ANTARCTICA

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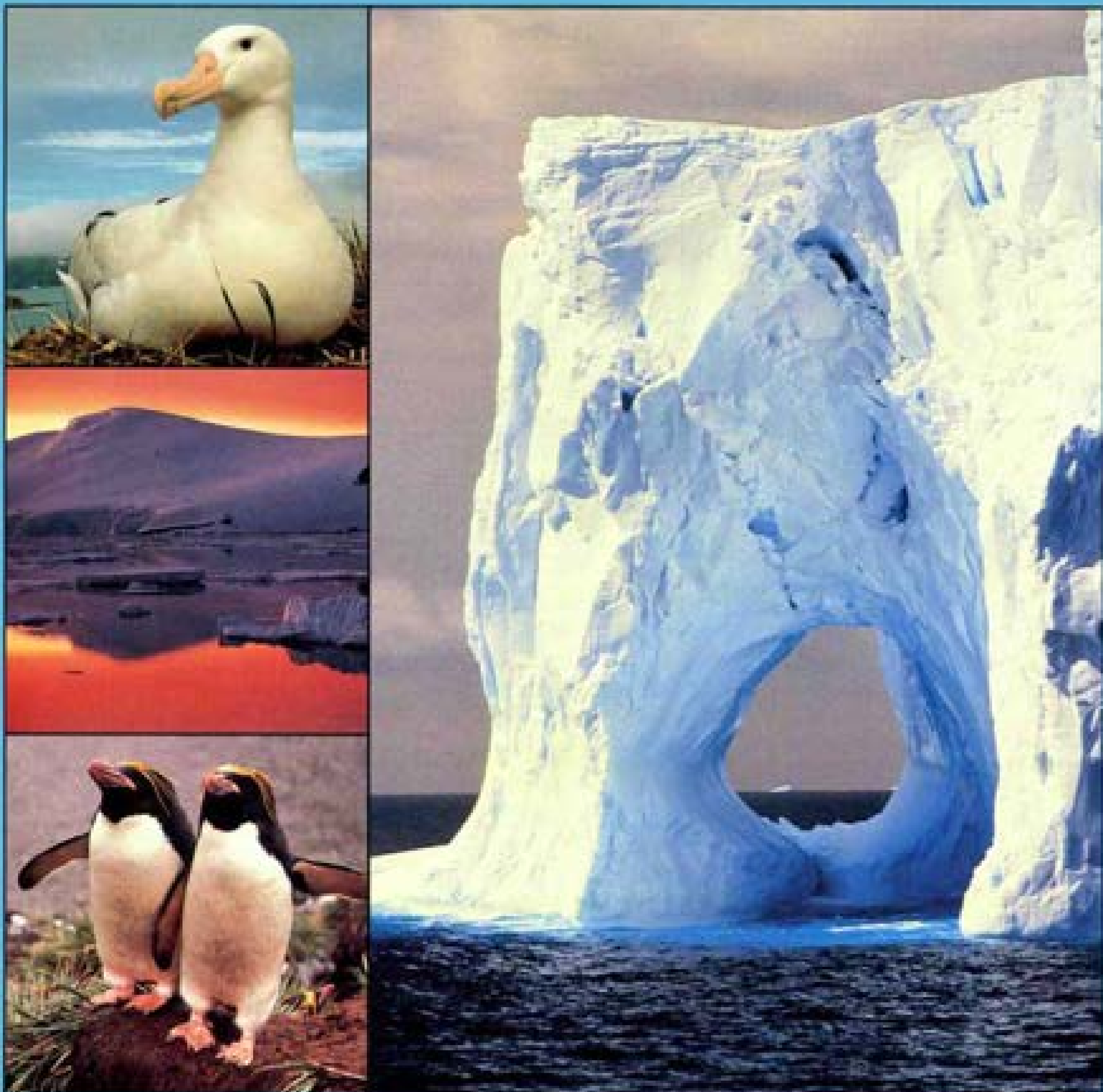
Ron Naveen



Carolina Biology Readers

J. J. Head, Editor

INTRODUCTION

Antarctica is the coldest, driest, highest, and windiest continent on Earth. Its total land area is 14 million square kilometers, approximately 1.5 times the size of the United States including Alaska. In winter, pack ice (frozen ocean) increases the area of Antarctica about 2.5 times, or up to 35 million square kilometers. The continent and its surrounding oceans south of the Antarctic Convergence comprise just under 30 percent of the Earth's surface and are the wilderness home of penguins, sea birds, whales, seals, fish, krill, and other organisms. About 90 percent of the world's ice and snow are located in Antarctica. It contains glaciers, snow-capped peaks, and icebergs, and is the resting place of thousands of meteorites. Depending on seasonal and atmospheric conditions, its skies dazzle with shimmering displays of auroras, halos, and other phenomena caused by reflection and refraction of light from the sun and moon by atmospheric ice crystals.

There have been over three hundred recorded expeditions to the mainland of Antarctica, dating from 1675. The first landing was made in 1821 (Figure 1), but it was during the early part of the twentieth century that the great romantic explorations, centering on reaching the South Pole as well as on scientific investigation, took place. The feats of Sir Ernest Shackleton (United Kingdom), Roald Amundsen (Norway), Robert Falcon Scott (United Kingdom), and Richard E. Byrd (United States) captured the attention and the imagination of the Western world.

Although few people have visited Antarctica, it is creeping increasingly into our collective consciousness. As examples, demand for Antarctic krill (a shrimplike crustacean) and fish is increasing. Also, there is rising concern about possible future exploitation of the continent's mineral, oil, and gas resources. We read that the deterioration of the ozone layer in the stratosphere above Antarctica may threaten to disrupt the entire Antarctic food web. Also, global warming may melt the continental ice, which constitutes 90 percent of the Earth's freshwater; if it were all to melt, world mean ocean levels would rise by 55–60 meters (see CBR 165, *The Greenhouse Effect*).

This Reader provides an overview of Antarctic geology, geography, climate, marine and terrestrial ecosystems, and of man's scientific and political involvement on the continent.

GEOLOGY AND GEOGRAPHY

About 160 million years ago, in the Jurassic period, the supercontinental plate called Gondwanaland, located in the Southern Hemisphere and stretching from the Equator to the South Pole, began to break up (see CBR 113, *Plate Tectonics and Biological Evolution*). Over roughly the next 60 million years its fragments became what we know today as South America, Africa, India, Australia, and Antarctica. The final separation, which left the Antarctic landmass isolated, occurred when South America finally separated from Antarctica about 23 million years ago, forming the Drake Passage (Figure 2), an event that drastically altered the worldwide oceanic circulation.

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Present-day Antarctica is divided into two distinct portions, East and West Antarctica, separated by the Transantarctic Mountains, which stretch for some 3,200 kilometers (2,000 miles) from the Weddell Sea to the Ross Sea (Figure 3). Many Transantarctic peaks are more than 3,000 meters high, the highest being the Vinson Massif at 5,140 meters (16,865 feet).

East Antarctica is an elevated ice sheet resting on a rock base that is mostly above sea level. Almost nothing is known about the underlying rocks, but the depth of the ice sheet can be measured by radar, and entire mountain ranges completely covered by ice have been found in this way (for example, the Pensacola Mountains, Figures 3 and 4). East Antarctica lies mostly in the Eastern Hemisphere. It is geologically older, more quiescent in terms of volcanic activity, and twice as large as West Antarctica. The average depth of the ice sheet is 2,000 meters. Only about 1 percent of the Antarctic land mass is not covered by ice. Ice-free areas generally occur only along the edges of West Antarctica. In places, glaciers have carved deep U-shaped valleys that are currently characterized by the absence of snow and ice cover. Some of these dry valleys (Figures 5 and 6) contain lakes formed by the deposition of glacial moraines, which, at depth, are 13 times more saline than seawater and have freezing points as low as –48° Celsius. These lakes receive small amounts of melt water, but this is often not enough to match the rate of evaporation, and the lakes become more saline, or dry up altogether. Bacteria, algae, and zooplankton live even in these inhospitable surroundings (Figure 7).

East Antarctica originated from a large continental plate that was once part of Gondwanaland. Some of its underlying rocks are as much as 3.5 billion years old. (The Earth was formed about 4.5 billion years ago.) About 400 million years ago these rocks sustained an extensive erosion, which produced an almost flat landscape. Sedimentary rocks were later deposited on this surface, and those from the Permian period, about 280 million years ago, show evidence of the glaciation that then affected huge areas of the southern continents. A warmer climate succeeded in which forests flourished; these are the origin of the large coal seams that are today exposed in the Transantarctic Mountains. In the Jurassic period, about 170 million years ago, enormous amounts of igneous rock welled up from the Earth's mantle into the Antarctic sedimentary rocks. One body of this igneous rock in the Pensacola Mountains covers more than 8,000 square kilometers. There was little subsequent geological activity in East Antarctica until volcanism commenced along the coast of Victoria Land about 15 million years ago. Mount Erebus on Ross Island is still an active volcano.

Date	Nationality	Leader
1819–21	Russian	Bellingshausen
Circumnavigated Antarctica. First to sight the mainland.		
1820–22	American	Davis
First recorded landing on the Antarctic mainland, in Hughes Bay, February 7, 1821.		
1837–40	French	D'Urville
First big expedition to land on the mainland. First rational assessment of the nature of Antarctica.		
1839–43	British	Ross
First expedition to force its way through pack ice. Discovered and charted 800 km of new coastline, including the active volcano Mount Erebus.		
1898–1900	British	Borchgrevink
First scientific program.		
1907–09	British	Shackleton
Sledged to within 155 km of South Pole.		
1910–12	Norwegian	Amundsen
First to reach South Pole, December 14, 1911.		
1910–13	British	Scott
Five men reach South Pole January 17, 1912, but die on return journey. Extensive exploration and scientific research.		
1914–16	British	Shackleton
First attempted crossing of Antarctica. Ship crushed by ice. Shackleton sails 1,280 km by open boat to South Georgia to organize rescue.		
1928–30	American	Byrd
Extensive air reconnaissance, including first flight over South Pole.		
1933–35	American	Byrd
Semipermanent base established. Extensive air and sledge reconnaissance and scientific program. Advance weather station 160 km inland manned for seven months.		
1946–47	American	Byrd
Largest expedition so far attempted. Thirteen ships and 4,000 men. Extensive photographic reconnaissance.		
1949–52	British/ Norwegian/ French	Giaever
First fully international expedition. Extensive meteorological and glaciological program.		
1956–58	Russian (IGY)	Treshnikov
Stations established inland. Extensive scientific program.		

Figure 1. Some of the principal expeditions to Antarctica.

West Antarctica is thought to have had a separate geological origin from East Antarctica and to have been formed from several small continental blocks that moved independently of each other

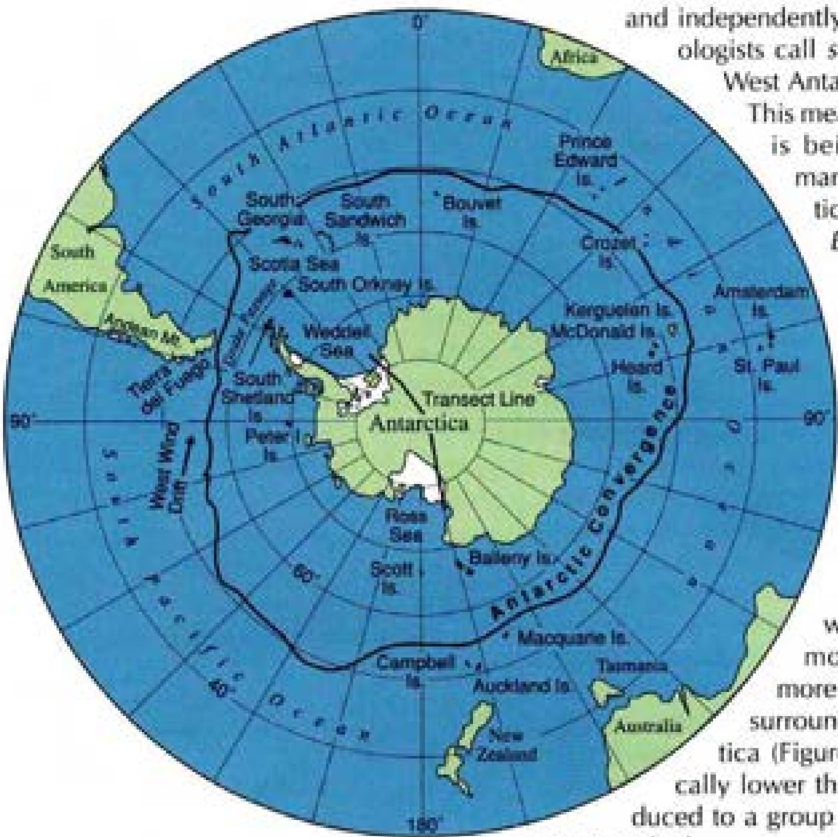


Figure 2. The Antarctic continent, subantarctic islands, and adjacent continents. Note the line showing the position of the transect shown in Figure 4. The Antarctic Convergence is located at approximately 50°S. It is a zone 30–50 km wide where cold Antarctic waters meet warmer waters of the temperate zone. Antarctic and temperate waters differ also in their chemical composition, density, and biota.

and independently of East Antarctica. The process geologists call *subduction* has been taking place in West Antarctica for the last 200 million years. This means that the oceanic crust of the Earth is being dragged downwards into the mantle along the margin of West Antarctica (see CBR 113, *Plate Tectonics and Biological Evolution)*. Subduction is associated with volcanic activity, and volcanic rocks are found along the Antarctic Peninsula. There have been volcanic eruptions on Deception Island in the South Shetland Islands since 1967. Although ancient rocks underlie the Peninsula (Figure 3), the oldest exposed rocks are younger than 500 million years.

West Antarctica lies wholly within the Western Hemisphere. It has more exposed mountain ranges and more nunataks (isolated mountain peaks surrounded by glacial ice) than East Antarctica (Figure 8). West Antarctica is topographically lower than East Antarctica and would be reduced to a group of scattered islands if its present ice cover melted.

There may be large amounts of minerals, oil, and gas in Antarctica. The Antarctic Peninsula may contain extractable quantities of copper, lead, and zinc, and precious metals like gold and silver. The ice-covered inland Dufek Massif in the northern Pensacola Mountains could yield platinum, chromium, copper, cobalt, and nickel. Antarctica's offshore sedimentary basins, particularly the Weddell and Ross embayments in West Antarctica, and Prydz Bay and the Wilkes Basin in East Antarctica, offer the prospect of oil and gas reserves.

The Ice

The Antarctic continental landmass is 99 percent covered by a gently domed sheet of ice. In a crude sense, Antarctica consists of one huge glacier, of which the gently domed sheet and the floating ice shelves are integral parts. The sheet creeps downwards to the sea, where it is continuous with ice shelves that float on open sea and comprise about 10 percent of the continental area. The shelves consist mainly of freshwater, though they do contain frozen seawater. They are particularly distinctive features of the Weddell Sea and the Ross Sea, with the Ross Ice Shelf covering an area larger than France.

The ice flows outward at a rate of a few meters per year in the interior and as much as 200 meters per year at the continental margin. The flow is greatest at the surface and slowest at bedrock level.

In the ice shelves the rate of movement is as much as 1,200 meters per year, and the outer margins "calve" up to ten thousand flattopped icebergs throughout the year (Figure 9). Icebergs are also calved from the mouths of land-based glaciers. Icebergs are moved by ocean currents and wind as much as 60 kilometers per day, and some reach as far north as South Georgia. At present, it is not known whether more ice is being lost from Antarctica than is being replenished by fresh snowfalls.

The continent possesses spectacular glaciers, many of which pass through the Transantarctic Mountains and may be up to 100 kilometers wide. They usually reach the ice shelves and the sea, but some, like those in the dry valleys, end on land. The great Beardmore Glacier, which provided access to the Antarctic interior for Shackleton, Amundsen, and Byrd, is more than 200 kilometers long, 22 kilometers wide, and moves more than 1 meter each day. The Lambert Glacier, opening into Prydz Bay in East Antarctica, is the world's largest glacier: 400 kilometers long, 40 kilometers wide, and moving 225–1,000 meters per year.

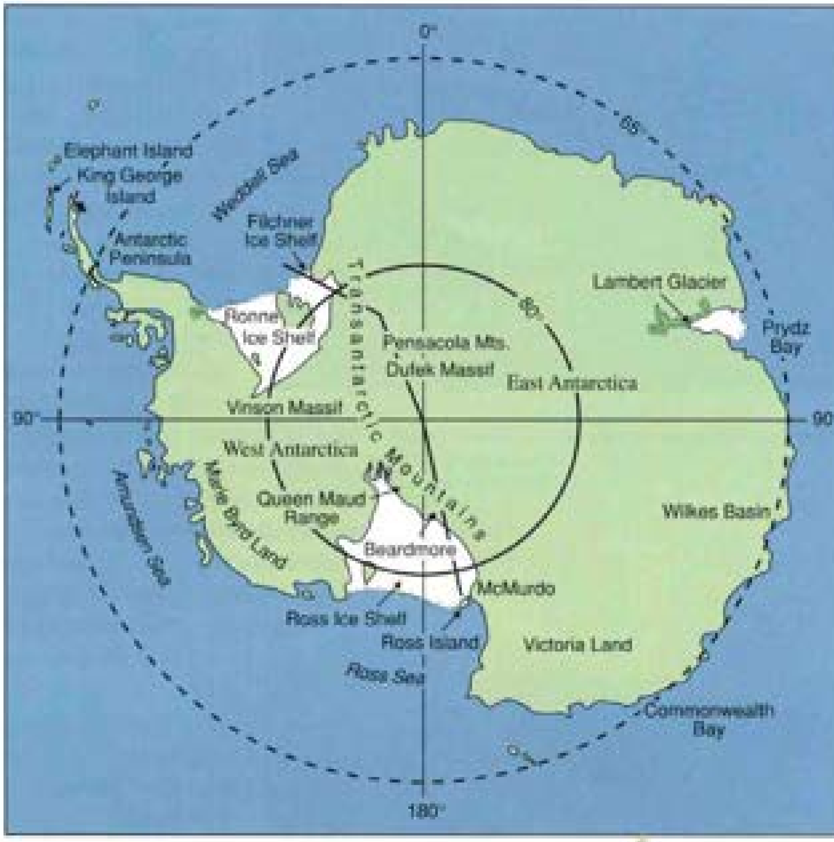
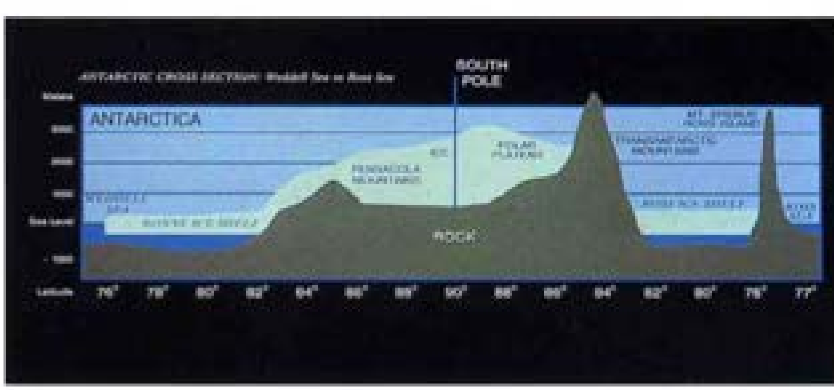


Figure 3. The Antarctic continental landmass. East (or Greater) Antarctica is separated from West (or Lesser) Antarctica, which includes the Antarctic Peninsula, by the Transantarctic Mountains. Most of the places are named after Antarctic explorers.

During the southern, or *austral* winter, from late March to October, the seawater freezes along the coast, forming pack ice several meters thick, and by midwinter this has more than doubled the size of the continent. Pack ice is not a continuous solid mass but forms floes that are moved by the wind and sea currents (Figure 10). It melts in the spring, and 85 percent of it has disappeared by the end of the Antarctic summer in February.

Figure 4. Transect of Antarctica from the Weddell Sea to the Ross Sea (see Figure 2). Note the massive amount of freshwater ice, average thickness 2,000 meters. The Ronne and Ross ice shelves are permanent ice. The location of this transect is shown on Figure 3. (Drawing by the author.)



WEATHER AND CLIMATE

Antarctica is an icy desert, and the continent averages only 14 centimeters of precipitation per year. On the coast there may be as much as 60 centimeters, but less than 4 centimeters in the interior, about as much as that falling in the Sahara Desert. In the northernmost coastal regions the mean summer temperature is just above

Figure 5. The Taylor Valley in Victoria Land, one of the dry valleys where glaciers reach their terminus on land. (Courtesy Dr. Geoffrey L. Leister.)

freezing, but at the South Pole it is around –25° Celsius. The lowest temperature ever recorded on Earth was –89.6° Celsius (–129.3° Fahrenheit) at the Russian Vostok station near the South Geomagnetic Pole.

Antarctic weather influences the global climate. The extent of floating sea ice varies greatly between the austral summer and winter. In winter, when there are 24 hours of darkness, the pack ice is at its most extensive cover, and it prevents the transfer of heat from the sea to the atmosphere. In summer, when there are 24 hours of daylight, the great Antarctic ice cap reflects as much as 80–90 percent of the incident radiation. (By contrast, ice-free ocean reflects only 5 percent of incident radiation, and snow-free land up to 35 percent.)

The local gravitation of cold, dense air down steep slopes produces *katabatic winds,* which make some Antarctic coastal sites the windiest places on Earth. The strongest winds known, up to 300 kilometers per hour, have been recorded at Commonwealth Bay in Victoria Land. In general, however, there are few calms or full gales. The katabatic winds drive the pack ice from the shore and produce bands of open water along the Antarctic coast; and since the ocean south of latitude 40° S is unobstructed, these winds help to generate the "Roaring Forties" and "Furious Fifties" that have always harassed Antarctic ocean travelers. Katabatic winds cause saucer-shaped lenticular clouds (Figure 11), telltale signs to mariners that foul winds and seas are imminent.

Figure 6. Glacial U-shaped valley: North fork of Wright Valley in Victoria Land. Lake Vanda, a brackish freshwater lake, can be seen in the distance. (Courtesy Dr. D. Koob.)

Antarctica's ice cap, its high winds, and the open ocean surrounding the whole continent, combine to produce an enormous global weather machine. In the austral winter, the seas are cooled and pack ice forms. Sinking, colder water displaces warmer water, which rises to the surface, where it loses its heat to the atmosphere. Cold water is blown northwards from the coast by the katabatic winds, and the total effect of these forces is to divide the Southern Ocean into two distinct areas, like concentric rings around the continent. In the northern ring, the dominant westerly winds blow cold currents clockwise around Antarctica (*West Wind Drift,* or *Antarctic Circumpolar Current,* Figure 2). This current has more than four times the flow of the Gulf Stream, and it stretches unobstructed around the continent for 24,000 kilometers. Its northern margin is the favorite playground of albatrosses (Figure 12). In the southern ring, the ocean circulates in the opposite direction (the *East Wind Drift*).

BIOLOGY

Antarctic fossils reveal that the continent was at one time linked to other continents and that its climate has varied through geological time. Fossil invertebrates—trilobites, ammonites, belemnites, and clams—are known, and one of the most important finds, from the Beardmore Glacier in the Transantarctic Mountains, has been the bones of a reptile some 250 million years old. It is called *Lystrosaurus* and was about the size of a corgi dog. Reptiles were the dominant terrestrial fauna at that time, and *Lystrosaurus* has also been found in Africa, India, and China, showing that these continents were then linked (see CBR 119, *Biogeography*). In 1991, dinosaur fossils were found on Mt. Kirkpatrick. Fossil plants found in the transantarctic coal seams include ferns and gymnosperms.

Figure 7. Lake Vanda. The soil is covered by mats of cyanobacteria (blue-green algae). (Courtesy Dr. Geoffrey L. Leister.)

The present-day land fauna of the Antarctic continent is unlike that of any other major landmass. Springtails and mites exist in great numbers in the soil and among the mosses and lichens. They are small, and the continent's largest invertebrate is the 12-millimeter-long midge, *Belgica antarctica*. Other small invertebrates found in the Antarctic lakes and in the moist mosses and soils are protozoa, nematodes, rotifers, and tardigrades (microscopic arthropods). Apart from seals and birds, which feed on fish, no terrestrial vertebrates live there. The few very slow-growing plants could not support terrestrial vertebrate herbivores, so there is no ecological basis for terrestrial vertebrate carnivores. It is only very recently that man has lived there, and he can do so only by taking his own microenvironment with him.

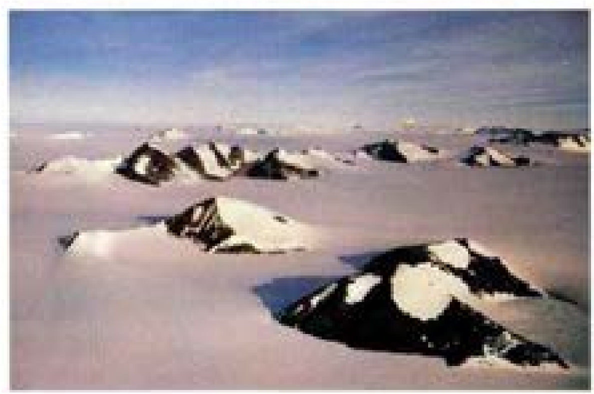


Figure 8. Exposed mountain peaks surrounded by glacial ice are called nunataks. These are near Mount Passal in Marie Byrd Land. (Courtesy Dr. Geoffrey L. Leister.)

Animals and plants have crossed more formidable ocean barriers than those that isolate Antarctica, but the very bad weather, and especially the cold summer, prevents the growth of nearly all plants. Only two species of flowering plants are native to Antarctica, both confined to the Antarctic Peninsula. These are *Deschampsia antarctica*, the Antarctic hair grass (Figure 13), and *Colobanthus quitensis*, the Antarctic pearlwort. They grow on moist, sunny slopes near the shore. The predominant land vegetation is slow-growing lichens and mosses (Figures 13 and 14), which literally keep a very low profile. Their growth is so slow that a bootmark on a mossbank may persist for 10 years. A few species of liverworts and toadstools are found in wet moss banks, and freshwater algae and cyanobacteria (Figure 7) occur in the freshwater lakes which, as we have seen, may be very saline.

Antarctic Food Web

The ecosystems of the Southern (or Antarctic) Ocean are the largest and most fertile on Earth. They extend over 36 million square kilometers, equivalent to 10 percent of the planet's oceanic surface. Their northern limit is marked by the Antarctic Convergence where the cold Antarctic surface water sinks beneath the less dense, warmer subantarctic surface water from the Atlantic, Pacific, and Indian oceans. The Convergence is a floating and changing boundary between latitudes 47° and 63° S (Figure 2). Waters south of it contain higher concentrations of chemical nutrients, and these provide the food basis of the rich Antarctic marine ecosystem.

Figure 9. Up to 10,000 flattopped icebergs are calved from Antarctica's great freshwater icesheets each year. (Photograph by the author.)

Phytoplankton. Near to the continent, cold water sinks and forms bottom water that moves northward towards the Convergence and beyond. Above this layer, warmer, more saline water flows southward, and this movement creates a zone of upwelling that brings nutrients to the ocean surface. Here the photosynthesizing phytoplankton, containing upwards of 170 species of single-celled algae, the primary producers of the Antarctic food web, flourishes (see CBR 91, *Ecological Energetics*). Offshore winds tend to prevent this phytoplankton from inhabiting its optimal position near the surface, where daylight in the sunny seasons could be best used for photosynthesis.

Zooplankton. A varied zooplankton, animals that cannot swim against ocean currents and therefore drift, feeds on the phytoplankton. Two important components are copepods and euphausids. (Antarctic euphausids collectively are called *krill.*) Copepods and krill are both crustaceans, though not closely related. There are over four thousand species of copepods. They have a typical crustacean appearance, and nearly all are from one to a few millimeters long.

There are upwards of a hundred species of krill. Closely related to shrimps and lobsters, krill are filter-feeders perfectly suited to consuming floating phytoplankton. About 1–6 centimeters long, they contain up to 20 percent protein when wet, and since they themselves are the food of larger animals—notably cephalopods, also fish, penguins, seals, and several species of whale—they form a very important link in the oceanic food web. The most abundant Antarctic krill is *Euphausia superba* (Figure 15).

Krill are found at the ocean surface and down to depths of 3,500 meters; they swarm in almost unbelievable numbers, often extending over hundreds of square kilometers. Krill migrate vertically, coming to the surface during the long Antarctic night and moving to 100–200 meters below the surface during the daylight seasons. Millions of tonnes of krill are consumed annually—one estimate is 500 million tonnes. Estimates of the biomass of krill range from 100 to 700 million tonnes. Research is currently being conducted into the factors that affect krill biomass, including their life span, the amount of newly spawned krill per year, and the natural mortality of krill other than by predation.

Figure 10. During the Austral winter, pack ice can more than double the size of the Antarctic Continent. (Courtesy British Antarctic Survey. Photograph by M. Sievwright.)

Human exploitation of Antarctic krill began in the 1960s. In recent years, one-third to one-half million tonnes have been taken by international fishing fleets annually and used mostly for animal feed and fishing bait. Some is processed for human consumption in the form of paste, frozen sticks, and tails. Krill deteriorates rapidly, and large-capacity freezer ships are needed to exploit it. The current small take compares with a total world consumption of fishing products of about 80 million tonnes. The 1982 Convention on the Conservation of Antarctic Living Marine Resources (part of the Antarctic Treaty System, see below) regulates the exploitation of krill and is designed to ensure that krill does not suffer the fate of the great whales, namely being hunted to near extinction.

Figure 11. Lenticular (biconvex) clouds caused by katabatic winds. (Photograph by the author.)

Squid, octopus, and fish. Squid and octopus (both cephalopod mollusks) are important components of the Antarctic marine ecosystem. They consume perhaps 100 million tonnes of krill per year and are themselves eaten by fish, sea birds, penguins, seals, and sperm whales. Sperm whales alone consume about 50 million tonnes of squid annually. As yet squid are not exploited commercially.

Very little is known about the magnitude of Antarctic fish stocks, and this is another area where international scientific investigation is needed. Antarctic fish show adaptations to life at low temperatures (such as the presence of glycoproteins acting as antifreeze in the blood) that are unique in vertebrates. These adaptations are the subject of much current research.

Whales. Whales are mammals (warm-blooded, air-breathing animals), which spend their entire existence in the sea. They are classified in the mammalian Order Cetacea, and the suborder Mysticeti (baleen whales) feed by filtering huge numbers of krill from the Antarctic plankton. To accomplish this, baleen whales have flattened baleen plates that project downwards from the sides of their palates. The large whales all breed in warmer, more northern waters. They feed in the Southern Ocean and build up large reserves of blubber, which sustains them during their migration in the breeding season.

Whaling operations in Antarctica once flourished, but under the auspices of the International Whaling Convention they have ceased, save for a small take for scientific purposes. The central north coast of South Georgia Island (on the northern edge of the Antarctic Convergence, Figure 2) is dotted with rusting, abandoned whaling stations. In the 60 years of their operation, these stations processed between one-half to two-thirds of the Southern Ocean's whales. Some species were brought to the brink of extinction.

Figure 12. The wandering albatross is the world's largest albatross, having a wingspan of up to 4 m. These birds mate for life but do not spend the nonbreeding season together. On returning to their particular breeding ground, the mates engage in a ritualized courtship display that renews the pair bond and acts as a stimulus to nesting. (Photograph by the author.)

Penguins. Vertebrates of the Antarctic continent are limited to some 30 breeding species of sea birds (including penguins), and 6 species of seals. These animals feed from the ocean and show many adaptations for swimming, diving, and prolonged submergence.

There are 17 species of penguins worldwide, and 6 are found regularly on the Antarctic continent. The largest of these is the emperor penguin, at 1.4 meters and 40 kilograms. The three members of the genus

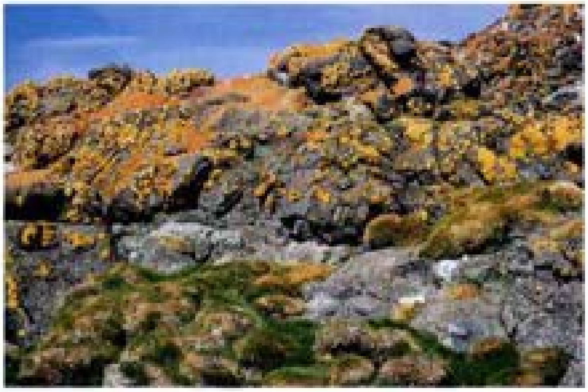


Figure 13. *Xanthoria* and *Caloplaca* spp. These brightly colored lichens are seen here growing on coastal rocks. Away from sea spray, the lichens are drab-colored. Lichens are the first colonizers of bare rock faces and are well adapted to Antarctic life. They can survive low temperatures and require less light and water than other plants. The high concentration of pigments and acids in lichens retards freezing. In the foreground, the grass *Deschampsia antarctica*. (Courtesy William R. West, F.B.P.A.)

Pygoscelis found here are the chinstrap, the Adélie, and the gentoo. The tuft-headed macaroni penguin and the 1-meter tall king penguin (Figure 16) are the other two species. Predators that penguins face include, on land, skuas and sheathbills, which take penguin chicks and eggs; and, at sea, orcas (killer whales), leopard seals, and Kerguelen fur seals.

Penguins rest and breed on land (or in the case of emperor penguins, on fast ice, the marine ice that abuts the continent), where they waddle rather clumsily. In the water they move with expert ease, and they possess adaptations that enable them to exploit this environment fully. In their forelimbs (corresponding to wings), the bones, unlike those of other birds, are solid, flattened, and fused so that the limb moves only at the shoulder; their feet are webbed, and their bodies fusiform. Penguins carry up to 70 well-oiled (unwettable) feathers per square inch, the densest arrangement on any bird. With the air trapped by their feathers, and a layer of subcutaneous blubber, penguins are well insulated.

They can swim up to 12 miles per hour in bursts, and the emperor penguin can dive to 274 meters and stay submerged for almost 20 minutes. These adaptations make penguins good hunters of fish and cephalopods.

The emperor penguin breeds on fast ice near the continental margin. It lays a single egg at the onset of austral winter (late March), which the male incubates for about two months during the long, dark Antarctic winter, huddled with other males in a group called a crèche. At this time, the female heads north to open water to feed for two or more months. She returns in the spring, when the pack ice breaks up, to relieve her mate, who has lost one-third or more of his body weight, and to start feeding the newly hatched chick for a further month. Until the female returns, the male can feed the chick with a reserve of stomach oil. Chicks depart for the open sea in December.

Figure 14. *Bryum* sp. Mosses grow along side lichens in sheltered and moisture-rich niches. This species is photographed growing in Cape Hallett, Victoria Land. By growing in dense patches, mosses and lichens make the best of scarce Antarctic moisture. (Courtesy Dr. Geoffrey L. Leister.)

By contrast, the breeding seasons of brushtails—Adélie, chinstrap, and gentoo penguins—essentially start as the pack ice breaks up in the austral spring. For Adélie penguins, wintering on the edge of the pack ice, and chinstrap penguins, wintering in the open water beyond the pack, the breeding season requires a return migration of many hundreds of miles to reach particular nest sites. Gentoos are less migratory, and winter in the Antarctic as long as there is open water in which to feed. These species breed on land, and their nest sites are mere scrapes in the rock, often ringed with pebbles and small stones. The brief breeding season of two to three-and-a-half months includes courting, copulation, laying and incubating eggs, and fledging the young. Adélies and chinstraps form huge colonies (often many thousand breeding pairs). Gentoos are less numerous, and their colonies are much smaller. These three species are called *brushtails* because of their stiff, woodpeckerlike tail feathers, which help to hold them erect (Figure 17). The female normally lays two eggs, with incubation and feeding shared by both parents. The chicks hatch after approximately one month of incubation (Figure 18). They are brooded and fed for up to six weeks. Then Adélie and chinstrap chicks instinctively leave the breeding grounds and take to sea, presumably migrating northward, as self-sufficient birds. Gentoo chicks are less independent, lingering for a few more weeks to be fed by their parents.

Adélies and chinstraps are site-specific animals and return to their previous year's breeding ground. Mates do not spend the nonbreeding season together. If both members of a pair survive the year, they will mate again; otherwise they change mates. The chinstrap male returns to last year's breeding site early in the breeding season. The more experienced breeders access the taller, more rugged nesting sites that have been blown free of snow by the spring winds. The male displays in the expectation that last season's female will return in short order (Figure 17). If she does not, he will mate with another available female. If the original mate ultimately does return, a battle ensues, with the losing female being pummeled and often tossed downhill.

Figure 15. *Euphausia superba* is the most abundant species in the Antarctic krill. (Courtesy William R. West, F.B.P.A.)

Gentoos have a strong pair-bond, and pairs may stay together year-round. They tend to change breeding sites often. Unlike the other brushtails, if the first clutch of eggs is lost, gentoo parents will lay again. Young gentoos gradually learn to forage on their own, going to sea at about eight weeks but returning each night to be fed by one of their parents. By their tenth week of life, they must be fully independent, since at that time both parents come ashore to molt and cannot provide any food to their young. The young gentoos return to their natal grounds the following season but will not attempt breeding until the age of two years. Chinstraps may return to their natal ground in their second year, Adélies in their third, but neither of these species breeds until the age of three years.

Figure 16. The king penguin (*Aptenodytes patagonicus*) is the second largest penguin. Its breeding grounds are the subantarctic islands to the north of the Antarctic continent. Here, an adult king raises its beak to the sky in display. (Photograph by the author.)

Seals. Seals are the only indigenous terrestrial mammals in Antarctica. They show many anatomical and physiological adaptations for swimming and diving, but of course they are air-breathing and, unlike whales, which spend their whole lives in water, breed on the ice or the shingle beaches.

Six species are encountered, all belonging to the mammalian suborder Pinnipedia. Five belong to the Family Phocidae: the crabeater seal, *Lobodon carcinophagus*; the leopard seal, *Hydrurga leptonyx*; the Ross seal, *Ommatophoca rossi;* the Weddell seal, *Leptonychotes weddelli*; and the elephant seal, *Mirounga leonina*. The remaining species, the Antarctic fur seal, *Arctocephalus gazella*, belongs to the family of eared seals, the Otariidae, which also includes sea lions.

Pinnipeds have streamlined, torpedo-shaped bodies (Figures 19 and 20). The foreflipper is short and clawed; the animal does not use it to paddle and keeps it close to the flank

Figure 17. Chinstrap penguins (*Pygoscelis antarctica*) engaged in a mutual display, which reinforces the pair bond. (Photograph by the author.)

when swimming. The hind flippers are webbed and turned backward, soles together, making a rudder. Seals use these flippers, together with side-to-side movements of the body, to propel themselves through the water. The Phocidae cannot turn their hind flippers forwards; they are useless for locomotion on land, which is accomplished by an awkward humping of the body with some assistance from the foreflippers. The Otariidae, by contrast, can rotate the hind flippers forward, with soles turned against the ground; and these animals walk in an upright position. The pinniped upper lip bears many vibrissae (whiskers), which are important sensory organs (Figure 19).

Weddell seals inhabit the fast ice and the shore around the whole Antarctic continent. They feed mainly on fish, though some squid and other invertebrates are taken. The birth and rearing of pups takes place from September to November on the ice near cracks that allow the male to patrol an underwater "territory."

Experiments on Weddell seals show they can dive as deep as 600 meters for periods of up to 13 minutes; they also undertake shallower, exploratory dives to around 130 meters, traveling as far as 4,400 meters in 30 minutes. During diving, the animal's heart rate slows, and its blood is selectively redistributed to the central nervous system and heart and away from the other viscera. Effectively, the animal becomes a "heart/brain preparation." The Weddell seal has characteristically arranged incisor and canine teeth to ream breathing holes in the ice and keep them from freezing up. It is not understood how the animal knows the location of a distant, vital breathing hole.

At 3.4 meters, leopard seals (Figure 20) are larger than crabeaters; they inhabit the pack ice and are easily recognized by their sinuous neck and reptilian-shaped head. They have complicated teeth for straining krill, though a large portion of their diet is penguins and young crabeaters. They also take smaller quantities of fish, squid, and other invertebrates.

The crabeater seal (Figure 21) is the world's most abundant seal, perhaps with a population exceeding 30 million, which is greater than the total population of all other seals put together. Perhaps it should be called "krilleater seal" because it feeds predominantly by gulping water and straining out the krill through specially modified teeth and palates, much in the fashion of baleen whales. Crabeaters are abundant on the outer fringes of the pack ice. They are usually solitary except during the spring breeding season when they form family groups of mother, father, and solitary pup. Crabeaters of all ages are preyed on by killer whales (*Orcinus orca*). A group of killer whales may rock an ice floe back and forth until one of the seals slides off into waiting jaws. Younger crabeaters are preyed upon by leopard seals, and scars on a crabeater's body often indicate a close brush

Figure 18. Adélie penguins (*Pygoscelis adeliae*): mother, chick, and unhatched egg. Brushtails normally lay two eggs, while the larger Antarctic penguins—the emperor and the king—lay a single egg. (Courtesy Dr. Geoffrey L. Leister.)

with this predator. Crabeater numbers have increased greatly because of the decimation of whale populations by whaling fleets.

Ecological Productivity

To get an idea of the productivity of the Antarctic ecosystem, you must realize that between 240 and 6,400 million tonnes of plankton are produced per year; this supports a standing stock of 100–700 million tonnes of krill. The standing stock of large predators includes some 500,000 whales, weighing 9 million tonnes, 33 million seals weighing 7 million tonnes, and some 60 million sea birds (other than penguins) weighing more than 200 million tonnes.

Figure 19. Weddell seal (*Leptonychotes weddelli*) asleep. Note the vibrissae, absence of pinnae, and the fore and hind flippers. (Photograph by the author.)

Threat to the Antarctic Food Web

Measurements made since 1957 on the "ozone layer" in the stratosphere, 20–25 kilometers above the Earth, show that it becomes thinner in the austral spring, producing the so-called "ozone hole" (Figure 22). Ozone (O_3) is a molecular form of oxygen that is of great importance to life on Earth because it absorbs solar ultraviolet radiation of wavelength 280–320 nanometers, called UV-B. This radiation produces mutations—changes in the DNA of living organisms—and it kills many microorganisms. Marine phytoplankton are susceptible to UV-B, and it is possible that if the UV shield were to disappear, the whole Antarctic marine ecosystem, whose primary producers are single-celled algae, such as dinoflagellates, and cyanobacteria, would be disrupted, or even destroyed. UV-B has been shown to penetrate down to 6 meters in Antarctic waters, but predictions are not simple because many of the planktonic photosynthesizers migrate downwards during the day; and pack ice reflects UV radiation during the austral spring and part of the austral autumn. Nevertheless there is concern for the ozone layer and its depletion at the hands of man, largely, it is thought, because of the release into the atmosphere of chlorofluorocarbons (CFCs), which are used in refrigerators, aerosols, and as foam-producing agents.

Figure 20. Leopard seal (*Hydrurga leptonyx*). Note the characteristic shape of the head and neck. (Photograph by the author.)

Figure 21. Crabeater seals (*Lobodon carcinophagus*). Family group resting on a drifting ice flow. Note the body shape, the absence of ear pinnae, the small fore flippers, and the webbed hind flippers. (Photograph by the author.)

INTERNATIONAL SCIENTIFIC INVESTIGATION

The early twentieth century expeditions of Shackleton, Scott, and Amundsen involved feats of endurance and heroism. From 1928 to 1947, Admiral Byrd of the United States made three extensive investigative expeditions. With improvement in transportation and communications, many nations have established permanent bases and extensive scientific programs. These are beyond the capacity of any one nation, not least because of the great size of Antarctica and its very long coastline.

The Antarctic Treaty

The success of the International Geophysical Year (July 1957–December 1959), when scientists from many countries participated in an unprecedented, cooperative scientific research program, led in 1959 to the signing of the Antarctic Treaty. It was ratified in 1961 by the 12 nations principally involved, namely Great Britain, Norway, France, New Zealand, Argentina, Australia, and Chile (all countries which had previously laid claim to sovereignty over areas of Antarctica and who now agreed to stop discussing this issue), as well as South Africa, Belgium, Japan, the United States, and the Soviet Union, nations that had never claimed any Antarctic territory.

The Treaty is short and simple. It defines Antarctica as the area south of 60° S latitude and provides that Antarctica shall be used for peaceful purposes only; there shall be freedom of scientific investigation and a free exchange of scientific information; there shall be no military measures nor weapons testing, no nuclear explosions, and no nuclear waste disposal; there shall be free movement and inspection among the various nationals working in the Antarctic; countries shall take measures to further the Treaty's objectives, including the preservation and conservation of living resources; and countries shall discourage activities that are contrary to the Treaty's principles. Any United Nations member is eligible to join, but only those conducting significant scientific operations may become voting parties. At present, there are 26 voting and 14 nonvoting parties. These 40 nations represent more than two-thirds of the world's population.

Since 1961 the Treaty has been supplemented by the consensus recommendations of the parties and two additional agreements (the Conservation of Antarctic Seals, 1972, and the Convention on the Conservation of Antarctic Marine Living Resources, 1972). Also, in 1991, the parties signed an environmental protocol that deals with marine pollution, waste disposal, and environmental impact assessments, and which contains a 50-year prohibition on oil, gas, and minerals exploitaton. The whole system of treaties and recommendations is collectively called the Antarctic Treaty System (ATS).

One of the most important recommendations adopted by the parties is called the Agreed Measures for Fauna and Flora, which, for example, prohibits the killing, wounding, or capturing of native mammals and birds; requires participating countries to take appropriate measures to minimize harmful interference with these animals; requires these countries to prevent the pollution of Antarctica; and prohibits the introduction into Antarctica of nonnative species. An outgrowth of the Agreed Measures has been the creation of Specially Protected Areas (SPA) and Sites of Special Scientific Interest (SSSI). The new environmental protocol contemplates revisions to this scheme of protected areas and new measures for protecting flora and fauna.

The Antarctic Treaty has had remarkable success, especially considering that it contains no policing provision. It forms a political framework for Antarctica. A separate Scientific Committee on Antarctic Research (SCAR), based at Cambridge, England, initiates, pro-

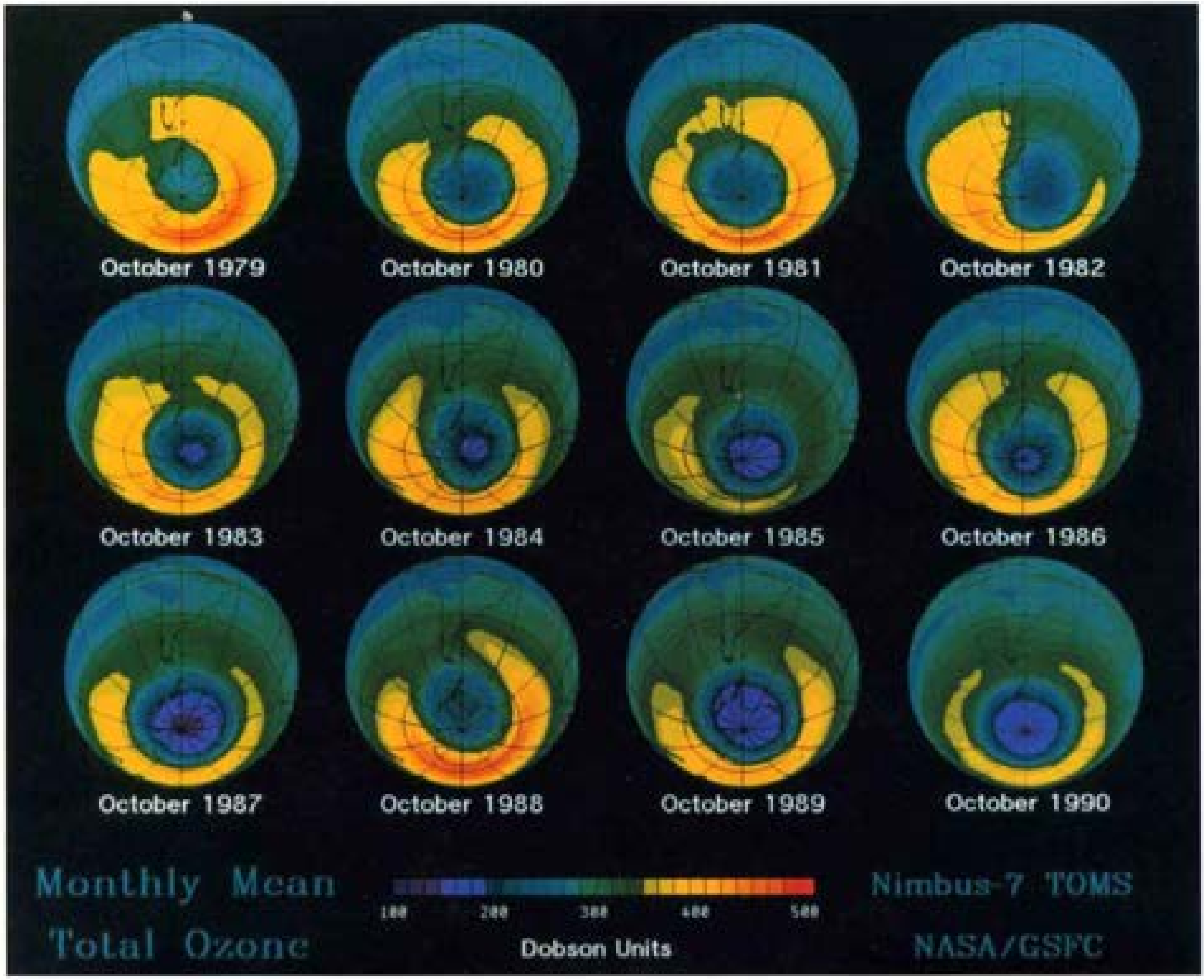


Figure 22. The photo displays 12 Total Ozone Mapping Spectrometer (TOMS) false color images. They show October monthly average total ozone levels for the years 1979 through 1990. The dark purple color indicates extremely low ozone values, while the orange/yellow colors indicate high ozone values. The ozone hole development from 1979 is indicated by the appearance of low ozone values in the later years over Antarctica; this contrasts with the relatively higher ozone values over Antarctica in the early years (blue green/green). (Courtesy NASA.)

motes, and coordinates international scientific research in Antarctica. SCAR advises ATS on such matters as the possible impacts of mining developments on Antarctic science.

Themes of Scientific Research

Atmospheric research. The depletion of stratospheric ozone in the austral spring (Figure 22) was first observed in Antarctica, and research continues there. Antarctica also provides the best location for studying the changes in density in the Earth's upper atmosphere that follow disturbances on the Sun. These changes affect radio communications and the life span of satellites in polar orbit.

Geological research. West Antarctica is a region of geological subduction, and the Antarctic Peninsula is a very good location to study this process, which is of fundamental importance to the theory of plate tectonics. Geophysical studies in the Scotia and Weddell seas are yielding information about one of the major geological events in the history of the Earth, the breakup of Gondwanaland some 160 million years ago. Other geological studies will assess the mineral resources of the continent, including its coal reserves.

The ice sheet contains evidence of the past climatic and environmental conditions of up to one million years ago, which can be studied in ice cores. Minute bubbles of ancient atmospheres trapped in the ice show the rise of greenhouse gas concentrations since preindustrial times. The ratios of oxygen and hydrogen isotopes can reveal paleotemperatures. Acids and particulate matter trapped in the ice reveal past volcanic activity.

Biological research. Organisms living in this extreme environment survive because of many specialized anatomical and physiological adaptations. We noted some of those applying to seals and whales. There are 80–100 species of bottom-dwelling fish in Antarctic waters. They are able to exist at temperatures that freeze the body fluids of most animals because their tissue fluids contain an antifreeze, and this substance has been isolated and has already found medical applications. The flow of energy through the marine ecosystem is a major area of research interest. The stocks of krill, fish, and squid in the Southern Ocean have a potential economic value exceeding that of fisheries in all the other world oceans combined. Since the world's human population has already passed 5.3 billion and is predicted to reach 12 billion before the middle of the next century, demands on this unexploited ecosystem may well increase substantially. If this does happen, the Antarctic ecosystem can be regulated and conserved wisely only if it is first understood.

Let us hope that the spirit of international cooperation generated by international research in Antarctica, which has so far prevented the spoilage of this last pristine ecosystem, persists into the future.

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