-subduction of India–Asia intercontinental collision. The Tibetan plateau’s youth leaves it poorly connected to intense denudation systems of neighbouring orogens.
- The orogens inhibit meridional weather circulation but the Tibetan plateau in particular has an impact on global weather. Its very recent Pliocene–Pleistocene uplift is instrumental in the creation and character of the Asian monsoon.
- New Zealand occupies a fascinating microplate position with east-to-west subduction and stratovolcanoes in North Island, contrasting with west-to-east subduction and orogenesis of the Southern Alps in South Island, which drives intense denudation there.

Mountain meteorology and climate

- Mountain meteorology shows a systematic decline in temperature with altitude and a tendency towards higher humidity, cloud cover and precipitation which can obscure a complex mosaic of rapid seasonal, spatial and synoptic variation.
- The presence of a landsurface capable of exchanging radiation, heat and moisture with the free atmosphere at high elevations complicates standard atmospheric changes, in temperature etc., with height.
- On balance, mountains may act as high-altitude heat sources and they orographically enhance precipitation, not merely in terms of amount but in terms of intensity. They also encourage azonal snow and ice cover and its meteorologically sensitive surfaces where mountains project above regional potential snowlines.
- Mountains which penetrate the mid–upper troposphere generate major atmospheric disturbances which influence global climate. On a regional scale, they create airflow perturbations through thermal and mechanical effects, which set up a variety of mountain winds, including lee waves, rotors and foehn disturbances and anabat–katabat and cold air drainage circulations.
- The mountain climate can generate marked local variations and departures from altitudinal norms through intense differences in shade, albedo, moisture, materials and other components.

Mountain ecosystems

- Mountain geocology – climate, geomorphology, pedology and ecology – is more integrated than in most terrestrial ecosystems, owing to the high variability over short distances and mutual sensitivity to instability and environmental change.

- Within the short vertical distances and space of the mountains there can exist montane forest, alpine tundra and their ecotones and a cryonival system of permanent snow, glaciers and permafrost.
- Montane forest and its timberline are generally defined by summer temperatures but drought may be the limiting factor in rain-shadow areas. Occasionally, forest girdle and cloud forest above the regional timberline reflect the importance of mountain surfaces as a moisture source and moist topographically induced updraughts respectively.
- Steep and high coastal orogens such as the equatorial Andes can show a full range of vegetation belts from tropical forest to arctic–alpine in five or six vertical kilometres.
- Modern timberlines and Pleistocene snowlines are separated vertically by < 1 km in tropical and arid mountains but are virtually identical elsewhere. Modern timberlines and snowlines constrain the arctic–alpine zone, which is therefore of Holocene age. Its marked edaphic and microclimatic variations makes for a fluctuating forest tundra ecotone.
- Alpine tundra, with dwarf shrubs, herbs, mosses and lichens, shows strong taxonomic similarities with arctic tundra, with similar adaptations in life forms, growth and reproductive behaviour. However, it is noted that patterns of radiation receipt and seasonality range from polar to equatorial compared with the far more restricted patterns in the Arctic proper.
- Highly adapted plant forms, which support a similar food web, and their distributions suggest that mountains act as plant refugia during Quaternary cold stages and arctic–alpine flora may have evolved from low-latitude communities during poleward tectonic drift since the Cretaceous.

The alpine landsystem

- The alpine landsystem is a model which integrates glacial, cryonival, slope and fluvial elements of the landscapes of high mountains with mountain climates and ecosystems.
- The landsystem is partially isolated by the timberline and glacially excavated lake basins, which buffer sediment and water transfer to fluvial systems below. It may also be tectonically active and, for all these reasons, is one of Earth's most geomorphically active environments.
- The landsystem is best developed in areas of intense Pleistocene glaciation, where excavated deep troughs with oversteepened rock walls allow large spreads of unstable debris (talus or scree).
- The continuing presence of glaciers in some mountains 'insulates' subglacial surfaces from other alpine processes but promotes them at their margins and intensifies the mosaic of microclimates and materials.
- A cryonival belt of snow and ice occurs in all alpine mountains irrespective of a permanent snowline and/or glaciers. Nivation or snow-bed weathering and mass

- wasting may operate alongside frost weathering, cryoturbation and solifluction above sporadic permafrost.
- High potential energy, enhanced by continuing uplift in some mountains, permits the reworking of landforms and sediments of the alpine landsystem. High rates and variable styles of mass wasting in small areas are characteristic of the system.
 - In particular, this promotes the progressive large-scale destruction of glaciated rock walls and attendant debris slope landforms, incorporated in a model alpine landsystem.

CASE STUDY Biodiversity in Antarctica

The first explorers of the Southern Polar Regions carried out the initial studies of the biogeography of Antarctica. Who has not read and marvelled at the epic winter journey by Wilson, Bowers and Cherry-Garrard to study the Emperor penguin colony at Cape Crozier in 1911 during Scott's Last Expedition? (Cherry-Garrard 1965) Less well known are the researches of the marine biologists on the expedition, Lillie and Nelson. They made numerous catches of plankton and marine fauna.

“Good collections of sea-anemones, worms, urchins, starfishes, crustacean, sea-spiders, molluscs and fishes were obtained. The collection of fishes has already been found to contain some new genera and several new species. There can be no doubt that many new forms will be found among the other groups.” (Scott's Last Expedition, Vol II, pp. 482-3.)

In Chapter 22 we have seen how biodiversity is low in the Arctic Ocean and on surrounding tundra landscapes. Many factors contribute to this, including (a) environmental stresses, (b) the recent age of the ocean, (c) the short time-span since Pleistocene glaciations, and (d) the large inter-annual instability of the terrestrial tundra environment. Climatic stresses restrict arctic plant species to those which have successfully adapted to low temperatures and physiological drought. The Arctic Ocean is young geologically, being only 4 million years old. Time since the last Pleistocene glacial maximum has been very brief, and obviously parts of the region are still glaciated. The Arctic climate is also highly variable from year to year, which makes the productivity of plants and the breeding success of animals highly unpredictable. The fragility and instability of permafrost is clearly an additional factor in terrestrial arctic ecosystems.

Antarctica presents contrasts. The Antarctic continent and its surrounding Southern Ocean are much older than its Arctic equivalent, being about 40 million years old. This has allowed much more time for evolutionary change and adaptive radiation. Additionally, isolation of habitats on the ocean floor and on land has increased the rates of allopatric speciation. We have seen in Chapter 22 that there is a general rule of increasing biodiversity with decreasing latitude. However, some groups of organisms such as whales and benthic invertebrates achieve greatest species richness at high latitudes in the Southern (Antarctic) Ocean. The surface (pelagic) and ocean-floor (benthic) fauna of the Southern Ocean have only been intermittently studied since

Captain Scott's time, therefore there is still much to learn. Foremost among the most active research institutes have been the British Antarctic Survey (BAS), Cambridge, and the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany.

The German research vessel *Polarstern* has been particularly active in studies of the marine biology of Antarctica, normally carrying about 50 scientists on board. Recently attention has been focused on those Antarctic waters newly exposed by the collapse of the Larsen A ice shelf in 1995 and Larsen B ice shelf in 2002. Many new species of shrimp, ice fish, sea squirts, sea urchins, sea lilies, jelly fish and sea cucumbers have been discovered, echoing the words quoted above of the biologist Lillie a century ago.

In addition to age, what other factors have promoted such marine biodiversity at high latitudes in the southern hemisphere? One important factor is the physical and chemical stability and predictability of its ocean-floor environment. The light levels and salinity values of the water are constant, and water temperature does not depart from close to 0°C either seasonally or from year-to-year. This gives a stable environment for species to evolve according to the 'stability-time' hypothesis discussed in Chapter 22.

Any instability that exists comes from the final factor, unique to polar regions, which contributes to the biodiversity of the Antarctic Ocean. Calving ice-bergs from the outlet glaciers and ice shelves of the Antarctic Ice Sheet frequently scrape across the sea floor, removing all organisms from affected areas. The sea floor has thus become a mosaic of areas of species-poor, bare sea-bed with adjacent species-rich unaffected areas. Processes of re-invasion and re-colonisation will start again on the scraped areas once the ice-berg passes by. The result is an ocean floor made up of a complex of successional (seral) communities at different stages of damage and recovery. In other words, the floor of the Antarctic Ocean has very high beta (β) diversity.

The costs and logistical difficulties associated with studying the polar oceans make the exploration of the ocean depths extremely difficult. This is why it has been said: "*the depths of the ocean represent one of the great unexplored frontiers of biogeography.*"

References

- Cherry-Garrard, A. (1965) *The worst journey in the world*, Harmondsworth: Penguin.
Scott, R.F. (1914) *Scott's Last Expedition*, Vol. II, London: John Murray.



Figure 1 *RV Polarstern*, the German research ship equipped for work in the polar oceans. Research in polar regions is expensive and hazardous. Europe possesses two premier-league research institutes involved in such activity, the British Antarctic Survey (BAS), Cambridge, and the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven. Much of the research of the Alfred Wegener Institute into the polar oceans is conducted from the ship *RV Polarstern*. This is a polar icebreaker which has been converted into a modern floating laboratory.

From <http://www.awi.de> Source: NJ Ziegler/ Alfred-Wegener-Institut, Germany. © J.C. Ziegler. Reproduced with permission of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven.

Essay questions

1. Examine the *factors* which produce such a variety of landforms in mountainous regions. How successful have been investigations in the past 50 years to discover the *processes* involved, and their *rates* of operation?
2. Making use of a modern atlas, describe the physiography of The Arctic Ocean and the water flows into it.
3. Write an essay on the distinctive features of the climate and weather of polar regions.
4. Explain why and how the climates and microclimates of mountainous regions are so variable in time and space.
5. Discuss how the *alpine landsystem model* enables us to have a better understanding of alpine environments.
6. Discuss why and how polar and alpine ecosystems differ from those of more temperate climate regions.
7. Examine the causes, nature and remedies of environmental pollution in polar and alpine regions.

Discussion topics

1. Explain how landforms, soils, vegetation and wildlife can be regarded as closely integrated in arctic ecosystems.
2. “Non-renewable resource development in arctic regions has always faced immense environmental challenges. Unfortunately it has failed to avoid serious impacts”
3. Discuss these challenges and impacts, and suggest ways in which present and future impacts might be minimised.
4. Discuss the variety of anthropogenic impacts upon fragile mountain ecosystems, and suggest ways in which adverse effects might be mitigated.
5. Discuss the positive and negative effects of ecotourism in alpine, Arctic and Antarctic regions?
6. Examine the success of governments in promoting national parks and wildlife conservation areas in polar and alpine regions.

Further reading

Arctic Monitoring and Assessment Program (AMAP). (2004) *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, Cambridge: CUP. The most important study to emerge from nearly 300 scientists in Arctic nations. It expresses particular concern about ‘feedback loops’ exacerbating climate change, and points to the need for immediate and appropriate actions by the world’s decision-makers.

Atkinson, K. and McDonald, A. (1988) *Arctic Canada*, Leeds: Centre for Canadian Studies. A collection of essays covering the physical geography, ecosystems and development problems of Arctic Canada.

Barry, R.G. (1992) *Mountain Weather and Climate*, 2nd edition, London and New York: Routledge. This detailed text may be too advanced for many but there are few books which can match the specialist attention paid to its subject. It is still possible to derive a greater understanding of mountain weather and climate without being drawn into its mathematical explanations.

French, H.M. and Slaymaker, O., (1993) *Canada's Cold Environments*, Montreal: McGill-Queens University Press. A collection of studies on Canada's alpine and arctic ecozones and their physical and biological features. It deals comprehensively with impacts on northern development, and is especially strong on the role of climate and its impact on the lives of Canadians.

Gerrard, A.J. (1990) *Mountain Environments: An examination of the physical geography of Mountains*, London: Belhaven Press. A comprehensive review of the ecology and geomorphology of mountains and Earth's principal mountain systems. Specific chapters on mountain climate and weather are omitted but relevant material appears as a component of chapters on geocology, hydrology and glaciers. The geological origins of orogens are outlined and a whole chapter is dedicated to volcanoes before the book concludes by looking at mountains under pressure.

Hall, C. M., and Johnston, M. E., eds (1995) *Polar Tourism in Arctic and Antarctic Regions*, London: Wiley. This is an excellent discussion of the issues raised by this growing activity.

Hansom, J. D., and Gordon, J. E. (1998) *Antarctic Environments and Resources: a geographical perspective*, London: Longman. A most detailed and scholarly account of all geographical aspects of the continent.

Ives, J.D. and Barry, R.G. eds (1974) *Arctic and Alpine Environments*, London: Methuen. Although over twenty years old, this book of almost 1000 pages still sets standards for the breadth of cover of these two environments. It is a valuable reference work alongside other books which update individual subjects.

Nuttall, M. and Callaghan, T.V. (2000) *The Arctic: environment, people, policy*, Harwood Academic. The most up-to-date and comprehensive text on the arctic, covering most aspects of its physical and human geography.

Ørbæk, J.B. et al. (eds.) (2007) *Arctic alpine ecosystems and people in a changing environment*, Meppel: Springer-Verlag Berlin Hinderburg.

Price, M. (2007) *Mountain areas – global priorities*, Geneva: IUCNNR. An important statement on research into degradation of mountain ecosystems, and pointers to their restoration and sustainable use.

Stone, P. ed. (1992) *The State of the World's Mountains: A global report*, London and Atlantic Highlands, N.J.: Zed Books. This book stems from popular concern for mountain environments and the cultural and social health of its inhabitants. Variable coverage and quality of illustration of the principal physical and human components of mountain

environments are compensated for by its assessment of virtually all Earth's mountain systems.

Stonehouse, B. (1989) *Polar Ecology*, Glasgow: Blackie. A scholarly yet readable analysis of the ecosystems of both Arctic and Antarctic regions. Covers both the physical and the biological aspects.

Williams, P.J. (1986) *Pipelines and Permafrost: Science in a cold climate*, 2nd edition, Ottawa: Carleton University Press. A classic study which considers the opportunities and limitations of the polar environment for development. It deals with much more than pipelines.

Web resources

<http://www.amap.no>

The Arctic Monitoring and Assessment Programme (AMAP) was established by the nations of the Arctic Council to study the changing environments of the Arctic. Its headquarters are in Oslo, Norway, and its work covers all aspects of marine and terrestrial physical geography.

<http://www.antarctica.ac.uk>

This is the website of the British Antarctic Survey (BAS), Cambridge, the British government's scientific institute for the study of the Antarctic, South Georgia, South Sandwich Islands, and South Orkney Islands.

<http://www.awi.de>

The Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, is a prestigious research institute for the study of polar and alpine environments.

<http://www.caff.is>

The Conservation of Arctic Flora and Fauna is another working party set up by the Arctic Council.

<http://www.iasc.no>

The International Arctic Science Committee is a non-governmental organisation which promotes cooperation among arctic scientists.

There are many university-based research institutes studying polar regions. These are some of the most prestigious:

<http://www.arctic.ucalgary.ca>

Arctic Institute of North America (AINA), University of Calgary, Canada

<http://instaar.colorado.edu>

Institute for Arctic and Alpine Research (INSTAAR), University of Colorado at Boulder, USA

<http://nsidc.org>

The National Snow and Ice Data Center (NSIDC), University of Colorado at Boulder, USA, is a valuable source of up-to-date information and statistical data on many aspects of the cryosphere, including relevant satellite photographs.

<http://www.spri.ac.uk>

Scott Polar Research Institute (SPRI), University of Cambridge, UK