Chapter 5

The Antarctic Environment and Potential Impacts From Oil and Minerals Development

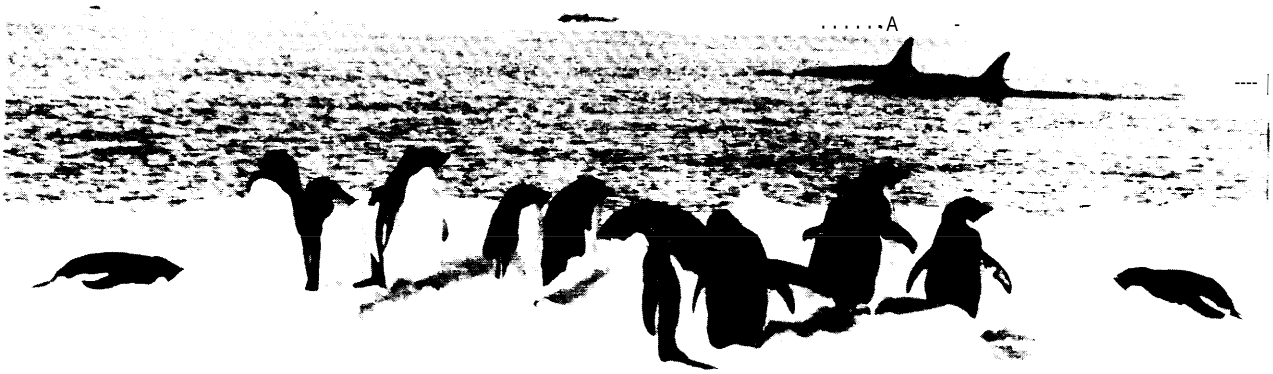

Photo credit: Ann Hawthorne

Mt. Erebus, killer whales, penguins

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The Antarctic Environment and Potential Impacts From Oil and Minerals Development

SUMMARY

Any serious consideration of mineral development in Antarctica requires abetter understanding of likely ecosystem impacts. Primitive terrestrial flora and fauna sparsely populate Antarctica's ice-free coastal areas. The waters surrounding the continent are nutrient-rich and contain an abundance of plankton, benthic organisms, fish, squid, seals, whales, and sea birds. The ice cap, which covers 98 percent of Antarctica, has virtually no life forms.

Of the potential impacts from development activities that might occur in Antarctica, oil spills from tanker accidents or blowouts would probably produce the most significant short- and long-term environmental impacts. Due to the extremely cold temperatures found around Antarctica, the total recovery of coastal areas impacted by oil spills would probably require several decades, or perhaps longer. Far offshore, spills would tend to break up naturally and disperse, causing much less damage than coastal spills.

Mining operations and land-based activities required to support onshore and offshore development would permanently destroy or significantly impact local terrestrial flora and microfauna. Ice-free coastal areas would probably be most prone to impacts, both because of their relatively easy accessibility and because they would be the only practical locations for most facilities. It would probably not be possible or practical to restore most areas impacted by minerals activities to their original condition, so future human activities will need to be planned to minimize impacts from the beginning. Local terrestrial impacts are not expected to have a significant regional effect on the marine ecosystem. Of some concern, however, is the potential of onshore activities to compete with wildlife and research bases for scarce ice-free sites.

Prospecting prior to resource exploration and development would generally produce environmental impacts similar to those caused by onshore, offshore, or airborne scientific research. Thus, impacts are expected to be insignificant.

Despite continuing research, there are still significant uncertainties about the environment of Antarctica. For example, baseline data on the marine ecosystem are still incomplete. Environmental research required before and during offshore petroleum development could amount to several hundred million dollars.

To date, the most significant environmental impacts to the terrestrial and nearshore marine environments have occurred near the few dozen year-round scientific research bases in Antarctica. These impacts, generally involving small, accidental releases of fuel and other chemicals and the disposal of wastes are considered by many to be insignificant. A notable exception is the oil spill from the 1989 sinking of the *Bahia Paraiso* off the Antarctic Peninsula, an incident which will provide insight into the environmental impacts of future spills.

INTRODUCTION

The continent of Antarctica, which covers an area almost 1.5 times the size of the United States, is a vast, largely untouched frozen wilderness dominated by majestic views and bleak, but beautiful landscapes. In fact, about 90 percent of the world's ice is locked up in Antarctica's mile-thick ice sheet. Although the mineral resource potential of Antarctica has been a subject of much speculation over the years, exploration and development has only recently been seriously considered.

As indicated in chapter 3, the Antarctic Minerals Convention provides many general standards and procedures that are designed to ensure that any future minerals development would occur in an environmentally sound manner. For example, no mineral exploration or development is allowed without adequate information about possible environmental impacts that such activities might generate. Opening an area for exploration and development by the Commission requires the consensus of *all* voting parties. Technical advice about decisions is provided by a Scientific, Technical, and Environmental Advisory Committee.

Protecting Antarctica's environment may conflict with issues of sovereignty, politics, logistical convenience, financial considerations, and the facilitation of scientific research.[1] Environmental groups are, therefore, concerned about the scope of procedural and informational requirements for reviewing proposed projects and regulating development activities, especially in light of **potentially** large financial and political incentives associated with minerals development.[234] Liability for environmental impacts from serious accidents is also an issue. The detailed procedures for addressing these issues will be worked out only after the Convention has been ratified.

If minerals development proceeds within the framework of the Minerals Convention, future debates will likely focus not on decisionmaking procedures, but on the definitions of the Convention's many qualitative terms such as "adequate,' "effective," "acceptable," "significant," "safe," etc. These terms can only be defined within the framework of scientific knowledge and uncertainties about Antarctica's environment. Therefore, this chapter provides general background material on the marine and terrestrial ecosystems of Antarctica and evaluates what is known about potential impacts from minerals activities.

EnvironmetilSe#"n#67 [8]

Antarctica covers almost 10 percent of the Earth's land surface, or about 5.4 million square miles (14 million km^2). (See figure 5-1.) Most of the continent is buried beneath an ice cap that depresses the underlying land mass and averages about 6,000 feet (2 km) thick. Fed by falling snow, the ice slowly migrates north at rates that vary from about 10 feet (3 m) to a few thousand feet (1,000 m) per year. The surface of most of the icecap lies between 6,500 feet (2,000 m) and 13,000 feet (4,000 m) above sea level, making the mean elevation of Antarctica three times higher than other continents. The depth of the continental shelf ranges from about 1,200 feet (400 m) to 2,600 feet (800 m), much greater than the global mean.

Of the seven continents, Antarctica is the least hospitable to human activities. Summer temperatures average about O 'C (+32 'F) along the coast and -30 "C (-22 "F) in the interior winter temperatures average about -20 "C (-4 'F) along the coast and -65 "C (-85 "F) in the interior. The most moderate climate is found on the Antarctic Peninsula where average temperatures generally range from about O "C (32 "F) to -15 "C (-5 "F). During the winter months (i.e., mid-June to mid-September) the Sun never rises over the continent's interior and much of its coastal areas. During the summer months (i.e., mid-December to mid-March) it remains up all day. Days and nights are of more equal length during the spring and fall.

Antarctica's interior is essentially a frozen desert. Snowfall is about 10 inches (25 cm) per year. Coastal areas annually receive about 80 to 300 inches (200 to 800 cm) of snow. Coastal areas also tend to be cloudy, but rarely foggy. Blizzards and hurricane force winds with velocities of over 100 miles per hour (50 m/see) occur frequently along the coast of Antarctica. In fact, the Southern Ocean between 40° S. latitude and the Antarctic Circle (i.e., 66° S. latitude), commonly referred to as the ''roaring forties, ' has the strongest sustained winds

[1]F.M. Auburn, *Antarctic Law and Politics* (Indiana University Press, 1982), pp. 274-277.

[2]J.I. Charney (ed.), ''Future Strategies for an Antarctic Minerals Resource Regime.-Can the Environment Be Protected?'' *The New Nationalism* and the *Use of Common Spaces: Issues in Marine Pollution and the Exploitation of Antarctica* (Totowa, New Jersey: Allenheld, Osmun Publishers, 1982), pp. 216-217.

[3]L.A. Kimball, ''The Antarctic Minerals Convention, ' ' Special Report, World Resources Institute, July 1988, p. 36.

[4]L.A. Kimball, ''Environmental Issues in the Antarctic Minerals Negotiations, ' L.M. Alexander and L.C. Hanson (eds.), Antarctic *Politics* and Marine *Resources Critical Choices for the 1980s* (Kingston, RI: Center for Ocean Management Studies, 1985), pp. 204-214.

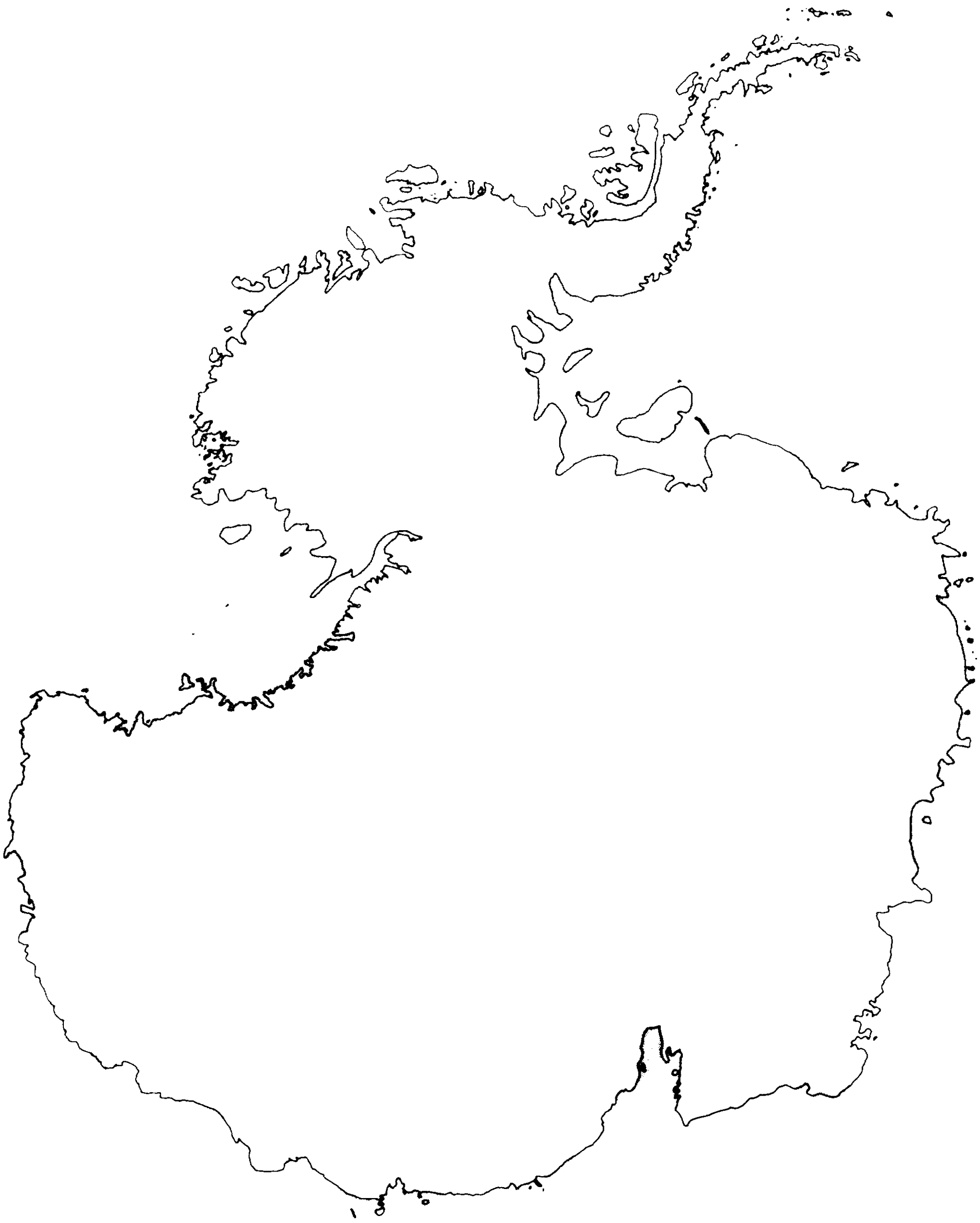
[5]Central Intelligence Agency, National Foreign Assessments Center, *Polar Regions Atlas*, GC 78-10040, May 1978, pp. 35-39.

[6]D.H. Elliot, ''A Framework for Assessing Environmental Impacts of Possible Antarctic Mineral Development, ' The Institute Of Polar Studies, The Ohio State University, January 1977, Part 1, NTIS PB-262 750, pp. vii, xvi, 11-10, V-15.

[7]R.H. Rutford, "Reports of the SCAR Group of Specialists on Antarctic Environmental Implications of Possible Mineral Exploration and Exploitation (AEIMEE), " Scientific Committee on Antarctic Research (SCAR) of the International Council of Scientific Unions, 1986, pp. 18-19.

[8]J.H. Zumberge (cd.), "Possible Env ironmental Effects of Mineral Exploration and Exploitation in Antarctica, ' Scientific Committee on Antarctica Research, March 1979, pp. 17, 18,59,

Figure 5-1-The Comparative Size of Antarctica and the United States

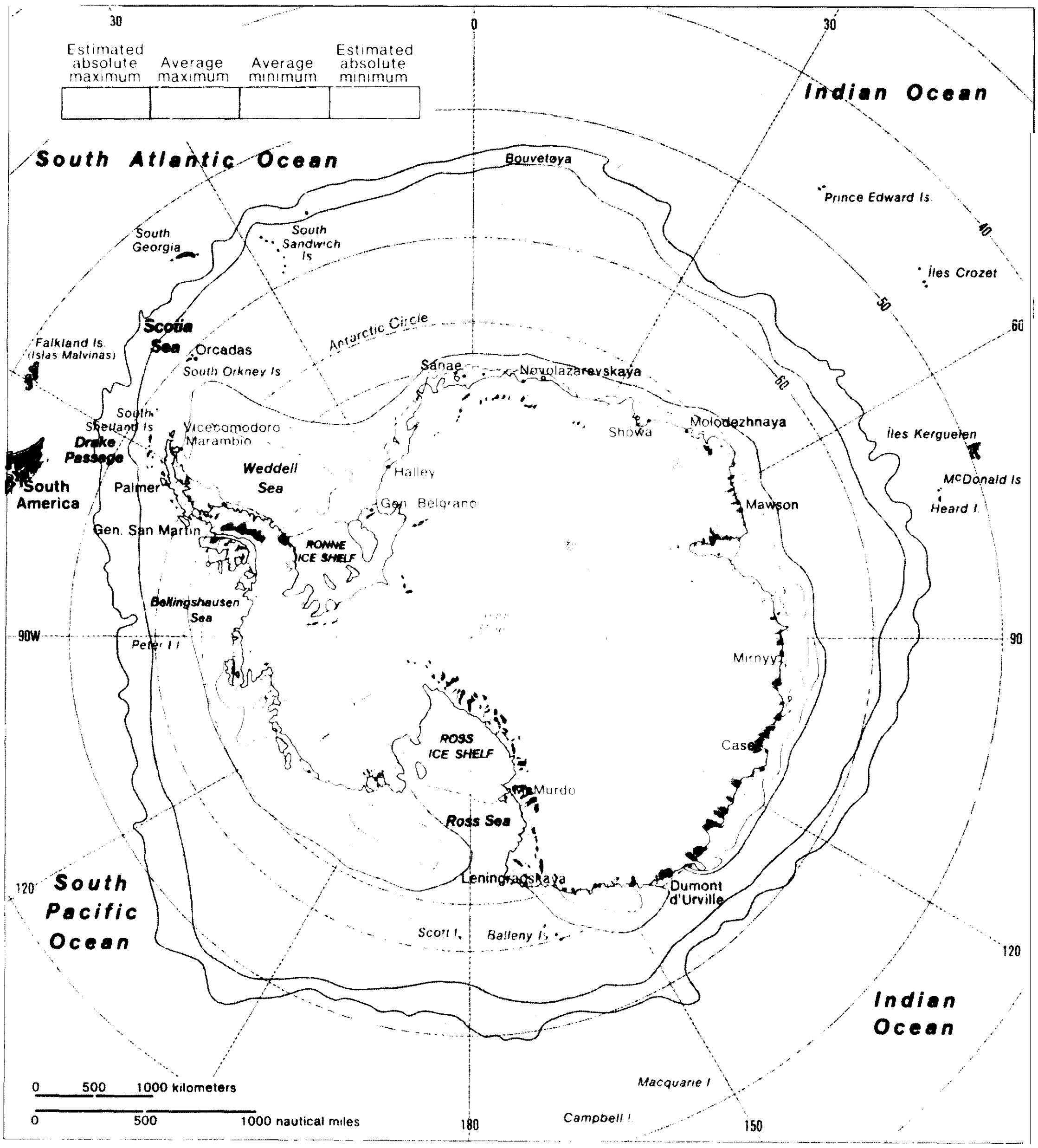


SOURCE: U.S. Geological Survey, 19S9

found anywhere on Earth. High winds and large waves make navigation in this part of the world especially dangerous.

As shown in figure 5-2, the icepack around Antarctica (excluding the permanent ice shelves) grows a maximum of 900 miles out from the continent during the winter and covers about 8 million square miles (20 million km^2), an area larger than the continent itself. Since about 85 percent of the sea ice melts during the summer, the new ice formed during the winter has a relatively uniform

Figure 5-2—Extent of Pack Ice Around Antarctica



SOURCE: U.S. Government, 1982.

thickness of about 3 to 6 feet (1 to 2 m). In the summer, the icepack breaks up as it melts and is dispersed northward by strong winds that can move broken ice up to 40 miles (65 km) per day. At its March minimum, the sea ice covers about 1 million square miles (2.5 million km^2) of the Southern Ocean. Due to wide temperature ranges, sea ice coverage varies substantially from year to year.

Photo credit: Earth Observation Satellite Company

The iceberg B-9 with a number of smaller tabular bergs. The Ross Ice Shelf is to the right. B-9 is about twice the size of Rhode Island.

Huge tabular icebergs break off the Ross, Ronne, and other floating ice shelves and drift around Antarctica at speeds of up to 10 mph. At **any** one time a dozen such icebergs exceeding 15 miles (25 km) in length may be floating around the continent. Some have dimensions of more than 60 miles (100 km) by 35 miles (60 km). Tabular icebergs can rise some 250 feet (75 m) above the sea surface, and extend to water depths of up to 1,500 feet (450 m). Movement of grounded icebergs can produce gouges on the seafloor measuring 100 feet (30 m) wide, up to 15 feet (5 m) deep, and 2 miles (3 km) long. Small icebergs that break off the many glaciers at the edge of Antarctica are also found along the coast of Antarctica throughout the year.

Biological Communities

The biological environment of Antarctica is composed of two distinct and very different ecosystems: a terrestrial ecosystem (including freshwater lakes and streams) and a marine ecosystem. Land-based plants and microorganisms are distributed primarily along ice-free coastal regions of Antarctica in discontinuous patches characterized by typically low population densities. Marine organisms, on the other hand, are widely distributed around Antarctica, often in patches with high population densities. Some marine mammals, such as seals and sea birds, spend some time both on land and at sea. Sea birds also supply land-based plants with vital nutrients,[9] but terrestrial organisms provide no nutrients for marine flora or food for marine fauna.

Due to higher population densities, greater complexity, and greater continuity, **the marine ecosystem of Antarctica is probably somewhat more resilient to impacts than is the land-based ecosystem.**[10] **The** impacts of man's harvesting activities on fish, seals, and whales from the Southern Ocean are discussed in a later section of this chapter.

The Terrestrial Ecosystem

A total of about 200 mostly microscopic species of terrestrial fauna permanently inhabit the continent. These species include **protozoans, rotifers** (i.e., microscopic multicelled aquatic invertebrates), **nematodes (i.e.,** round worms), **tardigrades** (i.e., microscopic arthropods with four pairs of legs that usually live in water or in damp moss), **insects,** and **mites;** there are no land-based vertebrates. With several hundred different kinds of **lichen** and mosses, plant species outnumber animal species by about 4 to 1. Some **grasses are** found on the

[9] M.W. Holdgate and J. Tinker, "Oil and Other Minerals in the Antarctic: The Environmental Implications of Possible Mineral Exploration or Exploitation in Antarctica, " results of a Rockefeller Foundation workshop held in Bellagio, Italy, March 1979, p. 20.

[10] Rutford, op. cit., footnote 7, p. 24.

[11] Elliot, op. cit., footnote 6, pp. ix, II-3 & 5.

[12] Zumberge, op. cit., footnote 8, pp. 43-44.

[13] Central Intelligence Agency, op. cit., footnote 5, p. 50.

[14] J.H. W. Hain, "A Reader's Guide to the Antarctic, ' Oceanus, vol. 31, No. 2, Summer 1988, pp. 3-4.

Antarctic Peninsula, but there are no trees, shrubs, or vines. Poorly developed soils also contain **bacteria, algae, yeast, and other fungi.**[11 12 13 14]

The majority of land-based and freshwater organisms of Antarctica are found on or near its ice-free coastal areas, which cover a combined area about the size of Colorado. Antarctica's coastline is about three times longer than that of the United States, but there is probably less ice-free shoreline during the summer than exists between Boston and Washington.[15] **Potential resource development raises concerns about competition between development activities and wildlife for ice-free terrestrial environments.** Avery few terrestrial species are also found in ice-free areas of the Transantarctic Mountains.

The Marine Ecosystem[16]

The nutrient rich and highly productive waters surrounding Antarctica are characterized by an abundance of phytoplankton, zooplankton, fish, squid, benthic (i.e., bottom-dwelling) organisms, seals, whales, and birds. There are more marine than terrestrial species, but fewer marine species than are typically found in most temperate or tropical marine environments. A simplified diagram of the Antarctic marine ecosystem is shown in figure 5-3.

The base of the marine food chain is supported by about 100 species of **phytoplankton-mostly diatoms--and zooplankton. But the marine ecosystem in areas** of the ocean covered by seasonal ice is dominated by Antarctic **krill,** a small shrimp-like crustacean. As shown in figure **5-4, patchy swarms of krill provide the principal source of food for many Antarctic vertebrates,** including whales, seals, fish, squid, penguins, and other sea birds.[17]

Although small amounts of krill have been harvested from Antarctic waters for human consumption since 1973, the long-term potential of krill as a food and/or protein source for man is not clear. More than 20 species of **squid also provide an important component of the diet** of seals, sea birds, and sperm whales in the open ocean.[18] Benthic organisms, such as **sponges, starfish, and clams are very common in shallow, nearshore waters.**[19]

Of the approximately 20,000 species of finfish found worldwide, about 100 species inhabit the Southern Ocean around Antarctica; most of these species are found only in this area of the world. With commercial fisheries from over a half dozen countries, the potential for overfishing has grown significantly over the last two decades .20

Six species of **seals** live in Antarctic waters; four species live and breed on the pack ice around Antarctica, as shown in figure 5-5. Crabeater seals, with a population of about 15 to 30 million, are the most abundant of these seal species. The southern fur seals are commonly found not only on Antarctica, but also on many islands in the Southern Ocean north of Antarctica.[21 22]

Seven species of **whales are found in Antarctic waters during the** summer. Of these seven species, blue, fin, humpback, sei, and minke whales feed exclusively on the rich supplies of plankton and krill. Sperm and right whales are found both in Antarctic waters and in other temperate waters of the world's oceans.

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[11] Elliot, op. cit., footnote 6, pp. ix, II-3 & 5.

[12] Zumberge, op. cit., footnote 8, pp. 43-44.

[13] Central Intelligence Agency, op. cit., footnote 5, p. 50.

[14] J.H.W. Hain, ''A Reader's Guide to the Antarctic, ' *Oceanus*, vol. 31, No. 2, Summer 1988, pp. 34.

[15] Holdgate, op. cit., footnote 9, P. 31.

[16] J.L. Bengtson, ' 'Review of Antarctic Marine Fauna, ***Selected Papers Presented to the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources 1982-1984,*** Part 1, pp. 1-219.

[17] Elliot, op. cit., footnote 6, p. ix.

[18] R.M. *Laws,* ''The *Ecology* of the Southern Ocean, ' ***American Scientist, vol. 73,*** January -February 1985, pp. 26-40,

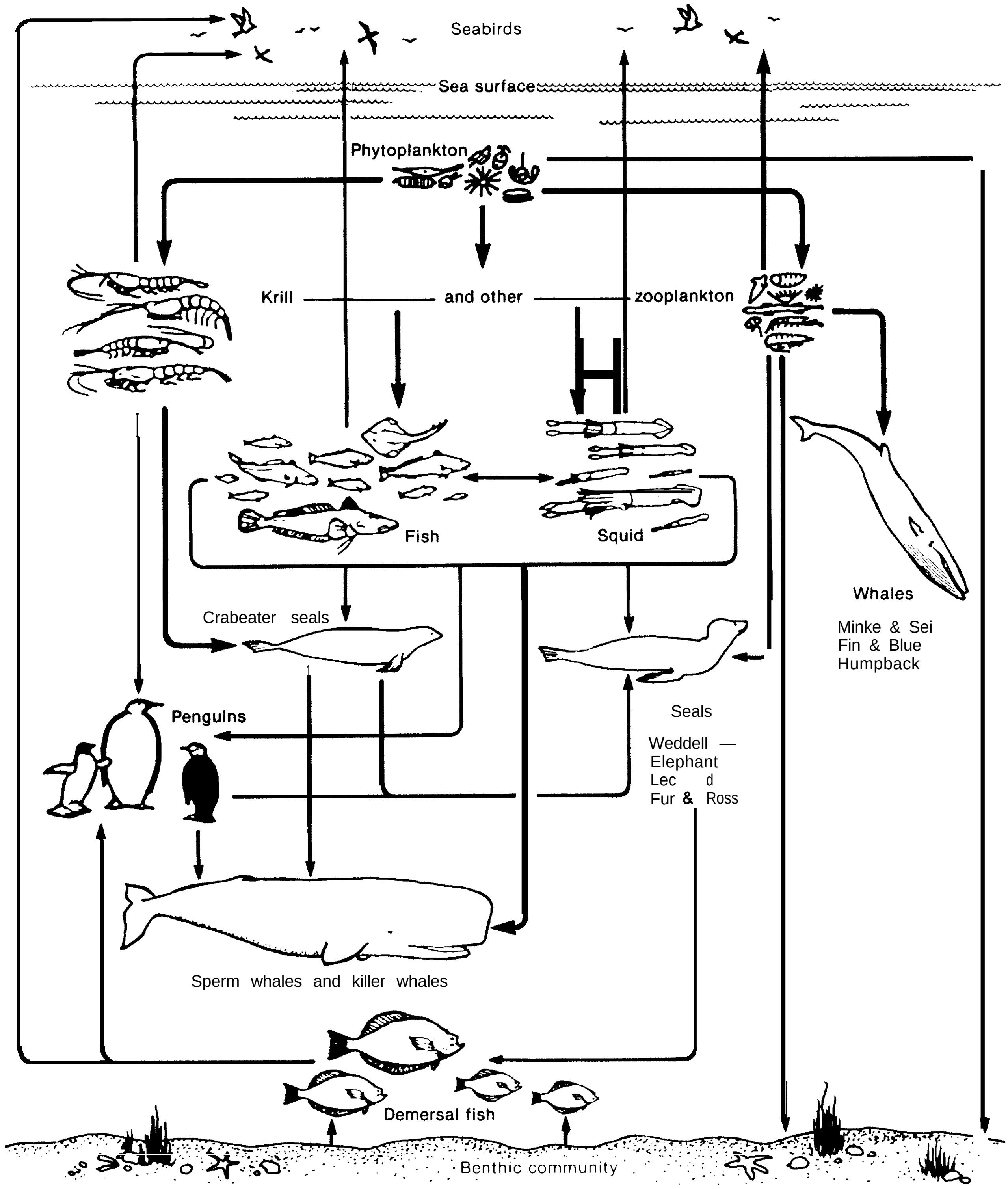
[19] Elliot, op. cit., footnote 6, p. II-16.

[20] J.R. Beddington and I. Everson, "The Assessment of Exploited Antarctic Fish Stocks, ' ***Selected Papers Presented to the** Scientific* Committee ***of the co**remission **for the Conservation of Antarctic Marine Living Resources 1982-1984,*** Part 1, pp. ***385-394.***

[21] D.B. Siniff, ' 'Living Resources: Seals,'' *Oceanus*, vol. 31, No. 2, Summer 1988, pp. 71-74.

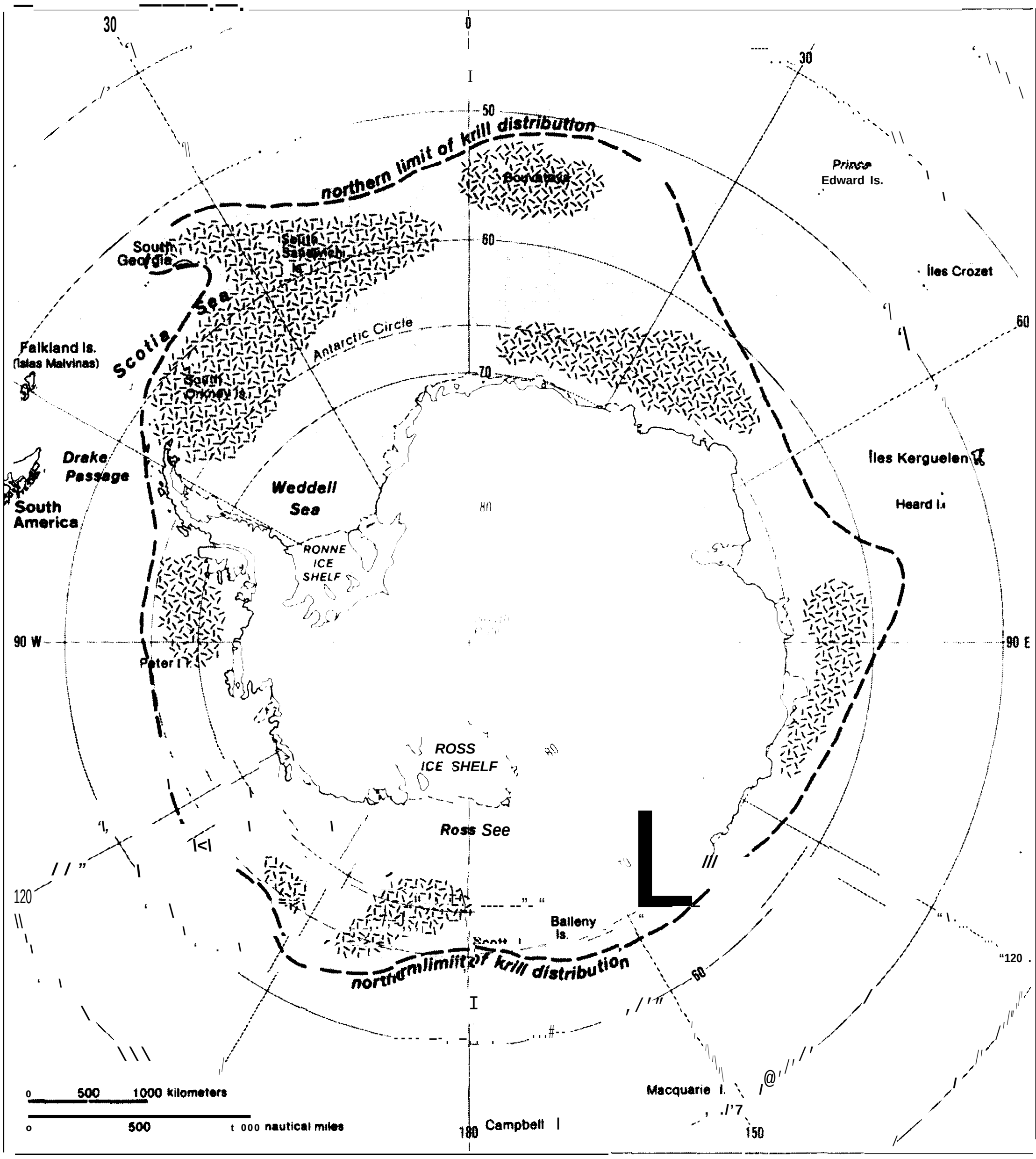
[22] Central Intelligence Agency, op. cit., footnote 5, p. 51.

Figure 5-3-The Antarctic Marine Ecosystem



SOURCE: Office of Technology Assessment, 19S9

Figure 54-Krill Distribution Around Antarctica



SOURCE: U.S. Government, 1978.

About 50 species of **sea birds,** with a total population that may approach 200 million, are found at least seasonally around Antarctica. Penguins, principally Adelie penguins, comprise close to 90 percent of the biomass of all bird populations. Other Antarctic birds include albatrosses, petrels, shags,

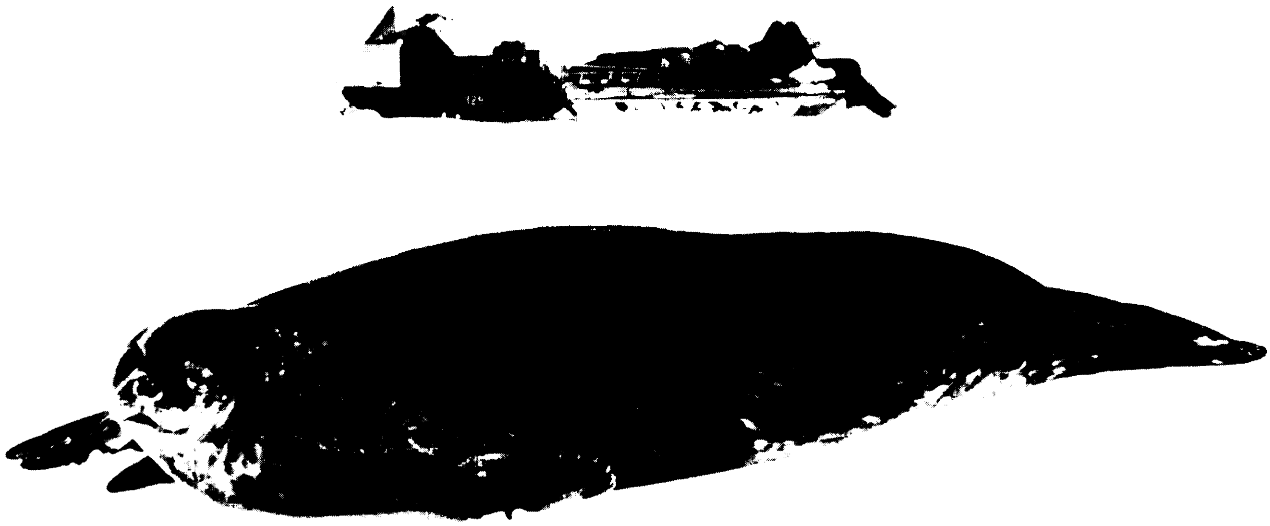


Photo credit: Ann Hawthorne

Weddell Seal, Hutton Cliffs, Ross Island.

prions, shearwaters, skuas, gulls, fulmars, and terns. Krill account for almost 80 percent of bird diets. All penguins and many other sea birds are dependent on pack ice and exposed, ice-free shorelines for breeding.[23,24]

Ongoing Research Activities

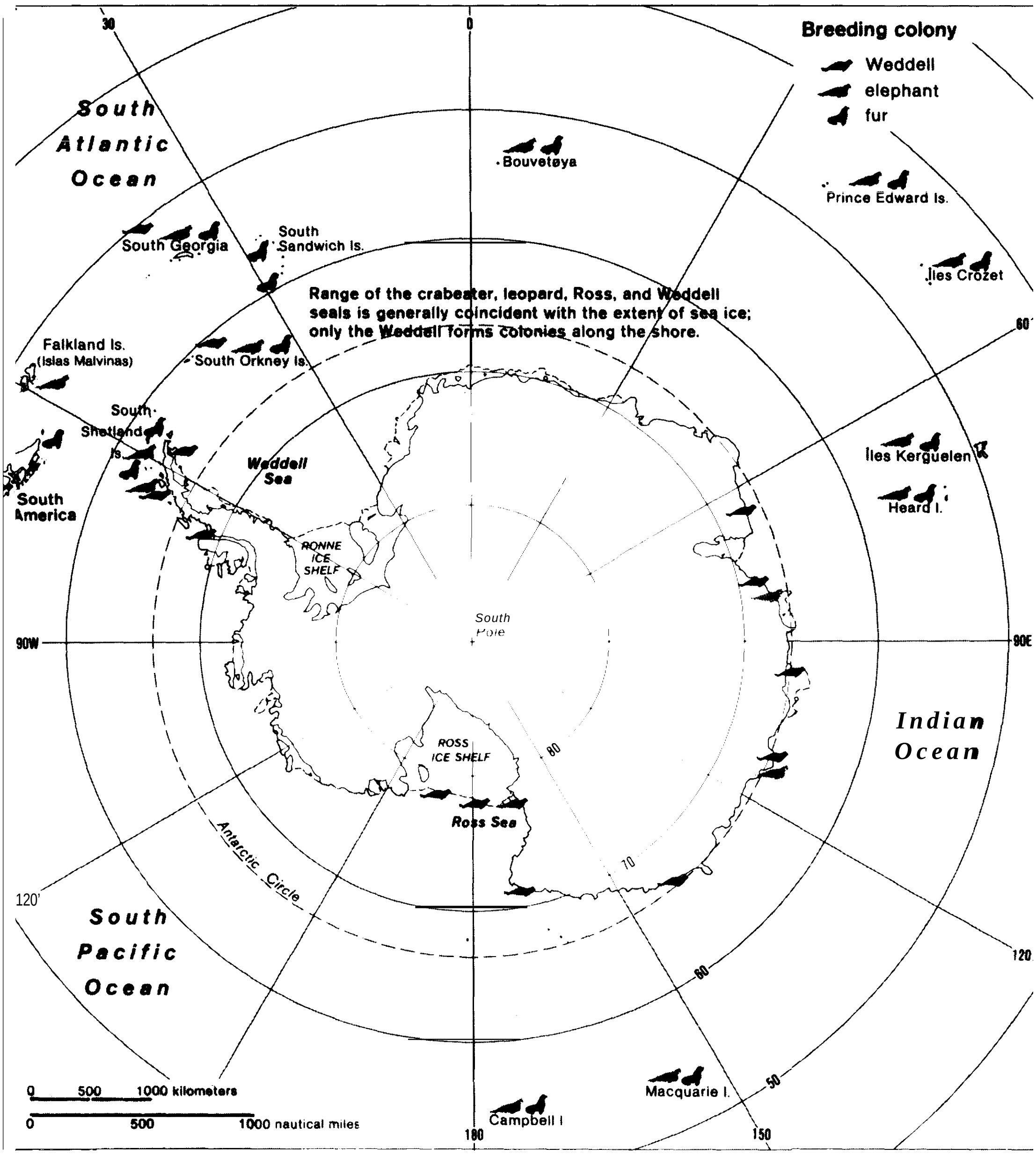
Scientific research has long been the most important activity occurring in Antarctica. In fact, research is the primary means by which countries maintain a presence in Antarctica for political purposes. Currently, there are about four dozen year-round scientific research bases in Antarctica, plus many other temporarys ummer camps.[25] Most research bases are located in coastal regions; only three permanent bases---one United States, one Japanese, and one Soviet—are located in inland areas. The United States base at McMurdo Sound is the continent's largest scientific base and logistical facility with 150 buildings, plus 200 year-round and up to 1,300 summertime personnel.

The Scientific Committee on Antarctic Research (SCAR) was formally established in 1958 by the international scientific community following the 1957-58 International Geophysical Year. Although not a formal part of the Antarctic Treaty system, SCAR initiates, promotes, coordinates, and reviews ongoing scientific activity in Antarctica. The 18 full members and 7 associate members of SCAR meet every other year to discuss ongoing research and

[23] Laws, op. cit., footnote 18, pp. 26-40.
[24] Zumberge, op. cit., footnote 8, p. 22.

[25] The number of research stations varies somewhat from year to year. Eight of these research stations are located north of 60" S.

Figure 5-5—Distribution of Seals Around Antarctica



SOURCE: U.S. Government, 1978.

other issues related to waste disposal, environmental impacts, and the exploitation of Antarctic living and mineral resources.[26] SCAR is often requested by the consultative parties to the Antarctic Treaty to provide advice on scientific, technical, and environmental matters, or to undertake special studies.

[26] David J. Drewry, "The Challenge of Antarctic Science," *Oceanus, vol.* 31, No. 2, Summer 1988, pp. 5-10.

Photo credit: Steve Zimmer

Lone skua over open water near McMurdo.

Through the Division of Polar Programs, the United States' National Science Foundation (NSF) annually supports about 75 research projects in Antarctica involving about 330 scientists and technical staff. (See table 5-1.) These projects cost about $15 million per year. An additional $20 million of NSF funding goes toward direct support of scientific research (e.g., ship and aircraft time). Another $90 million of NSF funding and about 1,200 people provide operational and logistical support for United States research activities.[27] Although there is little comprehensive data on other nation's research budgets, a few Antarctic experts estimated that the United States probably supports about 20 to 30 percent of all research on Antarctica.

The United States, through its National Oceanic and Atmospheric Administration, supports another $2 million of fisheries research in the Southern Ocean each year. This is at most about 10 percent of the total international budget for this type of fisheries research.

POTENTIAL IMPACTS FROM MAN'S ACTIVITIES IN ANTARCTICA

Future minerals exploration and development in Antarctica, *if it occurs,* would most likely involve exploring for and recovery of oil from offshore deposits, and/or the mining of minerals from ice-free coastal regions. Such activities would unavoidably generate some significant local environmental impacts (i.e., within a few square miles), and perhaps some minor regional impacts (i.e., extending over tens of square miles). **Ice-free coastal areas, and benthic nearshore areas are the habitats most likely to be significantly impacted by onshore or offshore resource development and any support activities.**[28]

The impacts of resource development activities on the Antarctic environment could be either more or less severe than these activities would generate in other parts of the world. Impacts from development activities are naturally site-specific, and should be evaluated on a case-by-case basis relative to the potential benefits from the proposed development activities. Monitoring of ongoing development activities is essential. Impacts from Antarctic development would be easier to detect due to the relatively pristine nature of the surrounding environment; however, it will be difficult and expensive to implement effective monitoring programs because of Antarctica's remoteness and adverse working conditions. Cumulative impacts are very difficult to accurately predict.

The impacts that could be expected from different types of activities in Antarctica are discussed below, based on information from similar activities in other parts of the world. These activities include: prospecting, oil exploration and development, land-based minerals exploration and development, and dredging with open-water disposal of the dredged material. All of these activities would require support facilities and transportation systems. These are addressed in a separate section. This discussion is followed by additional material on: impacts from man's past activities in Antarctica, the potential for rehabilitating locally impacted areas, regional and

[27] National Science Foundation, ' 'The Role of the National Science Foundation in Polar Regions: A Report to the National Science Board, ' NSB-87-128, June 1987, pp. 45-48.

[28] Rutford, Op. cit., footnote 7, pp. 24,35.

Table 5-1-NSF-Supported Scientific Research in Antarctica

Research categories: typical research areas	Percentage of United States research
Meteorology/climate: atmospheric processes and chemistry	7
Oceanography: ooean circulation and ice/sea/air interactions	16
Earth sciences: tectonics, paleoclimates, and geophysics	20
Glaciology: ice sheet dynamics and sea ice/iceberg formation	17
A8tronomy/upper atmosphere: aurora and magnetic field dynamics	12
Biology/ecology: biological processes and ecosystem dynamics	26
Medicine/health: human physiology and immune system disorders	1
Engineering: facility and transportation system construction, waste disposal, and oil spill cleanup	1

SOURCE: NSF, "The Role of the National Science Foundation in Polar Regions: A Report to the National Science Board," NSB-87-128, June 19S7, p. 57; figures for annual funding from NSF.

global impacts from Antarctic development, and research required to better predict environmental impacts.

Prospecting Activities[29]

Prospecting for mineral resources is conducted prior to commercial exploration and development using onshore, offshore, and airborne techniques similar to those used for basic research. A prospecting party might consist of several geologists and technicians and several dozen additional support staff.[30] Like scientific research, prospecting activities would generally occur during the summer months. Although some geophysical research resembling prospecting has been conducted in Antarctica, **there has been no prospecting,** at least as it is defined by the Antarctic Minerals Convention. Chapter 3 explains the Convention's definition of and provisions for prospecting.

Prospecting for **offshore petroleum** might include the collection of sediment cores and other data on seabed conditions in offshore areas; seismic reflection profiling; bathymetric, magnetic, and gravimetric surveys; and the mapping of geologic formations. Prospecting for **land-based minerals might include the collection of rock samples from** surface outcrops; magnetic, gravimetric, and electrical conductivity surveys; mapping of geologic formations; collection and interpretation of aerial photographs; and surface drilling with portable rigs, As defined by the Minerals Convention, prospecting activities would not include dredging, excavation, and drilling into rock or sediment to depths greater than 82 feet (25 m).

Since prospector often use the same techniques used by geologists and geophysicists for basic research, it will be very difficult to distinguish between scientific research and prospecting activities. In addition, the impacts to Antarctica's terrestrial and marine environments from the vast majority of prospecting activities will be very similar, except perhaps in scale, to those generated by ongoing land-based and offshore geologic research.[31] **In most cases, the impacts generated by prospecting would be insignificant relative to the impacts from full-scale development activities.**[32]

Oil Exploration and Development

The development of offshore oil deposits in Antarctica, if allowed, would produce numerous environmental impacts. The sea floor will be significantly, but locally disrupted by the drilling of wells

[29] Ibid., pp. 14,43-58, 63.

[30] Elliot, op. cit., footnote 6, p. IV-2.

[31] Ibid., pp. XV, VII-8.

[32] Holdgate, op. cit., footnote 9, p. 24.

[33] U.S. Congress, Office of Technology Assessment, *Oil and Gas Technologies for the Arctic and Deepwater*, OTA-O-270 (Washington, DC: U.S. Government Printing Office, May 1985), pp. 163-201,

and the laying of pipelines. Some benthic marine organisms will be smothered by discharges of drilling muds.[34] The construction of land-based support facilities will generate impacts in coastal areas. However, **the accidental spillage of oil, especially in coastal waters, would probably produce the greatest short- and long-term impacts of any resource development activities, especially oil development.**[35 36] **The** recent sinking of the *Bahia Paraiso off the* Antarctic Peninsula and the grounding of the Exxon *Valdez* in Alaska, highlight the significance of impacts associated with oil spills. (See box 5-A, box 5-B, and box 5-C.)

Major oil spills often result from a damaged and/or sinking oil tanker, or from a well blowout. Antarctic tanker spills would, by definition, occur in remote locations, and could involve the rapid release of large amounts of oil. Although there are several measures that can be taken to help prevent tanker accidents (e.g., double-hulled ship construction, weather forecasting, iceberg tracking, and sophisticated navigation equipment), even with tight regulations, human error can still occur. If shipping is confined to summer months, any tanker accident would occur when the resident seals and penguins and other birds are clustering and breeding along Antarctica's coast.

A blowout is a sudden, uncontrolled escape of hydrocarbons from an exploratory or production well. Oil discharge rates will probably be slower for leaking wells than for tankers, but releases from wells may continue for longer periods of time, especially if the well cannot be quickly controlled. Blowouts that occur on the sea floor in water depths of a few thousand feet or beneath ice-covered seas would be extremely difficult to control, especially during the winter months, Oil produced during the winter months in Antarctica may need to be stored for transport during the summer. If so, these land-based or offshore storage facilities could be an additional source of oil spills.

The following discussion briefly addresses the likelihood of oil spills, their potential impacts on the marine environment, and the effectiveness of different technologies for dispersing oil spills and/or cleaning them up.

Probability of Oil Spills[37]

It is possible to project scenarios for exploration and development of offshore oil deposits in Antarctica, as shown in appendix A. The likelihood of oil spills from future oil development has been estimated for the relatively shallow water (450 feet) of the Bering Sea, based on current production activities in the Gulf of Mexico. These figures, which are summarized in table 5-2, suggest that for *each* billion barrels of oil produced, four spills of 1,000 to 10,000 barrels in size, and two spills larger than 10,000 barrels can be expected. The probabilities of spills from oil development off Antarctica would likely be higher due to 1) water depths of a few thousand feet, 2) ice islands and numerous large icebergs that could threaten sea surface and seabed operations, and 3) extreme working and navigation conditions.

Perhaps the most likely oil spills around Antarctica may result from accidents involving ships resupplying bases or used for tourism. In the last 4 years four ships have sunk in Antarctica: one supply ship, one tourist ship, one tourist/supply ship, and one research vessel. Only the *Bahia Paraiso,* a tourist/supply ship that ran aground off the Antarctic Peninsula in January 1989, spilled a considerable amount of fuel oil. (See box 5-A).

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[34] There have been several studies of the potential impacts on Arctic marine environment produced by the discharge of drilling muds contaminated with heavy metals and other potentially toxic substances. These studies indicate that major impacts on the marine environment are unlikely, except in restricted areas such as shallow coastal waters or protected bays (Rutford, op. cit., footnote 7, p. 17; Elliot, op. cit., footnote 6, p. VII-4).

[35] Rutford, op. cit., footnote 7, p. 8.

[36] Elliot, op. cit., footnote 6, pp. xvi, VII-26.

[37] U.S. Congress, op. cit., footnote 33, pp. 185-186.

Box 5-A—An Oil Spill Off the Antarctic Peninsula

On January 28, 1989, the *Bahia Paraiso,* a 435-foot, double-hulled transport/tourist ship operated by the Argentine navy, ran aground in clear weather off the northern tip of the Antarctic Peninsula, The 81 tourists and crew of 235 safely abandoned the ship before it rolled over on its side 4 days later in 50 feet of water. It had a 30-foot gash in its side.

About 250,000 gallons of diesel fuel were stored on board, in bulk and in 55-gallon drums; about 170,000 gallons of fuel were lost. Within a few days after the accident a 15-mile-long slick covered an area of about 10 square miles and had reached the beaches and rookeries surrounding the United States' Palmer Station research center, killing krill and *oiling seals,* penguins, cormorants, skuas, and giant petrels, The entire brood of skua chicks in the Palmer area was lost.

The NSF responded within 36 hours by sending 52 tons of U.S. Navy cleanup equipment along with 15 oil spill experts from the United States, Argentina, and Chile. NSF has spent about $2.5 million to date on its response efforts. Removing the fuel remaining on board will cost about $3 to $5 million, Another $50 to $60 million might be required to remove the ship and to sink it in the open ocean,

The accident highlights the following points:

- Antarctica's environment is vulnerable to accidental oil spills, even without petroleum development.
- Most countries conducting research in Antarctica are ill-prepared to deal with oil spills. Even if cleanup equipment is available, much valuable response time can be lost shipping the equipment to the spill site.
- The impacts associated with a spill of crude oil will likely be longer lasting than the impacts from the *Bahia Paraiso* spill due to the greater abundance in crude oil of organic compounds with low volatility.
- Since the early 1960s, NSF has spent about $80 million on the Palmer Station and its biological research. This research will provide excellent baseline data for evaluating the effects of the spill, but many ongoing projects at Palmer and other U.S. stations have been significantly impacted.
- Studies of the fate and effects of the *Bahia Paraiso* spill will help scientists predict likely impacts from larger oil spills in Antarctica, should oil exploitation occur in the future.
- Appropriate response action and liability for accidents-dealt with in articles 4 and 8 of the Minerals Convention, respectively-are essential elements of arty plan for future resource development.

SOURCE: Information gathered from various sources, including the National Science Foundation; April 1989 newsletter from The Antarctican Society; New *Scientist*, Feb. 11, 1989, p. 31; and B. Rensberger, Washington *Post*, Jan. 31, 1989, Feb. 1, 1989, Feb. 3, 1989, and Feb. 4, 1989.

Potential Impacts From Oil Spills in Antarctica[38] [39] [40] [41] [42]

Although a major oil spill in Antarctica would likely be a rare event, the impacts from such a spill would probably be damaging and long-lasting. Marine organisms in Antarctica would experience the greatest short-term impacts from oil spills, especially if they drifted into nearshore areas and onto coastal beaches and rookeries. Organisms (e.g., plankton, birds, and fur seals) that come into direct contact with floating oil would likely be coated and killed. Benthic organisms would also be smothered by sinking oil.

Many organisms living in the water column would suffer lethal or sublethal impacts by directly

[38] Zumberge, op. cit., footnote 8, pp. 17,22, 26.32136138

[39] Rutford, op. cit., footnote 7, pp. 22, *35.36.*

[40] Elliot, op. cit., footnote 6, pp. xiv xv, VII-1, 5,6,28, IX-2, 3.

[41] J.H. Zumberge, "Potential Mineral Resource Availability and Possible Environment Problems in Antarctica," J.I. Charney (cd.), *The New Nationalism and the Use of Common Spaces: Issues in Marine Pollution and Exploitation of Antarctica* (Totowa, New Jersey: Allenheld, Osmun Publishers, 1982), pp. 143-144.

[42] U.S. Department of State, "Final Environmental Impact Statement on the Negotiation of an International Regime for Antarctic Mineral Resources,' August 1982, pp. 6-18 to 6-26.

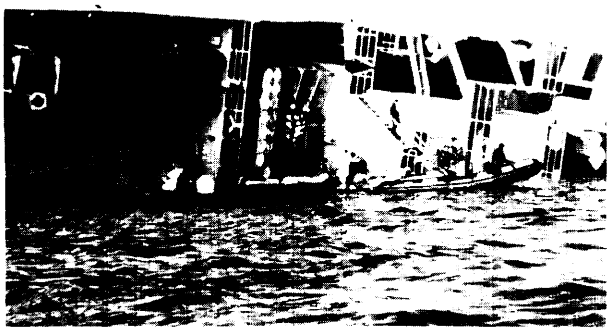

Photo credit: *Ted DeLaca, National Science Foundation*

The *Bahia Paraiso.*

ingesting oil or eating oil-contaminated organisms.[43] However, there seems to be very little evidence of increased accumulation of oil in higher levels of the food chain.[44] Marine organisms and sea birds are numerous enough and widely enough dispersed around Antarctica that mortalities from a small spill would probably not permanently impact overall populations of marine organisms. Many small spills or a few large spills, however, could have significant and long-lasting adverse impacts.

Long-term impacts on marine organisms from oil spills in Antarctica are not well-understood. It is known, however, that crude oil takes 20 to 50 times longer to degrade at 5 "C (41 °F) than it does at 25 °C (77 °F).[45] Oil would require art even longer time to degrade in Antarctica. Many biological processes (e.g., growth, sexual maturation, etc.) affecting individual organisms and entire populations also seem to occur at slower rates in cold environments. Some scientists have therefore hypothesized that the responses of the Antarctic marine ecosystem to an oil spill will be similar in type and magnitude to impacts from oil spills in other temperate marine environments.

Due to the cold temperatures of Antarctica, the subsequent recovery of impacted areas is likely to require an extended period of time[46]-perhaps several decades-rather than the several years required for warmer regions.[47] Ongoing studies of the short- and long-term impacts of the recent oil spill off the Antarctic Peninsula will help to resolve many of the current uncertainties about the impacts of oil spills from the potential development of petroleum resources.

Oil Spill Cleanup Techniques[48]

The limited experience with oil spills in the Arctic suggests that significant amounts of oil could not be recovered from a major spill in Antarctica, even with the most up-to-date equipment and well-formulated cleanup plans. The effectiveness of most cleanup technologies in Antarctica would be adversely affected by extremely cold temperatures, significant concentrations of broken and unbroken ice,[49] long periods of darkness during the Antarctic winter, and typically high winds and large waves. However, technologies and procedures could be improved over the next two or three decades to address some of these problems.

Three approaches for dealing with oil spills in Antarctica are discussed below. The usefulness of each technique depends largely on the nature and location of the spill; no single technique is ideally suited for all situations.

1) Oil **Dispersion: Chemical dispersants can be used in some situations** to enhance the breakdown of oil into smaller droplets more easily dispersed by winds and waves and more readily broken down by

43 Seabirds and other marine mammals can ingest oil directly or indirectly during feeding or when they clean their furor feathers. Although the ingestion of oil may not lead to fatalities, it can produce abnormal behavior which can in turn lead to abnormally high mortalities. For example, after ingesting oil from the recent spill in Antarctica, adult skuas began behaving abnormally and even attacked their own young. Within a week, about 60 percent of the skuas had disappeared from their nesting areas.

44 National Research Council, *Oil in the Sea: Inputs, Fates, and Effects* (Washington, DC: National Academy Press, 1985), p. *6.*

45 Central Intelligence Agency, op. cit., footnote 5, p. 28.

46 G.A. Robilliard and M. Busdosh, '*Need for Real World Assessment of the Environmental Effects of Oil Spills in Ice-infested Marine Environments, *Proceedings of the Sixth International Conference on Port and Ocean Engineering under Arctic Conditions*, Quebec, Canada, 1981, vol. *11, pp. 937-944.*

47 National Research Council, op. cit., footnote 44, p. 487.

48 U.S. Congress, op. cit., footnote 33, pp. 188-197.

49 Rutford, op. cit., footnote 7, p. 20.

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Box 5-B—The Exxon Valdez *Oil Spill*

On March 24, 1989 the 987-foot, single-hulled tanker *Exxon Valdez* struck a reef in clear weather in Prince William Sound about 25 miles from the oil loading terminal at Valdez, Alaska. Soon, 10 million gallons of oil spilled from several 20-foot gashes in the tanker's bottom, overwhelming efforts at control. The result was the largest oil spill in U.S. history. Driven by heavy seas and 70-mph winds, the slick covered more than 1,000 square miles of ocean and hundreds of miles of beaches.

Despite the existence of several industry and government contingency plans, the Exxon response to the spill was hampered by an insufficient amount of operating cleanup equipment, by a lack of trained people, by unclear lines of responsibility and authority, and by confusion over appropriate courses of action. Oil booms, skimmers, dispersants, and burning were all tried at various times during the cleanup effort, but with very limited success. This disaster contrasts with the success over the last 12 years of tanker operations between Alaska and the west coast of the United States. During this time more than 8,700 tankers with oil from Valdez had spilled only about 200,000 gallons of oil near Valdez and another 2 million gallons along the tanker route. The impacts of the *Exxon Valdez* spill on the fish and wildlife of Alaska are still being studied, but will undoubtedly involve the loss of thousands of birds, otters, and other types of wildlife.

This spill highlights the following points related to the potential development of petroleum resources in Antarctica:

- Even under the best of circumstances, it is difficult to clean up significant amounts of oil from large spills given the current state-of-the-art of cleanup technologies; improvements could result from further research.
- Although the chances of accidents can be minimized through the use of advanced technologies (e. g., for navigation), good planning, worker training, etc., it is difficult to avoid all human error.
- Written plans must clearly designate responsibilities for all parties involved in oil spill cleanup operations.
- The Exxon Valdez spill, although linger and more widespread than the *Bahia Paraiso* spill, will probably not have as long-lasting effects, since it occurred in warmer waters where recovery rates are faster.

SOURCES: E. Marshall, "Valdez: The Predicted Oil Spill," and L. Roberts, "Long, Slow Recovery Predicted for Alaska," Science, vol. 244, Apr. 7, 1989, pp. 20-24; The National Response Team, "The *Exxon Valdez* Oil Spill: A Report to the Congress," May 1989, p. 37; C. Peterson and J. Mathews, "Spill Raises Doubts on Oil Industry," *Washington Post*, Apr. 2, 1989.

photochemical oxidation, metabolic transformation within organisms, microbial degradation, and other natural processes.[50] Dispersants in current use are less toxic than oil; however, dispersing oil in shallow coastal areas may also cause some harm. In such situations, one would have to consider whether even more harm would occur by not using dispersants and allowing the oil to reach shore. Currently available dispersants are only effective in a limited number of situations; they are most effective when applied within about 5 hours after a spill occurs. The current potential for using dispersants in Antarctica is probably not very high due to the cold temperatures, the presence of broken ice, high chemical costs, and logistical problems involved in rapidly applying large volumes of dispersants to sizable spills.

Natural dispersion may be appropriate in the open ocean, and perhaps the only alternative, when the weather is stormy and the seas are exceptionally rough and/or when the spill is large or remote. The lighter components of oil are often eliminated from the water by evaporation.

2) **In Situ Burning: Burning spilled oil may be the best method available for oil spill cleanup in certain situations. Cold Antarctic temperatures would tend to increase the viscosity of oil and reduce its ability to spread, thereby increasing its amenability to burning. At the same** time, cold temperatures make ignition more difficult. Combustion efficiencies generally range from 20 to 80 percent by volume. Greater efficiencies can often be achieved if the oil can be naturally or artificially contained. Burning works best on lighter oil fractions which tend to evaporate within several days.

One drawback of burning could be the possible loss of the ship or platform in the process; but the

[50] National Research Council, op. cit., footnote 44, pp. 10-11.

Box 5-C-Oil Spilled in the Marine Environment

Of the approximately 22 million barrels of petroleum hydrocarbons entering the marine environment, about 37 percent comes from industrial, municipal, urban, and river runoff; about 34 percent from tanker operations and accidents; about 12 percent from other shipping accidents and sources; about 8 percent from natural sources; and about 2 percent from offshore petroleum production.

To date, the world's largest spill occurred in 1978 when the *Amoco Cadiz ran* aground off the coast of France and spilled 68 million gallons of crude oil along about 250 miles of shoreline. The largest recent blowout occurred near the Mexican coast during a 10-month period in 1979-80, discharging over 125 million gallons of crude oil into the Gulf of Mexico.

SOURCE: *Oil in the Sea. Inputs, Fates, and Effects* (Washington, DC: National Academy Press, 1985), pp. 82,561.

Table 5-2-(Oil Spill Probabilities for the Navarin Main, Bering Sea (per billion barrels of oil produced)

Source of spill	Number of oil spills (by size) (>1 ,000 barrels)	(>10,000 barrels)
Platform	1.0	0.4
Pipelines	1.6	0.7
Tankers at sea . . .	0.9	0.5
Tankers in port . . .	0.4	0.2
Total	3 . 9	1.8

SOURCE: Minerals Management Service, Navarin Basin Lease Offering. Final Environmental Impact Statement, November 1983.

cost to replace equipment destroyed by fire may ultimately be less than the cost to clean up the environment. Burning also produces air pollution and a bum residue and thus could have negative impacts on, for example, birds and seal rookeries during the summer breeding season. Considering the alternative of letting the oil reach sensitive areas, burning may still be appropriate in some circumstances.

3) **Mechanical Recovery:** Over the last two decades considerable effort has gone into developing surface booms and water jets to limit the spread of oil spills, and surface craft to mechanically skim and collect oil from floating slicks.[51] Such equipment, however, has its limitations even under the best of circumstances. Most currently available skimmers are incapable of cleaning up large amounts of spilled oil. Historically, skimmers have rarely been able to recover more than 10 percent of the oil from any large spill. In Antarctica, the performance of most oil recovery equipment would be adversely impacted by high winds, large waves, strong currents, cold temperatures, and ice. Any recovered oil would also have to be disposed of, possibly by landfilling or by incineration in air-transportable units.

Mineral Exploration and Mining Activities[52,53,54,55,56,57]

Chapter 4 indicates that the potential for recovering hard minerals from Antarctica is for the most part unknown. However, the mining of high-grade mineral deposits in ice-free areas of the Arctic has been underway for the past two decades. (See app. B.) For example, COMINCO operates a year-round, lead-zinc mining operation on Canada's Little Cornwallis Island about 600 miles north of the Arctic Circle. Open pit or underground mining operations of this sort typically involve considerable drilling, blasting, and the generation of rock waste, dust, and noise. Ore processing (e.g., crushing, grinding, and flotation) typically requires substantial amounts of energy and water, and generates large volumes of mill

51 The largest skimmer in the Arctic is a 65-foot single-purpose, catamaran that use-s continuously moving, absorbent, polypropylene rope to sop up oil; under actual operating conditions recovery rates could range from about 5 barrels (e.g., about 150 gallons) to about 30 barrels (i.e., almost 1,000 gallons) per hour.

52 M. Magee, ' 'A-merit of Mining and Process Technology for Antarctic Mineral Development-Volume I," OTA contract report, January 1988, p. 114.

53 Rutford, op. cit., footnote 7, pp. 33, 58, 45, 46.

54 Elliot, op. cit., footnote 6, pp. xiii, xv-xvi, [v-7, 12, 17, 18, V-1 to 19, VII- I to 4, 8,9.11 to 16, IX-~* 2.

55 Zumberge, op. cit., footnote 8, pp. 23-25, 36, 44-45.

56 Zumberge, op. cit., footnote 41, pp. 143-144.

57 U.S. Department of State, op. cit., footnote 42, pp. 6-11 to 6-18.

tailings and other wastes. Any ores mined in Antarctica would probably be shipped off-site for smelting.

Impacts on terrestrial flora and microfauna in the immediate vicinity of these mining and ore processing activities should probably be considered permanent total natural recovery of adjacent areas would require many decades to a few centuries. The physical disturbance (e.g., modification of terrain, destruction of soil **and** wet permafrost) and/or chemical pollution (e.g., accidental spills of fuel oil and other chemicals, etc.) from mining, ore processing, and associated construction activities in Antarctica will likely impact soils, ice-rich permafrost, and the terrestrial ecosystem (e.g., mosses and lichens) in the vicinity of mining operations. However, **mining operations are unlikely to occur on a large enough scale to pose a significant threat to the overall terrestrial ecosystem of Antarctica.**

The most significant potential impacts from mining operations in Antarctica would probably be associated with the disposal of mill tailings from ore processing and any subsequent leaching of heavy metals from such tailings.[58] Mill tailings could conceivably be disposed in the ocean, in inland lakes, in abandoned parts of the mine, in specially designed dammed or diked containment areas in ice-free regions, or perhaps on the ice. Land disposal of tailings and the subsequent treatment of any discharged water to meet stringent environmental standards is technically feasible, but often quite expensive.

The potential for mining Antarctic mineral deposits raises concerns about competition between mining activities scientific research, tourism, and wildlife for ice-free terrestrial environments. Seals and sea birds using the coastal environments surrounding Antarctica would be disturbed by noise from mining and associated kind-based development activities located near breeding grounds, congregating areas, or migratory corridors. Marine organisms would also be adversely impacted by accidental spills of chemicals and oil. Any areas of the marine ecosystem that might be locally impacted by mining activities would probably recover naturally; total recovery, however, could require several decades.

Scientists have speculated that the production and settling of dust from large-scale mining and construction activities in Antarctica could decrease the highly reflective character of its snow-covered areas.[59] However, volcanic ash that has been widely dispersed over large areas of Antarctica by past eruptions apparently had no such effect. Instead, these layers are apparently quickly buried by subsequent snowfalls.[60]

Dredging With Open-Water Disposal of the Dredged Material[61] *6263*

The construction of docking facilities along Antarctica's coast may require the dredging of nearshore areas and the subsequent disposal of the dredged material, presumably in open-water areas. Some dredging may also be required to bury pipelines from underwater wellheads, or perhaps to mine offshore placer deposits.[@] It is also conceivable that mill tailings from land-based mining operations could be disposed in nearshore marine environments, thereby generating impacts similar to those produced when dredged material is disposed in open-water environments.

Turbid plumes of fine-grained suspended material are usually found within a few hundred to several hundred feet of most dredging and open-water disposal operations. Such turbidity will decrease phytoplankton photosynthesis and may adversely

58M. Magee, op. cit., footnote 52, p. 114.

59"Albedo" is the fraction of incoming light or radiation that is reflected. Snow-covered areas have a high albedo; dark surfaces that absorb incoming radiation have low albedos.

60Zumberge, op. cit., footnote 41, pp. 134-136.

61U.S. Congress, Office of Technology Assessment, *Wastes* i*n Marine Environments*, OTA-O-334 (Washington, DC: U.S. Government printing Office, April 1987), pp. 243-246.

&US. Congress, Office of Technology Assessment, *Marine Minerals: Exploring Our New* Ocean ***Frontier, OTA-342*** (Washington, DC: U.S. Government printing Office, July 1987), pp. 215-223, 233-236.

@Elliot, op. cit., footnote 6, pp. VII-4, 5, 13, 14.

64Placers are deposits of minerals—either dispersed or locally concentrated in lenses—found within unconsolidated sands and gravels.

affect growth and reproduction of some pelagic organisms. However, field studies of dredging and disposal operations around the United States indicate few detectable physical impacts from water column turbidity; any chemical releases (i.e., manganese, iron, ammonia, and phosphorus) are rapidly diluted. Turbidity plumes typically dissipate within several hours after dredging and/or disposal operations cease.

Benthic organisms in dredged areas around Antarctica will likely be destroyed by most types of dredging equipment. In addition, at open-water disposal sites, most benthic organisms that are covered by more than a foot or so of dredged material will be suffocated. At disposal sites in a few tens of feet of water, such accumulations of dredged material are usually resticted to bottom areas within several hundred feet of the point from which the dredged material is discharged into the water column. In deeper water, the bottom area covered by dredged material will increase, but the thickness of accumulating material will decrease.

Recolonization of dredging and disposal sites by benthic organisms in temperate marine environments usually begins within a period of weeks after cessation of the disposal operation; extensive recolonization can take from several months to a few years in temperate climates. However, recolonization of Antarctic benthic environments may require considerably more time due to the colder temperatures.[65]

Development ofSuppotiFacil&”e@667 and Transportation Systems[68]

The development of support facilities and transportation systems would lead to the destruction or modification of Antarctic flora and fauna on a local scale, similar to those described in the previous section on mining activities. These types of activities will also compete with wildlife for ice-free terrestrial environments.

Oil and/or minerals development in Antarctica would involve constructing living quarters, oil storage tanks, mineral processing units, power generating stations, water and sewage treatment plants, fuel storage facilities, buildings for storage of equipment and supplies, etc. Developing and operating an average-sized mine or an oil field would require a few hundred personnel and support staff working at least 200 days per year over the life of the activity. Construction activities would involve quarrying rock and/or dredging sand and gravel for concrete and roads, modifying terrain, and installing surface and subsurface drainage. Accidental spills of fuel and other chemicals are also inevitable. Support activities will also generate wastes in the form of obsolete equipment, sewage and wastewater, biodegradable food, and other litter.

If oil or mineral resources in Antarctica are eventually developed, the existing transportation system (e.g., roads, air fields, docks and harbors, etc.) used to supply scientific research bases would have to be expanded. Additional ships, roads, railroads, vehicles, and/or pipelines would also be required to remove any resources. For example, an oil recovery operation for a 4-billion-barrel field probably would require special storage facilities and a few dozen specially built ships and docking facilities to remove the oil during the summer months. Some scientists also believe that oil discharges from routine tanker loading and from tanker accidents could have significant cumulative impacts on the Antarctic marine environment at a local and perhaps regional level.

IMPACTS FROM MAN’S PAST ACTIVITIES

Scientific Research Bases

During the 1800s and early 1900s, two dozen exploratory expeditions from various countries visited Antarctica. Since the early 1900s, about 80 temporary and/or permanent research bases have been established there. The first modern, internationally coordinated scientific effort to study the region occurred during the 1957-58 International Geophysical Year, during which 50 research stations

[65] Zumberge, op. cit., footnote 8, p. 38.

66 Elliot, op. cit., footnote 6, pp. xvii, Vii-2 to 11.19, 20.

[67] Zumberge, op. cit., footnote 8, pp. 28, 31-32.

[68] Rutford, op. cit., fcmt.note 7, p. 52.

were maintained by 12 countries,[69] The 48 year-round and 19 summer research bases operated by about 18 nations are shown in figure 5-6.[70] Three year-round bases are American.

Waste disposal practices in Antarctica during the 1950s, 1960s, and early 1970s were characterized by a lack of state-of-the-art disposal alternatives (e.g., incinerators, sewage treatment plants, etc.) and by a "frontier" attitude toward the environment. Since the mid-1970s most countries have become more aware of environmental impacts. With the exception of the oil spill from the *Bahia Paraiso* sinking, most impacts can be traced to accidental releases of small amounts of oil and other chemicals, the construction and operation of research bases and field camps, and the disposal of wastes. Some environmental groups contend that waste disposal practices (e.g., open burning and landfilling) could be improved significantly with the use of different technologies. Such technologies are often more costly.

Pollution in the immediate vicinity of most year-round research bases has probably killed or significantly impacted some or all benthic marine organisms. For example, oil in the sediments of Winter Quarters Bay, McMurdo Sound has largely eliminated all benthic organisms. However, benthic populations a few hundred meters beyond these localities do *not* appear to have been significantly impacted.[71] **Considering Antarctica's vast size, the impacts generated by past scientific research activities would be considered by most people to be insignificant; some environmentalists, however, view them as more serious.**

In recent years many countries have begun cleaning up their research bases in Antarctica. For example, in the 1986-87 season, the cargo ship *M/V Green Wave* took 1,700 tons of waste back to the United States for recycling and/or disposal. In 1988 NSF outlined a $30 million, 4-year cleanup program for American bases in Antarctica, and established an Environmental Protection Agenda for all future federally supported activities in Antarctica.[72]

Photo credit: Ann Hawthorne

Adelie penguins near McMurdo.

Since the late 1950s, about two dozen coastal bases have been abandoned or used only occasionally, often by expeditions from several different countries. In many cases, equipment, buildings, food, fuel drums, and much litter have been left behind. Assuming responsibility for cleaning up these abandoned bases could be difficult, especially those bases used by more than one country.[73]

Tourism[74 75 76 77]

Small air charters and expedition-type cruises on ships carrying up to 150 tourists have become increasingly popular over the last 25 years. Most tourists visit the Antarctic Peninsula. There is a 100-bed guest house and a bank for visitors to Chile's Teniente Marsh research base on King George Island off the Antarctic Peninsula. Over the next few years it is anticipated that two to three

[69] Central Intelligence Agency, op. cit., footnote 5, p. 40.

[70] S.R. Fletcher, "Antarctica: Environmental Protection Issues, Congressional Research Service Report for Congress, 89-272 ENR, Apr. 10, 1989, p. 11.

[71] Robilliard, op. cit., footnote 46, pp. 937-944.

[72] National Science Foundation, Division of Polar Programs, "U.S. Antarctic Program: Environmental Protection Agenda," Aug. 31, 1988, p. 45.

[73] Greenpeace, "1987-88 Greenpeace Antarctic Expedition Report,' Stichting Greenpeace Council, United Kingdom, p. 80.

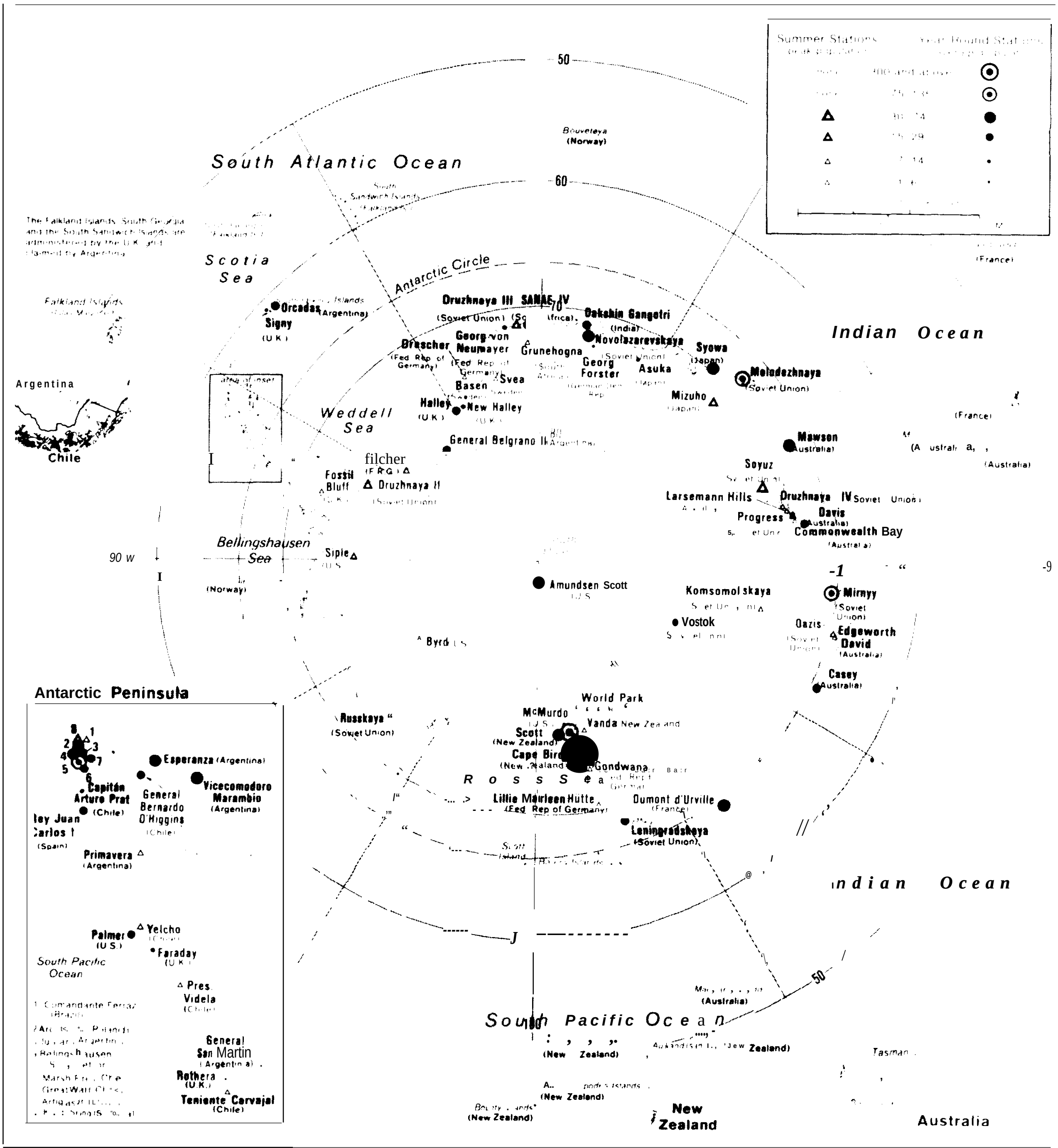
[74] P.D. Hart, "The Growth of Antarctic Tourism," *Oceanus*, vol. 31, No. 2, Summer 1988, pp. 93-100.

[75] National Science Foundation, *Safety in Antarctica*, NSF 88-78, 1988, pp. 9-1 to 9-10.

[76] F.M. Auburn, *Antarctic Law and Politics* (Bloomington, IN: Indiana University Press, 1982), pp. 277-283.

[77] Fletcher, op. cit., footnote 70, P. 57.

Figure 5-6-Research Stations on Antarctica



SOURCE: U.S. Government, 1989.

dozen tours-bringing about 3,500 people annually—will visit Antarctica. Many tour groups are well-informed and well-supervised; some are not.

Table 5-3 provides data on the approximate number of person-days spent in Antarctica by tourists and scientists. These figures indicate that scientists and their support staff account for about 95 percent of the person-days logged in Antarctica. The relative impact of tourist-related activities is probably much less than these figures indicate, since land-based facilities are usually not required to support tourist groups. In other words, the environmental impacts associated with normal tourist activities are at present minor compared to the impacts generated by research activities. The recent sinking of the *Bahia Paraiso* is an important exception to this generalization. However, if tourism increases and remains largely unregulated, the potential for adverse impacts will increase.

Harvesting of Fish, Seals, and Whales

The most significant impacts to the marine ecosystem of the Southern Ocean surrounding Antarctica have been generated by overharvesting of fish, fur seals, and five species of whales.

Antarctic Fishing

Major interest in Antarctic fishing developed initially during the 1960s, and expanded significantly during the 1970s. For example, fish catches increased from about 4,000 metric tons in the early 1970s to a peak of about 500,000 metric tons in the 1979-80 season, relative to almost 100 million metric tons worldwide. The Antarctic cod was the initial target of commercial fisheries in the early 1970s, but because of declining catches the focus shifted to ice fish toward the end of the 1970s. Both species are now depleted. Krill harvests increased from about 2,000 metric tons in 1973 to about 446,000 metric tons in 1986.[78]

The **Convention on the Conservation of Antarctic Marine Living Resources** (CCAMLR) was negotiated in response to heavy fishing, the consequent depletion of fish stocks in the 1970s, and concerns about the possible development of a krill fishery. It entered into force in 1982 and applies to offshore areas within about 1,000 miles (1,600 km) of Antarctica.[79,80,81,82] The United States implemented this convention in 1984 through passage of the **Antarctic Marine Living Resources Convention Act** (Public Law 98-623). The Convention encourages the study, management, and conservation of the living resources within Antarctica's *overall* marine ecosystem, rather than focusing on individual species of commercial importance.

Seal **Harvesting**

In the late 1700s and the early 1800s sealers from the United States, Russia, and other European countries began harvesting seals around the islands in the Southern Ocean near Antarctica. Over 1 million seals were killed around South Georgia (in the South Atlantic) alone between 1820 and 1822.[83] Uncontrolled slaughter of fur seals for their thick fur brought this species close to extinction by 1830. The harvest of elephant seals for blubber oil began in the early 1800s and continued until the 1960s. The four species of seals (i.e., crabeater, Weddell, leopard, and Ross) that only inhabit Antarctica have remained largely untouched by sealers due to their inaccessibility or poor fur quality.[84]

After some limited harvesting of seals in 1964, the then 14 parties to the Antarctic Treaty drew up the **Convention for the Conservation of Antarctic Seals,** which was signed in 1972 and entered into

78 K. Sherman and A.F. Ryan, "Antarctic Marine Living Resources, " *Oceanus, vol.* 31, No. 2, Summer 1988, pp. 59-63.

79 Ibid., pp. 59-63.

80 R.J. Hofman, "Conservation of Marine Living Resources in Antarctica, unpublished paper for Seminar on the Polar Regions, Center for Oceans Law and Policy, University of Virginia, Charlottesville, VA, March 1987, p. 14.

81 J.N. Barnes, "The Emerging Convention on the Conservation of Antarctic Marine Living Resources: An Attempt to Meet the New Realities of Resource Exploitation in the Southern Ocean, ' J.I. Charney (d.), ***The New Nationalism and the Use of Common Spaces: Issues in Marine Pollution and Exploitation of Antarctica*** (Totowa, New Jersey: Allenheld, Osmun publishers, 1982), pp. 239-286.

82 Signatory nations to CCAMLR include the principal fishing countries of the world including Japan with 13 percent of the world's catch, the Soviet Union with 12 percent, China with 8 percent, and Chile and the United States with 6 percent each.

83 H.J. Sutton and P.K. Park, "UNEP and Antarctica" (draft), United Nations Environment Programme, Nairobi, Kenya, August 1988, p. 20.

84 Central Intelligence Agency, op. cit., footnote 5, p. 51.

Table 5-3-Presence of Scientists and Tourists on Antarctica

	Approximate populations	Duration of stay in days	Person-days	Percent of total
Scientists and support personnel (UNEP):				
Summer (@ 67 bases)	3,500	120	420,000	
Remaining 8 months (@ 48 bases)	1,000	240	240,000	
(subtotal)			660,000	95%
Tourists	3,500	10	35,000	5 %
Total ., ...			695,000	

SOURCE S.R Fletcher. "Antarctica. Environmental Protection Issues." Congressional Research Service Report for Congress, 89-272 ENR, Apr. 10, 1989, p. 57.

force in 1978. The Convention totally protects the fur, elephant, and Ross seals from exploitation; prohibits the taking of seals that are **in the water (except in limited numbers for scientific purposes);** and sets annual quotas, seasons, and capture zones for crabeaters, leopards, and Weddell seals.[85 86] The enforcement of the agreed-upon conservation measures depends entirely on the self-policing policies of the signatory nations.

Whaling

Whaling around Antarctica began around the turn of the century, From the late 1920s and early 1960s, the world's principal whaling grounds were located in the Southern Ocean within about 600 to 1,200 miles of Antarctica. Particularly because of the introduction of explosive harpoons, harpoon cannons, motorized catcher boats, and large factory ships in the late 1920s, Antarctic whalers caused critical declines in the populations of right, blue, humpback, fin, and sei whales. Since the early 1960s more than 1 million whales have been killed in Antarctic waters.[87] (See table 5-4.[88])

Voluntary limits on whaling were established by the International Convention for the Regulation of Whaling during the 1930s.[89 90 91] These limits had little effect. In 1946 the International Whaling Commission (IWC) was established to regulate the whaling industry worldwide; its recommendations did not carry much weight until the late 1960s. In **1986** the IWC instituted a temporary moratorium on all commercial whaling; this moratorium is scheduled for review in the near future. As might be expected, there are differing views within the IWC about the exploitation of whales and how whaling should be managed.[92]

Avoiding Sensitive Areas and Rehabilitating Impacted Areas

Unique and/or especially sensitive areas should be avoided, to the extent possible, in any future Antarctic minerals exploration and development. For example, highly stratified saline lakes found in East Antarctica are especially susceptible to impacts in the summer when streams flow along adjacent ice-free valleys into them.[93] The Treaty Parties have set aside 28 Specially Protected Areas (SPAS) where research, plant and animal collection, and vehicular access are denied without entry permits. Due to their importance for scientific research, 17 other sites have been designated Sites of Special Scientific Interest (SSSIs). These areas are off-limits to visitors

85 Siniff, op. cit., footnote 21, pp. 71-74.

86 Hofman, op. cit., footnote 80, p. 14.

87 Ibid., p. 14.

88 D.C. Chapman, "Living Resources: Whales, " *Oceanus, vol.* 31, No. 2, Sumner 1988, pp. 64-70.

89 Ibid., pp. 64-70.

90 Central Intelligence Agency, op. cit., footnote 5, pp. 52-53.

91 J. Gulland, "The End of Whaling?" *New Scientist,* vol. 120, No. 1636, Oct. 29, 1988, pp. 42-47.

92 Hofman, op. cit., footnote 80, p. 14.

93 Zumberge, op. cit., footnote 8, pp. 24-25.

Table 5-4-Worldwide Populations of Whales Commonly Found In the Southern Ocean

species	Average adult size (in m)	Population (in thousands)[a]		
		Original world	Current world	Antarctic
Southern Right	12	100	3	3
Blue	23	228	14	11
Humpback	11	115	10	3
Fin	19	548	120	100
Sei	13	256	54	37
Sperm	12	2,400	1,950	950
Minke	7	140	725	380

[a]All estimates are highly speculative.

SOURCE: Most data from the International Whaling Commission, *Oceanus*, vol. 32, No. 1, Spring 1989, pp. 12-13. Data on Antarctic stocks from P.G.H. Evans, *The Natural History of Whales and Dolphins* (London: Christopher Helm, 19S7), p. 343.

and access must conform to a management plan for each SSSI. The locations of SPAS and SSSIs are shown in figure 5-7.

Much can be done to clean up previously used scientific research bases or resource development sites in Antarctica by removing garbage, unused fuel, **chemicals,** and other potentially toxic waste. However, it is not possible or practical to accelerate the natural recovery of impacted upland areas or marine environments to their original conditions. Future human activities should therefore be planned and designed to minimize potential impacts in the first place.

REGIONAL AND GLOBAL IMPACTS FROM ANTARCTIC DEVELOPMENT[94]95

The larger the scale of mineral development in Antarctica, the greater will be likely long-term regional impacts on terrestrial and marine ecosystems. Some of these would undoubtedly take the form of ill-defined sublethal and chronic effects on the terrestrial and marine ecosystems from low levels of contamination. Furthermore, **the more Antarctica is polluted by regional sources, the less useful the continent becomes for evaluating the effects of global pollution on the world's oceans and atmosphere.[%] However, available information suggests that resource development in Antarctica, even if pursued on a large scale, would probably not generate significant global impacts to the world's oceans and atmosphere relative to other activities of man,[97]**

Scientists would probably be especially concerned about the potential impacts of resource development occurring within or near designated research areas. As illustrated by the recent sinking of the *Bahia Paraiso,* oil spills probably represent the greatest risks to Antarctic research, especially biological and ecological research. The majority of nonbiological research in Antarctica would probably not be directly impacted by development activities; however, there would be indirect impacts from added logistics activities, land-based construction, and possible disruptions caused by accidents.

Research Required to Better Predict I[mpac]ts9899 100101102

Scientific exploration of Antarctica began in the early 1800s with several biological investigations.

94U.S. Department of State, op. cit., footnote 42, pp. 6-26 to 6-28.
95Zumberge, 0p. cit., footnote 41, pp. 115-154.
96Rutford, op. cit., footnote 7, pp. 34-35.
97Zumberge, op. cit., footnote 8, pp. 33, 44-46.
98Rutford, op. Cit., footnote 7, pp. 10, 36-3'7, 43, 53-55, 67.
99Elliot, op. cit., footnote 6, pp. xviii, VIII-1 to 4.
100U.S. Department of State, op. cit., footnote 42, pp. 6-28 to 6-31.
101Holdgate, op. cit., footnote 91 pp. 38-48.
102Charney, op. cit., footnote 2, pp. 214-215.

Photo credit: ***Ted DeLaca,*** National Science ***Foundation***

Palmer station, Anvers Island, off the Antarctic Peninsula. Areas in the vicinity of Palmer station were impacted by the Bahia Paraiso spill.

Geologic exploration of the continent began in the late 1800s. Numerous scientific expeditions during the 1900s continued to increase our knowledge about the Antarctic environment. The establishment of 50 bases by 12 countries during the International Geophysical Year in 1957 and 1958 transformed Antarctica into an international scientific laboratory.

Despite continuing research there are still significant uncertainties about the environment of Antarctica. As described in chapter 4, the geologic data is meager for accurately estimating Antarctica's mineral potential. The response of the continental ice sheet and surrounding seasonal sea ice to changing climatic conditions is poorly understood. More quantitative data is required to better understand the ocean circulation around Antarctica, especially during the winter and in coastal waters. Weather forecasting is still difficult. Floral and faunal distributions on the ice-free coastal areas are fairly well documented, although the ecosystem relationships are not well understood. Baseline data on the marine ecosystem are still incomplete, including information on biomass distributions, productivity, and food web relationships.

It is generally believed by both industry representatives and environmentalists that minimizing the possible impacts of resource development activities will be difficult without first collecting additional environmental information on the topics listed in table 5-5. Furthermore, a better understanding of Antarctica's environment, particularly the marine ecosystem, is necessary in order to evaluate the significance of impacts generated by development activities relative to natural variability and other independent trends, such as fishing. In fact, Article 4 of the Convention stipulates that no mineral exploration or development will be allowed without adequate information about the potential impacts that such activities might generate.

The Federal Government has spent about $200 million over the past 15 years to evaluate potential impacts of oil and gas development on the continental shelf of the United States. The environmental research required before and during offshore petroleum development in Antarctica could cost as much as a few hundred million dollars.[103] An additional ***$200*** to *$300* million could also be required for an ice-strengthened research ship for marine research. The research required to evaluate the impacts associated with minerals development and other land-based activities could be less costly than marine research. As in other expensive, large-scale scientific endeavors, the United States could seek to defray some of these costs through an international cooperative effort.

The Convention describes the general requirements and procedures for evaluating potential environmental impacts that will be associated with exploration and development activities. However, it is not clear in the Convention text whether the research in table 5-5 would be conducted and paid for by the Operator or by the Sponsor.

[103]Research in Antarctica might cost more or leas than this amount. On the one hand, research would probably not have to include the continent's entire coastline and continental shelf. On the other hand, research in Antarctica probably costs about two or three times more than comparable research on the U.S. continental shelf due to the continent's remote location, greater logistical requirements, and adverse working conditions. Also, impact assessments could be more costly if the study areas are more variable or complex than assumed. Based on NSF's funding figures for scientific research in Antarctica (noted at the end of this chapter's introduction), the international community has probably sponsored several tens of millions of dollars of research on the topics listed in table 5-5 over the last two decades.

Figure 5-7-Specially Protected Areas and Sites of Special Scientific Interest on Antarctica

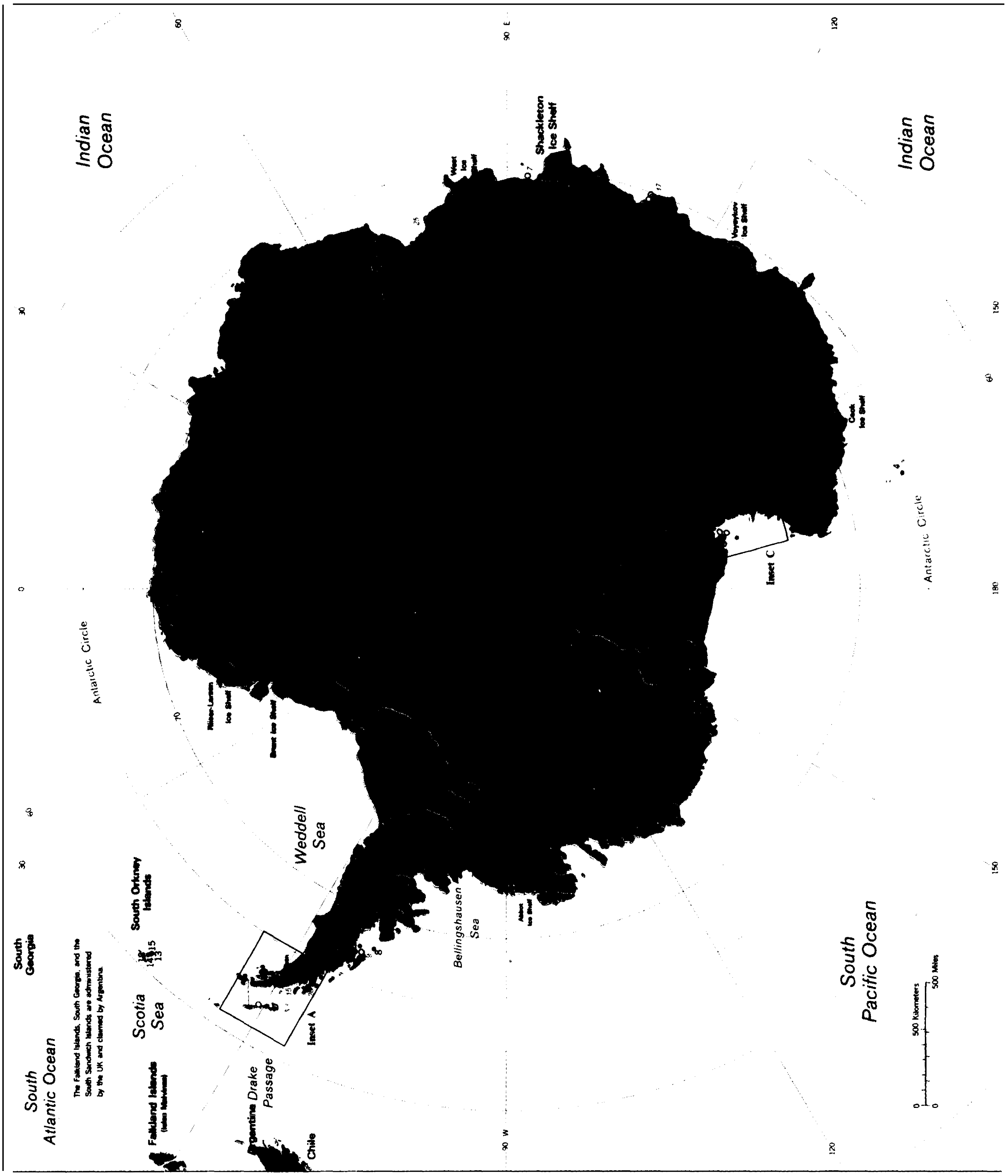
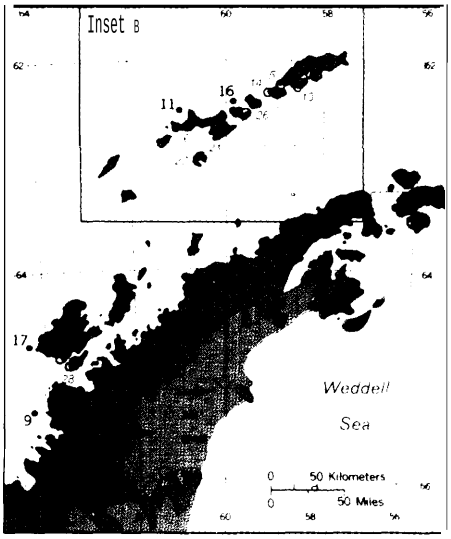
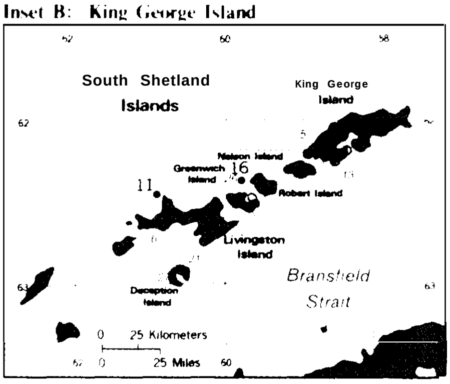


Figure 5-7-Specially Protected Areas and Sites of Special Scientific Interest on Antarctica-Continued

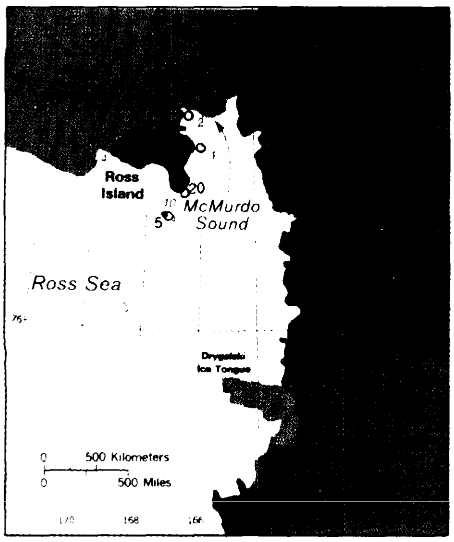
Inset A: Antarctic Peninsula



Inset B: King George Island



Inset C: Ross Sea



SOURCE: U.S. Government, 1989.

Sites of Special Scientific Interest

1 Cape Royds
2 Arrival Heights
3 Barwick Valley
4 Cape Crozier
5 Fildes Peninsula
6 Byres Peninsula
7 Haswell Island
8 W. shore of Admiralty Bay
9 Rothera Point
10 Caughley Beach
11 Tramway Ridge
12 Canada Glacier
13 Potter Peninsula
14 Harmony Point
15 Cierva Point
16 Bailey Peninsula
17 Clark Peninsula
18 White Island
19 Linnaeus Terrace
20 Biscoe Point
21 Shores of Port Foster
22 Yukidori Valley
23 Svarthamaren
24 Summit of Mt. Melbourne
25 Marine Plain
26 Discovery Bay
27 Port Foster
28 South Bay

Specially Protected Areas

1 Taylor Rookery
2 Rookery Islands
3 Ardery and Obert Islands
4 Sabrina Island
5 Beaufort Island
6 (now site of special scientific interest 4)
7 Cape Hallett
8 Dion Islands
9 Green Island
10 (now site of special scientific interest 6)
11 Cape Shireff
12 (now site of special scientific interest 5)
13 Moe Island
14 Lynch Island
15 Southern Powell Island
16 Coppermine Peninsula
17 Litchfield Island
18 North Coronation Island
19 Lagotellerie Island
20 New College Valley

Table 5-5-Basic Research Required to Evaluate Possible Environmental Impacts Prior to Resource Development

Research and Information requirements
- more detailed data on terrestrial, lacustrine, and marine ecosystems, especially those areas that are most likely to be considered for resource development, and those areas that are judged to be most sensitive to impacts
- content and composition of hydrocarbons and other contaminants In Antarctic waters. sediment. and marine organisms

Research requiring extended time-series measurements (e.g., over a decade)
- marine and terrestrial ecosystem dynamics in response to pollution and other impacts from potential resource development
- fate of oil and its degradation in open and ice-filled seas around Antarctica,, and under-shelf ice
- adverse short- and long-term effects (e.g., toxicity) of oil on Antarctic phytoplankton, krill, seals, and benthic communities

SOURCE: Office of Technology Assessment, 1989.

Chapter 4 contains a discussion of research required to evaluate the mineral resources of Antarctica. Appendix A presents an oil development scenario and discusses research needed on geologic hazards, weather, and ice movement prior to the development of petroleum resources in Antarctica.

Monitoring and environmental baseline studies will become increasingly important if minerals activities commence in Antarctica. The United States could be at a disadvantage in Minerals Convention meetings if it does not devote more attention to this type of work.