Appendixes

Photo credit: *U.S. Geological Survey*

Appendix A
Development of an Antarctic Oil Field

INTRODUCTION

This appendix was prepared to illustrate the most likely hypothetical scenario that would be employed if an Antarctic oil field were developed under the terms of the new Minerals Convention, It explores the technological capabilities and economic incentives that would determine the viability of a hypothetical Antarctic oil field and presents some possible approaches to development. If commercial quantities of oil are discovered in Antarctica in the future, companies experienced in developing offshore fields in harsh, Arctic environments today would, in some situations, have the capability and may also have the incentive to develop an Antarctic field, Whether they *would* have the capability depends on both specific environmental conditions where the field is located and the future status of needed technologies. Whether companies *would* have the incentive depends on profitability and risk-both financial and political.

The scenario presented in this appendix is based on admittedly optimistic assumptions about several determining factors. Three are key to the discussion:

-*first*, that a world-class giant field is discovered;

—second, that the parties to the Minerals Convention allow oil development in the area *in* which the field is located and assure the developer of rights to produce the field; and

—***third,*** that the world price of oil is and remains high enough to make Antarctic production economics attractive,

Some of the needed technology for selected Antarctic oil development has been built and is now successfully employed in other areas; other technology must be assumed to be available in the future as a consequence of oil field ventures in other harsh environments. These assumptions may or may not be realized in the future. If any condition is not met, an Antarctic oil prospect would probably not be developed. If the assumptions hold, however, it is not unreasonable to project that over time, the needed technology will be available and certain prospects will be profitable to develop.

An Antarctic oil venture could not be undertaken before the turn of the century. Substantial lead times will be needed to do further scientific resource assessment work, environmental baseline work, and surveys of physical environmental constraints. Following this work, substantial time must be devoted to reconnaissance surveys. At the same time the regulatory system will require preparation of exploration and development plans and evaluation of environmental impacts. Finally, long lead times will be needed to identify any oil field through exploratory drilling, to delineate that field through additional drilling, and to design and construct a production and transportation system. OTA concludes that the minimum total time elapsed before any major Antarctic field could be expected to produce oil would be 30 or more years from today.

The technology needed for Antarctic oil development in certain offshore regions is not substantially different from that under development or available to major firms for the Arctic and deep water temperate regions. For Antarctic regions with more severe conditions, it is not unreasonable to expect new technology to be available over the next few decades. Much of the needed research and development work is now underway. It is also reasonable to expect that the world oil price will rise sufficient y to make Antarctic oil production profitable in the next three to five decades, even though the current plentiful world supply may continue. Technology appears to be one of the lesser important constraints to future Antarctic petroleum development. Political, institutional, and environmental constraints appear more significant.

The following sections discuss a purely hypothetical development that might take place at a time at least 30 years in the future. Such a long range projection must contain a large amount of uncertainty, but it is necessary to look this far in the future in order to consider what development might be like under the new Minerals Convention. At the present state of knowledge and institutional maturity it would be unreasonable to expect commercial oil development to occur much sooner.

The following sections present:

. the design environment for Antarctic offshore oil development
. a discussion about technologies that may be used for Antarctic production; and
. a hypothetical scenario for Antarctic development.

THE DESIGN ENVIRONMENT FOR ANTARCTIC OIL DEVELOPMENT

The discussion in chapter 4 shows that the greatest potential for Antarctic oil development exists in one of the offshore sedimentary basins, such as that in the Ross Sea, that OTA selected for its hypothetical scenario. The environmental conditions that determine the major design criteria for development systems are quite severe in any

Antarctic offshore region, and the Ross Sea is no exception. The significant factors include:

- glacier ice (the origin of icebergs);
- sea ice (single-year ice 3 to 6 feet thick);
- icebergs (some very large-to tens of miles square); [1]
- extreme cold (annual mean temperature 0°F along coastline);
- heavy seas (frequent, severe storms);
- deep water (2,000 to 3,000 feet in Ross Sea);
- long periods of winter darkness;
- possible frozen gas hydrate present subsea;
- deep water iceberg scour (up to 1,500 feet);
- active faulting; and
- sea-bottom permm.frost

While the available data are sufficient to make the above list and identify the importance of these factors overall, much more data will be needed to set design criteria for any future oil production system. If oil development is expected to take place in the next century, it will also be necessary to spend considerable time and effort collecting information and analyzing environmental design conditions. Some of these data requirements are shown in box A-1. One of the most important areas where existing information is lacking is that of size and frequency of icebergs. Icebergs could be a major design constraint for specific production platforms. Other information, such as of deep currents, sea ice anomalies, etc., could also be potentially important but very few data are available to make a judgment.

Based on current knowledge of the Antarctic environment, ice appears to be the most significant factor in the above list both because very severe iceberg conditions are known to exist in Antarctica and because offshore oil operators have designed successful systems to operate under conditions suggested by many of the other factors. Ice is a significant design factor for any offshore system because the structural loads imposed by moving ice can be huge. Moving glaciers will not be resisted by any normal structure—nor will very large icebergs. The larger of the icebergs can also scour deep trenches in the seafloor (as deep as 1,500 feet in some *reports)* and thus *even* determine the depth to which pipelines must be buried.[2] In the last 10 years two ships have been sunk by ice in the Ross Sea.

The glacier ice that covers almost all of the Antarctic continent with an average thickness of almost 2 miles also extends offshore in many areas. The Ross Ice Shelf is more than 200,000 square miles in size. OTA's hypothetical oil field is located in water seaward of the northern edge of this shelf. Huge icebergs continually break off and are discharged into the ocean from the many ice shelves around the Antarctic coast.[3]

Box A-1—Antarctic Environmental Information Needs To Design Major Offshore Oil Production Systems

Ocean Environment	Knowledge of wind, waves, ocean currents, and seafloor conditions are needed to establish design criteria.
Glacial Ice	Physical properties of glacial ice are needed to develop systems that can operate on top, through, and below the ice. This includes such properties strength, temperature, plasticity, movement, etc., which can provide a basis for establishing design criteria.
Sea Ice	Thickness, coverage, strength and other physical properties of the ice are needed to develop design criteria for fixed and moored platforms, ice breakers, and shuttle tankers.
Icebergs	Size, distribution, frequency, velocities, and scour depth of icebergs are needed to design offshore structures and pipelines.
Field Description	A general knowledge of the probable location, size, depth, and formation characteristics is needed to define the most likely drilling and production means that might be used at specific reservoir 1ocations.

Note: The above data needs are general and relate to either the possibility of development in open water or beneath the ice shelf.

SOURCE: Office of Technology Assessment, 1989.

During the winter, the Southern Ocean surrounding Antarctica freezes and more than doubles the apparent size of the continent. This sea ice is generally annual ice (i.e., it melts and refreezes each year) and has a thickness of 3 to 6 feet. Such ice probably can be transited year-round with icebreakers or icebreaking tankers or, during the summer months, with only ice-reinforced ships. Annual sea ice does not appear to be a formidable problem, but more research is needed before reliable,

[1] A few icebergs arc of enormous size—one recently released in the Ross Sea was about twice the size of the State of Rhode Island.

[2] Deep Oil Technology, Inc., *Technology and Cost for Offshore Oil Development in Antarctica*, OTA contractor report, November 1988.

[3] L.F. Ivanhoe, "Antarctica—Operating Conditions and Petroleum prospects,' *Oil and Gas Journal, vol.* 78, No, 52, Dec. 29, 1980, pp. 212-220,

year-round ice transit systems could be designed. For example, some are concerned that if regular daily transits are made by icebreaking tankers, large mounds of ice rubble could build up and restrict normal passages.

Icebergs, on the other hand, appear to be formidable in some regions.[4] Antarctic icebergs can be very large (several square miles is not unusual) and thick. It would be impossible in some cases to design structures to withstand their impact forces. However, there may be some offshore regions where large icebergs are infrequent or where they can be tracked and predicted. It is not known whether iceberg-free regions would correspond to the location of a commercial oil field. Since there is such a vast territory to explore in Antarctica, it would make sense to initiate exploration efforts in those regions where production would be most feasible. However, until more research on iceberg occurrence is done, it will not be possible to design a specific oil production system for any region in Antarctica.

Other severe environmental factors include stormy seas, extreme wind chill factors, and very low temperatures. The greater depth of Antarctica's continental shelf (e.g., the seaward edge of the geologically interesting Ross Sea shelf[5] lies in about 2,600 feet of water) adds to the technical complexity of offshore drilling and production. In combination with severe storms and problems related to ice (such as quick moving pack ice and tabular icebergs that have been observed grounded at depths of more than 1,600 fee@), the difficulty of exploring for and producing oil in some regions of Antarctica could be formidable even compared to nearshore Arctic waters.

In general, the rigorous environment of Antarctica is such that oil and gas production there (if, indeed, exploitable quantities are discovered) is likely to be more difficult than existing production anywhere else in the world. Some of the biggest challenges to date for the oil industry have been exploration for oil and gas resources in the Canadian Arctic and in the Beaufort and Bering Seas offshore Alaska. Antarctica is colder, more stormy, and more isolated than these areas, and has a continental shelf three to six times deeper than the global mean.[7] But it is the iceberg problem that sets Antarctica apart from most Arctic offshore regions. Each of these environmental constraints adds to the difficulty of exploring for and producing oil in Antarctica.

For a future Antarctic development, structures could be designed and built to withstand the cold temperatures and to protect people from the worst effects of extreme cold; however, careful designs would be required to keep equipment running smoothly and people working efficiently. Offshore structures and ships would need to be built to withstand hazards caused by a variety of ice forms. These hazards include moving sea ice, pressure ridges, icebergs, ice buildup on platforms and ships, permafrost, and ice scour of the seabed. Innovative engineering solutions to some Arctic problems could be a useful guide. However, in areas such as the Beaufort Sea where ice conditions are severe, industry has not yet discovered fields that require production systems very far offshore, into very deep water, or into the dynamic multiyear ice zone. If such Arctic development does advance in the future, it could offer useful engineering lessons for Antarctica.

Antarctica is one of the most isolated places on Earth. The Ross Sea in Antarctica is about 2,000 miles from New Zealand. In contrast the remote Navarin Basin in the Bering Sea off Alaska is about 600 miles from a potential support base and itself poses extreme logistics problems that would significantly affect the economics of oil exploration and production there. Oil may be produced (if discovered) in the Bering Sea but even here a large amount would have to be recoverable to make operations profitable. One characteristic of frontier areas like the Navarin Basin and any area in Antarctica is that there is little or no existing infrastructure. The only existing infrasturcture in Antarctica supports the scientific program. This means that everything-men, equipment, supplies, housing, entertainment, etc.—must be brought from someplace else, and at considerable expense. Conversely, produced oil must be transported long distances to markets. Moreover, the currently feasible options for transporting Antarctic oil (e.g., icebreaking tankers) will be expensive and will require some technological development. It is worth noting that Alaska's North Slope oil is transported overland by an 800-mile pipeline to an ice-free port to avoid the need for icebreaking tankers.

An additional constraint in Antarctica is that about 98 percent of the land is buried beneath a thick continental ice sheet. Not only does this preclude oil drilling with today's technology on all but the 2 percent of Antarctica not covered by ice, but very few sites are available on which advance support bases for offshore exploration could be located. Ice-free areas may also be sites of penguin rookeries, and an oil company that wished to

[4]H. Keys, "Icebergs Off South Victoria Land, Antarctica," *New Zealand Antarctic Record,* vol. 6, No. 2, 1985, pp. 1-7.

[5]J.C. Behrendt (ed.), "Are There Petroleum Resources in Antarctica," *Petroleum and Mineral Resources of Antarctica*, U.S. Geological Survey Circular 909, 1983, p. 22.

[6]Central Intelligence Agency, *Polar Regions Atlas*, 1978, p. 38.

[7]Ibid., p. 35.

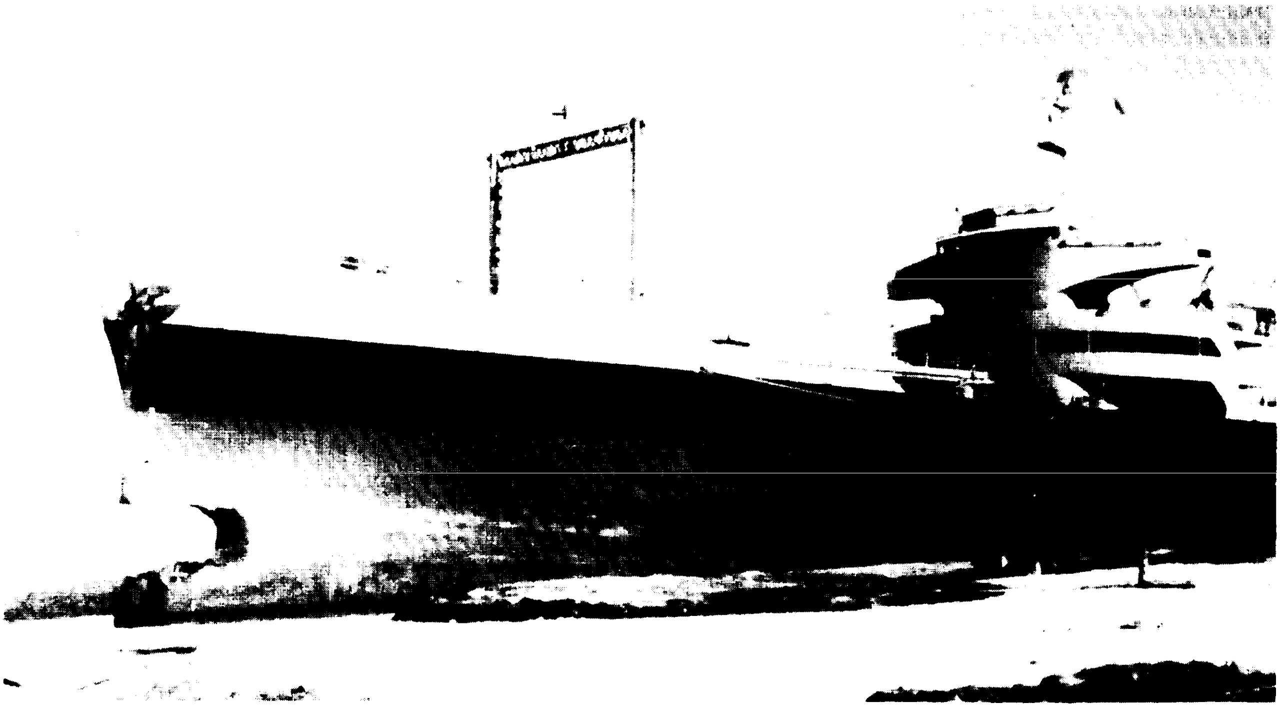


Photo credit: Bill Westermeyer

The Maumee, the oil tanker that resupplies McMurdo, after it hit an iceberg in 1976. The iceberg put a 35-foot gash in the tanker's bow, but no oil was spilled.

locate a support base at such a site could expect strong opposition from environmental groups. Moreover, there is no guarantee that a suitable location for a support base will be found near an offshore oil prospect.

Even so, a supergiant oil field of high-grade producibility could be a powerful incentive for industry to invest in Antarctica. The offshore petroleum industry is now working in some harsh environments that also pose large challenges to design engineers. Major exploration activities are currently underway in a number of hostile regions, such as in the severe ice conditions of the Beaufort and Chukchi Seas offshore Alaska and Canada, in iceberg areas along Greenland and eastern Canada, and in the North Sea, North Atlantic, and Norwegian Sea. The most significant oil production experience in harsh environments to date is in the North Sea, but very deep water production (2,000 feet) has begun in such areas as the Gulf of Mexico and offshore Brazil; and, in a few years, production will probably commence from fields offshore Labrador.

In addition, recent leases were sold and plans are underway to drill exploratory wells in the Chukchi Sea north of Alaska, where thick, moving, multiyear sea ice is prevalent. Some of these ice conditions maybe even more severe than those in Antarctica, even though the depth of water in the Chukchi Sea seldom exceeds 150 feet. Other companies are accomplishing exploration drilling in the North Atlantic west of the Shetland Islands in regions of deep water and very rough seas. Still other companies are planning exploration in areas of the Gulf of Mexico and elsewhere where water depths are as great as 10,000 feet.[8] One company is proceeding with development of an oil field just 500 miles north of the Antarctic Peninsula, off Argentina's Tierra del Fuego.[9] Another has begun engineering on the production facilities for the Hibemia oil field in "Iceberg Alley' on the Grand Banks of Newfoundland.[10] Harsh environments requiring unique and costly

[8] Keys, op. cit., footnote 4.

[9] "First Offshore Argentine Oil Being Developed by Total,'" *Ocean Industry*, vol. 23, No. 9, September 1988, pp. 115-116.

[10] "Mobil Names Firms Eligible To Bid on Hibernia Project, ' *Oil and Gas Journal*, vol. 86, No. 52, Dec. 26, 1988, p. 28.

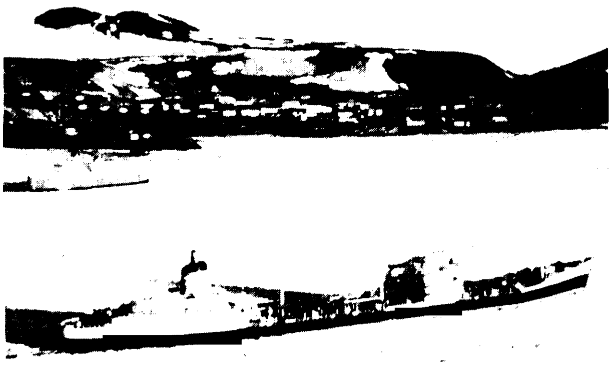


Photo credit: Ann Hawthorne

The Maumeenear McMurdo in 1988 escorted by the Coast Guard icebreaker, ***Polar Star.*** If oil is ever developed in Antarctica, ice-strengthened or, more likely, icebreaking, tankers will be needed.

technical approaches have not deterred petroleum exploration and development ventures.

OFFSHORE TECHNOLOGIES FOR HARSH POLAR ENVIRONMENTS

Current offshore oil and gas operations and planned systems for harsh environments around the world form the basis of any projections of technologies that may be used in future Antarctic petroleum development. Technologies employed by the offshore petroleum industry have changed dramatically over the past 20 years allowing exploration and production in environments that were considered almost prohibitive two decades ago. These technology changes can be expected to continue, but the nature and extent of advances three to five decades in the future are hard to predict, Industry has moved into hostile environments in discrete incremental steps, progressively resolving the problems encountered, adapting existing systems or techniques, and designing new ones as needed. That technology base today is available for adaptation to Antarctica by the major, experienced operators in the same manner-in discrete, incremental Steps.[11]

Offshore petroleum activities are commonly divided into three phases: exploration, development, and production. Exploration includes geological and geophysical surveys as well as exploratory drilling. In the Mineral Convention's terms, this includes both "prospecting" and ''exploration. Development begins after an oil discovery is determined to be economic and includes drilling of production wells and the design and construction of all platforms and facilities for producing the field. Production begins with the flow of oil to the market and continues until the field is depleted. In offshore hostile regions, exploration has taken on the order of 10 years or more, development work has taken about 10 years, and production continues for 20 years or more. After initial operations commence, some of these phases can be accomplished concurrently.

Adequate exploration technology (both geophysical survey ships and mobile exploratory drilling vessels) is available today to work in many of the offshore Antarctic regions, In fact, some seismic surveys have already been done by the U.S. Geological Survey and several nations working in Antarctica. Also, U.S.-based geophysical survey firms have proposed, to a number of oil companies, to conduct further seismic operations in Antarctica. These operations are conducted during the summer months in ice-free waters. Scientific drilling operations have also taken place at a number of sites surrounding Antarctica the most notable of which were under the auspices of the Deep Sea Drilling Program in the 1970s. These and other scientific drilling operations were conducted during the summer months in ice-free waters. None of this scientific drilling was to adequate depth or at the proper locations to be considered part of an oil exploration program.

A number of mobile drilling platforms operating in the world today have the capability of drilling exploration wells offshore Antarctica (such as in the Ross Sea) during the summer months and in up to 50 percent ice coverage. The most suitable drilling rig would probably be a heavy-duty semi-submersible exploratory drilling vessel similar to that used in the North Atlantic or the Bering Sea offshore Alaska. Exploratory drilling could be accomplished over a number of summer seasons, much as is done off Alaska and no major extension of existing technology would be needed.

The present technology for production systems will have to be developed further to make offshore Antarctic oil production feasible. Systems are currently available in areas of minimum ice encroachment. Where ice is present, parts of deepwater systems would have to be combined with systems designed for Arctic conditions. Such combinations could include floating terminals and/or subsea wells like those used in the North Sea; tanker shuttle operations like those used in the Labrador Sea; and ice-reinforced structures like those used in the Cook Inlet.

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

Ongoing industry R&D programs could develop additional components needed for Antarctic production. For example, considerable research is underway on remote control systems for subsea wells. Two-phase pumping systems are also being developed so that produced gas and oil can be moved long distances before it is necessary to provide a large separation facility. It is reasonable to assume that many of these technologies will advance in the next few decades and be available for any oil production allowed in Antarctica.

A HYPOTHETICAL SCENARIO FOR ANTARCTIC DEVELOPMENT

Technology Assumptions

OTA's hypothetical scenario contains a number of technology assumptions. It assumes that technology for operating in ice-covered continental shelves will advance on all fronts. This could bring the cost of oil extracted from frontier areas down, closer to the cost of today's cheaper oil. For example, oil is profitably produced in Prudhoe Bay on the North Slope of Alaska, moved to Valdez by pipeline, shipped to the Panama Canal by tanker, moved by pipeline across the Canal, and shipped by tanker to the Gulf of Mexico. It seems reasonable that 30 years hence, technology will be readily available to ship oil from offshore Antarctica to New Zealand or Argentina by ice-strengthened or icebreaking tankers and then to any location in the world in conventional tankers.

Developments in technology could also affect OTA's assumptions about Antarctic exploration and develop ment. For example, 30 years hence, improved geophysical techniques could significantly decrease the cost of finding oil. This could result in lower delineation drilling costs, because fewer wells will be needed to find and delineate fields. Improved drilling techniques such as use of down-hole motors and surface control and monitoring, could lower drilling costs as well. Improvements in production techniques such as use of multiphase pumps, flexible pipelines, compliant platforms, ice-strengthened platforms, etc., all tend to reduce the relative cost of harsh environment field developments. Transportation technology could also reduce costs through use of improved ice-operating tankers, deep-water pipeline systems, better loading techniques, etc. Box A-2 summarizes key technological advancements beyond current technology that OTA concludes are needed for developing an Antarctic oilfield.

If the above technical developments occur, there would seem to be no insurmountable technical barriers to oil exploration and development of Antarctica's offshore sedimentary basins. The relative technical difficulty in developing oil in Antarctica today is probably less than it was for developing fields in the Beaufort Sea 30 years ago. other fields (e.g., in the Chukchi Sea) will probably be developed and be operating over the next 30 years, advancing the technology needed for Antarctica.

Box A-2-Summary of Key Technology Advancements Needed To Design Antarctic Offshore Oil Production Systems

- High-capacity mooring systems to keep floating drilling and production platforms on location during heavy ice coverage.
- Seafloor storage tanks for holding oil on the seafloor in iceberg-infested waters.
- Long-range subsea control systems that will allow wells to be located long distances from production facilities.
- Two-phase flow pumps that will allow oil and gas to be transferred long distances without separation.
- Remote operated vehicles that will provide a means of installing and servicing seafloor equipment in deep water and Mow the ice shelf.
- Mini-submarin es or remotely operated vehicles that can provide direct access to seafloor equipment.
- Icebreaking tankers for transporting oil year round from Antarctica to an ice-free transfer terminal.
- Flexible pipelines that can accommodate relative movement between the seafloor and a floating platform.
- A means for keeping an access hole open through glacier ice to allow wellheads to be located on the seafloor or ground.

SOURCE: Office of Technology Assessment, 1989.

An Oil Consortium for Antarctica

Major international oil companies, in partnership with each other and/or with state oil enterprises, would be the likely "Operators" of any Antarctic oil exploration and development if the Minerals Convention enters into force.[12]

A consortium of major oil companies and national oil companies would be the most likely organizational approach because of the finances that will be required and because individual companies probably will be averse to "going it alone." Most major, high-risk oil development ventures, such as those in Arctic and deepwater offshore areas, are undertaken by such consortia.

[12] J.N. Garrett, *The Antarctic Minerals Regime: A Petroleum Industry Perspective*, OTA contractor report, November 1988.

For the purposes of this scenario, OTA has assumed that:

- The consortium chooses the United States to be its sponsor.
- Seismic prospecting in the Ross Sea identifies factors that suggest significant oil accumulations.
- The same area also would be recognized as highly prospective by other operators and that there would be competing applications for the area of interest.
- Subsequent to receiving an exploration permit for the desired blocks, a wildcat well and follow-up delineation wells indicated the existence of an oil field containing 4 billion barrels of recoverable oil with very good reservoir and producing characteristics.
- The field ultimately was developed to a peak producing capacity of 700,000 barrels per day of crude oil.

OTA chose the Ross Sea as a possible location for a hypothetical oil field development because some evidence points to favorable conditions for oil accumulation in the sedimentary rocks there and because reconnaissance seismic surveys have been conducted in some of the prospective basins there. Based on preliminary evidence, a number of geologists believe the Ross Sea to have the best basins for petroleum formation of any of the Antarctic prospects identified to date (see ch. 4).

The hypothetical consortium is assumed to be the operating unit of the oil venture and to consist of four major international oil companies headquartered in the United States, The joint operation would cover activities ranging from prospecting through exploration and development stages to the construction of a transportation system. Consortium members each would provide managerial, professional, technical, and support personnel required to staff the Antarctic operation,

If convinced that an initial investment in an Antarctic venture could be justified, the consortium would appreach the appropriate agency of the U.S. Government about prospecting (i.e., in the Ross Sea using seismic survey techniques). Subsequent to supplying the appropriate agency with the information prescribed in Article 3713 of the Minerals Convention, the United States, as the Sponsoring State, would notice the Commission of the proposed prospecting plan. If the Commission did not raise any objections, the survey would be conducted. The details pertaining to a hypothetical reconnaissance seismic survey are shown in box A-3.

Assuming the results of the reconnaissance seismic work indicated favorable areas, the most prospective sector would be selected. The consortium would then request its Sponsoring State to ask the Commission to have the subject area identified for possible exploration and development activities.

If the area identification request is approved, the consortium would tender an application for an exploration permit through its sponsor, to the Regulatory Committee formed for the area. At this point the consortium could also include a participation agreement with state oil companies of several developing countries. Such an approach may be desirable, given that a decision on an application is to be based on a measure of wide participation-especially if the area is of interest to a number of competitors.

Under the terms of the Convention, the Regulatory Committee will divide a given area into a grid pattern of ‘‘blocks, ’ that is, leasable tracts, and accept applications for permits for Operators to work within those blocks. The Committee would also put limits on the number of blocks that would be allocated to any Operator and then resolve competing applications for the same blocks. The method of resolving competition for the same blocks is not spelled out in the Convention but would be for the Regulatory Committees to work out. (The “bonus bid” method common to offshore lease sales in the United States could be one option.)

Since the convention does not specify a method for establishing the blocks, OTA has developed a method that appears to be practical and within the intent of the Convention terms. That method is described in box A-4.

A Hypothetical Exploration Program

Once blocks have been established and allocated, exploration commences. Reconnaissance seismic surveys indicate the areas of interest and reveal the most promising. For the purposes of this example, OTA assumes the most promising area to be the Terror Rift of the Victoria Land Basin. This region has been identified in a number of studies as having potential for hydrocarbon accumulation. *4 Assuming the consortium is awarded an exploration permit by the Regulatory Committee for three blocks of 3,600 square miles each (see figure A-2), it would then conduct a more detailed seismic survey of the three-block area.

[13]Such information includes identification of the area, the resources subject to prospecting, the prospecting methods and work program, and the monitoring and prevention practices; an assessment of environmental impacts; and organizational and financial qualifications.

[14]For example, see A.K. Cooper, F.I. Davey, and K. Hinz, ‘‘Rms Sea—Geology, Hydrocarbon Potential,'' *Oil and* Gas *Journal*, vol. 86, No. 45, Nov. 7, 1988, pp. 54-58.

Box A-3—A Hypothetical Reconnaissance Seismic Survey

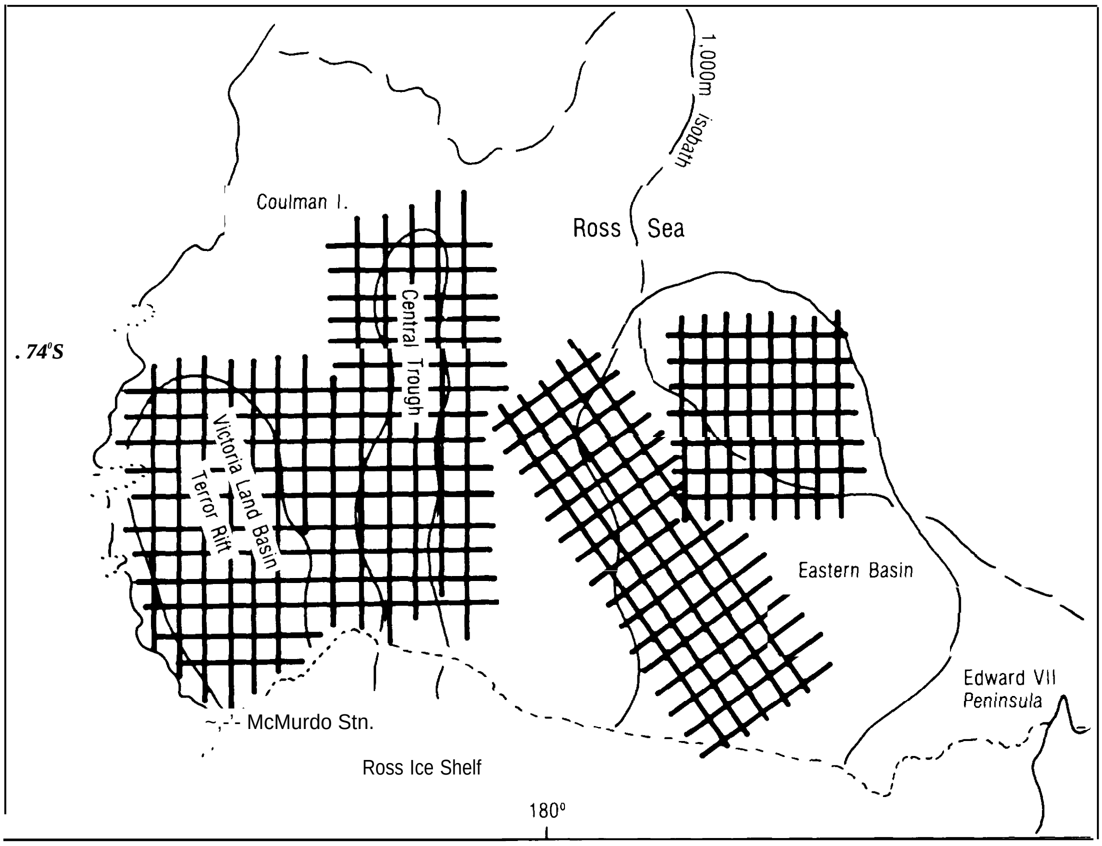
Within the Ross Sea, three prospective structural basins are indicated that warrant investigation by seismic methods. These basins and some of their physical characteristics are:

Basin	Basinal area with sediments >16,000' thick in square nautical miles	Maximum indicated thickness thickness of sediments in feet	Nautical Miles Seismic Line
Victoria Land Basin	8,650 nm²	46,000 (14,000 meters)	1,400
Central Trough	2,500 nm²	20,000 (6,000 meters)	1,500
Eastern Basin	11,000 nm²	20,000 (6,000 meters)	2,700
			Total = 5,600

Reconnaissance seismic surveying is conducted over the entirety of the Victoria Land Basin and the Central Trough. However, in the Eastern Basin (45,000 square nautical miles total area) much of the basin has a comparatively thin sedimentary cover; accordingly, only the deeper, potentially oil-bearing portions of the basin are investigated. All seismic surveying is carried out in open water. The lines are shot over a 20-nautical-mile grid. A map showing the approximate positions of the seismic lines is attached (figure A-l).

SOURCE: Office of Technology Assessment, 1989.

Figure A-l—The Ross Sea, Antarctica: Reconnaissance Seismic Survey Lines



The reconnaissance lines will be shot over a 20 nautical-mile grid across indicated structural basins

Seismic lines

Basin	Reconnaissance seismic line males
Victoria Land Basin	1,400 nm
Central Trough	1,500 nm
Eastern Basin	2,700 nm
Total	5,600 nm

SOURCE: J.N. Garrett, "The Antarctic Minerals Regime: A Petroleum Industry Perspective," OTA contractor report, January 1989, Adapted from D.H. Elliot, "Antarctica: Is There Any 011 and Natural Gas?" Oceanus, vol. 31, No. 2, Summer 1988, p. 35.

Box A-4-A Possible Approach To Delimiting Blocks for Petroleum Operations in Antarctic Walers

The Convention on the Regulation of Antarctic Mineral Resource Activities does not specify the size of, or the methods of determining, the blocks within which mineral extractive activities may be undertaken in Antarctica. Block size and designation in the Convention are not specified. Reference to such blocks is made in Article 43 only to the extent that the Antarctic Mineral Resources Commission will ''adopt measures with respect to maximum block sizes' and that the relevant Regulatory Committee will ''make provision for a limit in appropriate circumstances on the number of blocks to be accorded to any party. "

A practical approach to the delimitation of blocks pertinent to offshore petroleum operations is suggested here. The blocks would be vastly larger than those associated with the Gulf of Mexico or North Sea tracts because they must be large enough to facilitate operational flexibility and maximize the chances of discovery of billion-barrel plus oil fields. If the blocks are not very large, the petroleum industry would be unwilling to undertake Antarctic operations.

'The plan subdivides areas into blocks, each of which is 60 nautical miles on a side (i.e., each block side corresponds to one degree of longitude as measured at the equator). The dimensions of each block are:

Unit	Area
Square nautical miles	3,600
Square statute miles	4,774
Square kilometers	12,364
Acres	3,055,259
Hectares	1,236,430

The blocks apply, in this example, to the Ross Sea; wherever a block crosses a land/sea interface, only the seaward block portion constitutes explodable/exploitable acreage. The block grid system begins immediately north of the Ross Ice Shelf. The block mumbering system starts in the southwest, near McMurdo Station, with Blocks 1A, IB, IC . . . progressing eastward; block grid numbers increase progressively northward. See map in figure A-2.

SOURCE: Office of Technology Assessment, 1989.

If results of the detailed seismic work indicate the presence of many structural features, several would be drilled and tested, These are known as wildcat wells. OTA assumes the first four wildcat wells are either dry or did not penetrate a commercial discovery but that the fifth well indicates a significant oil discovery. This is a generally optimistic assumption for exploration success in a new frontier area, but it could be realistic if substantial y more scientific assessment of resource potential is accomplished.

Following intensive testing of the initial discovery well, OTA assumes that 11 additional wells are drilled to ascertain the extent of the discovery, the vertical height of the oil column, and whether or not a primary gas cap is present. Table A-1 illustrates the assumed field characteristics of this discovery.

The assumptions made here about wildcat well numbers, the extent of delineation drilling, and the size and characteristics of the oil field are very optimistic, and represent a "best case' scenario. It is not necessarily the most likely scenario, but it illustrates what a development might look like, what technologies are needed, what it might cost, and how long it would take to develop, By making favorable assumptions, OTA has established a baseline scenario that could be modified with a number of less favorable assumptions.

A Hypothetical Development Program

OTA assumes that, on the completion of delineation wells, the consortium, through the sponsoring state, would apply to the Regulatory Committee for a develop ment permit. This application would be accompanied by an updated and more detailed description of the develop ment plan, including the well spacing scheme, platform and gathering facility design, drilling and platform installation schedule, and the estimated field production profile. It would detail the transportation methods and would include a detailed, updated environmental impact statement for the planned development. The Sponsor would recertify the technical competence and the finan-

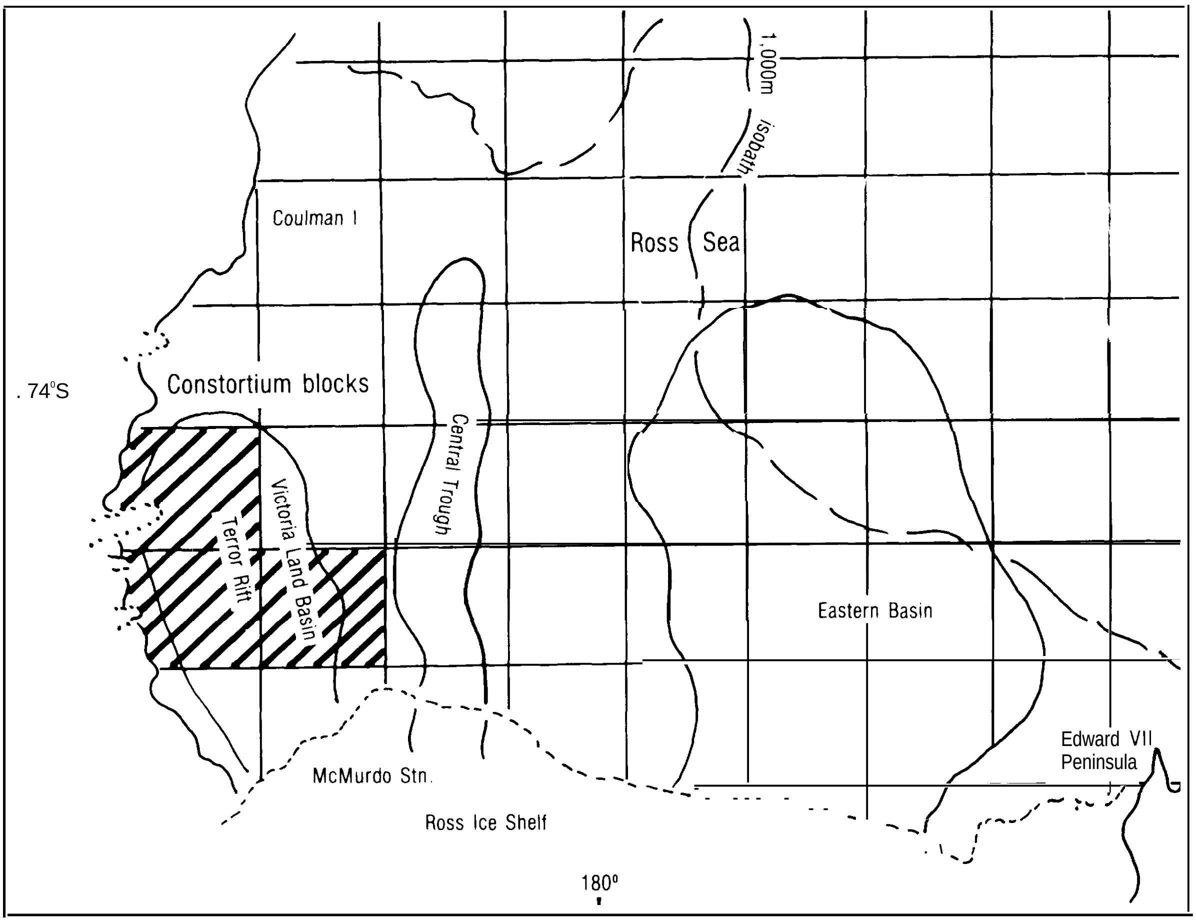
Table A-1-Characteristics of Hypothetical Discovery

Field classification	Field area	Average net oil	Recoverable oil reserves
Super-giant field	31,500 acres	200 feet	4 billion bbls.

NOTE: In the assumed discovery, no primary gas cap is penetrated, the oil pool is determined to be undersaturated and the reservoir drive mechanism is a partial water drive in conjunction with solution gas expansion.

SOURCE: Office of Technology Assessment, 1989

Figure A-2—A Hypothetical Plan for Dellmiting Blocks Dedicated to Offshore Petroleum Operation



Each square block measures 60 nautical miles on each side (i. e., each block side corresponds to one degree of longitude at the equator)

Area dimensions of each block

Unit	Acres
Square nautical miles	3.600
Acres	3,055,255

SOURCE: J.N. Garrett, "The Antarctic Minerals Regime: A Petroleum Industry Perspective," OTA contractor report, January 1989. Adapted from D.H. Elliot, "Antarctica: Is There Any Oil and Natural Gas?" ***Oceanus,*** vol. 31, No. 2, Summer 1988, p. 35.

cial capability of the consortium to carry out the updated development plan.

If the Regulatory Committee approved the updated development plan,[15] a development permit would be issued. (Note that the development plan that was submitted as part of the original application for the exploration permit would have been more general because the size and producing characteristics of the anticipated oil field discovery would have been unclear when the initial plan was drawn up,)

In the OTA scenario, the approved development plan provides for drilling 258 producing wells and 48 water injectors from 6 production platforms. Peak production capacity is 700,000 barrels of oil per day, and the expected field life is in excess of 30 years, during which approximately 4 billion barrels of oil would be produced (see box A-5).

[15] See ch. 3 about more detail regarding modifications to development plans.

Box A-5—Summary of Physical and Technical Aspects of the Hypothetical Oil Field

The Oil Field

- Field dimensions: 10 miles long x 5 miles wide
- Reservoir depth: 8,900 feet to 9,300 feet subsea
- Average net oil sand thickness: 200 feet
- Crude oil gravity: 32 degrees American Petroleum Institute
- Crude oil type: sweet
- Water depth: 2,500 feet

Recoverable Oil Reserves

- Reservoir volume: 6,300,000 acre feet
- Oil initially in place: 10 billion barrels
- Recoverable oil reserves: 4 billion barrels

Producing Characteristics

- ***Type of*** platform: floating drilling/production/ storage vessel; high-capacity mooring system; sub-sea wells with production risers to floating vessel
- Well spacing = 120 acres/well
- Total of 258 wells to drain the 31,500-acre field.
- Six platforms: 43 production wells and 8 water injection wells each.
- Maximum producing rate: 700,000 barrels per day
- First production platform yield 125,000 barrels per day for 8 years.

Transportation

- Icebreaking shuttle tankers to ice-flee terminal

Support

- All facilities on platform
- Crew/resupply with shuttle tankers

Development Schedule

- Commercial exploration: 2,000-2,010
- Initial discovery: 2,010-2,020
- Develop initial field: 2,020-2,030
- Start production: 2,030-2,040

Note: The production rate for this hypothetical field is low compared with other world class fields. A high production rate would improve the resulting economics.

SOURCE: Office of Technology Assessment, 1989.

Hypothetical Development Technologies

Three basic development systems could be used in this scenario. The actual system used would depend mainly on the prevailing ice conditions at the field site. System A would be used if the field were located where only sea ice is present and large icebergs are rare. System B would be used in an area where large icebergs were more frequent, thus requiring disconnection of the surface platform from the wellheads. System C would be used on an ice shelf or on the ice capon land. In general, then, *'A' would be an appropriate system farthest out to sea (or where icebergs are a rare occurrence), "B" closer to the shoreline (or where large icebergs are more frequent), and "C' on permanent ice. The following briefly describes the features of the three possible systems.

System A

This would incorporate large floating systems and be used in deep water where very large icebergs were extremely rare. It would have disconnect features that would allow it to be located in areas where icebergs might be unusual. Further, such systems could be designed to withstand icebergs as large as 1 mile square and 300 feet thick. A number of such systems have been tested or proposed.[16,17,18,19] One is shown in figure A-3.

System B

This approach incorporates substantial subsea systems, including seafloor well heads with advanced control systems and two phase pumps that allow oil to be transferred long distances. The production and storage system would be located remotely in a floating vessel, on the seafloor, or on land. Figure A-4 shows a floating vessel with emergency disconnect features.

Seafloor oil storage systems would allow fields to be developed in regions where icebergs are abundant and would make unnecessary the use of permanent surface facilities above well heads, From storage, oil could be transferred to surface facilities located up to several hundred miles away in an iceberg-tie area. Access to well heads could be achieved during ice-free months from the surface above. Recent industry designs, proposals, and R&D on components needed to develop this system

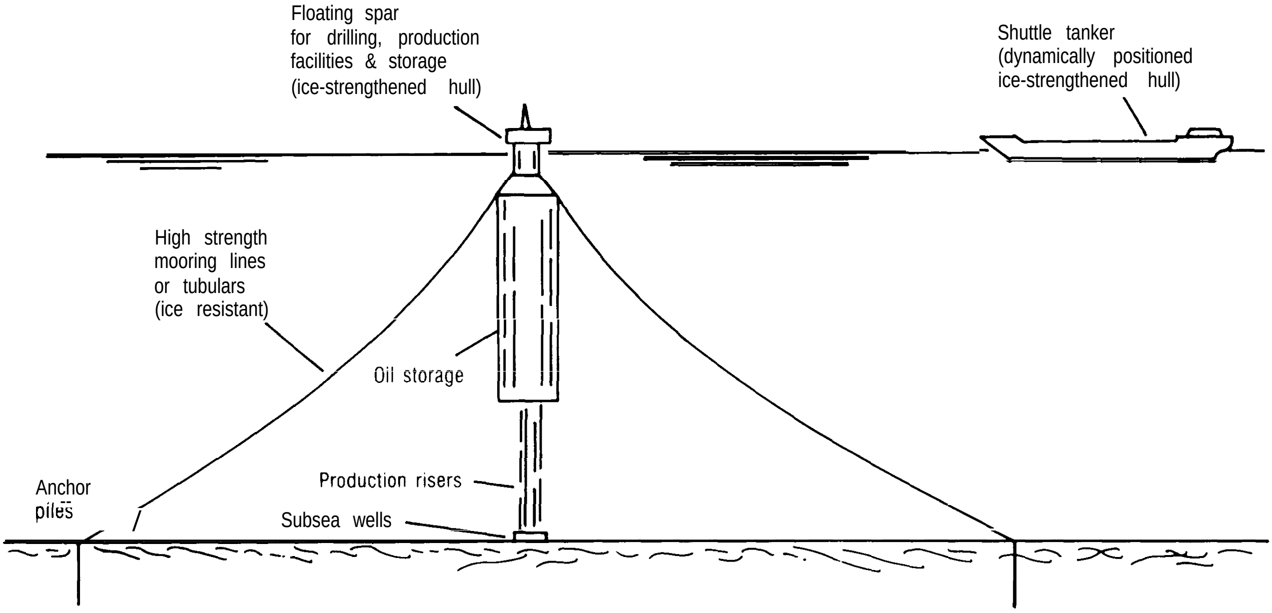
[16] G.D. Watson, S.P. Koch, and J.J. Every, 'Model Testing of a Deepwater SALM/Tanker System,'' *British Maritime Technology,* Offshore Technology Conference paper 5672, 1988, p. 505.

[17] R. Wilson, Cameron Iron Works Ltd., ''A Review of the Development of the SWOPS Subsea Production System,'' Offshore Technology Conference paper 5724, 1988, p. 373.

[18] J.E. Halkyard and T.L. Johnson, Arctec Offshore Corp; S. Hanna, Placid Oil co.; and L.C. Kwok, Arctec Offshore Corp; "A Summary of a Multi-Faceted Physical Model Test Program of a Floating Drilling and Production System,'' Offshore Technology Conference paper 5674, 1988, p. 523.

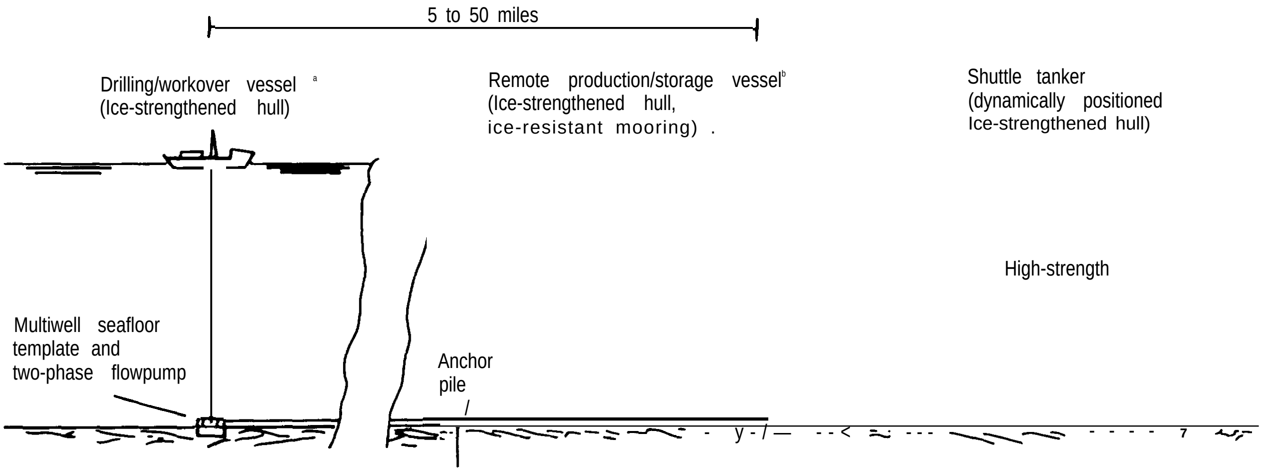
[19] R.J. Allan, Reading and Bates Drilling Co., "Integratd Motion, Stability, and Variable Load Design of the Trendsetter Class Semisubmersible Zane Barnes,'' Offshore Technology Conference paper 5625, 1988, p. 87.

Figure A-3-Antarctica Development System "A" (Iceberg-Free Region)



SOURCE: Deep Oil Technology, Inc., "Technology and Coet for Offshore Oil Development in Antarctica," OTA contractor report, November 1988.

Figure A-4-Antarctica Development System "B" (Iceberg Region)



[a] Vessel is on location only during drilling operations

[b] Other storage options Include seafloor storage or land storage

SOURCE: Deep Oil Technology, Inc., "Technology and Cost for Offshore Oil Development in Antarctica," OTA contractor report, November 1988.

provide a basis for projecting the availability of this technology.[20 21 22 23 24 25 26 27 28] If gas/oil mixtures could be pumped long distances and production complexes could operate effectively on the seafloor, a total production system could be built. The general problem of moving oil/gas mixtures long distances before processing is one the industry has been working on for a long time.

System C

From the ice shelf or on glacier ice covering the land mass (figure A-5), oil could be extracted through an open hole filled with heated water or another nonfreezing liquid. The well head would be located on the seafloor (or land) and connect by risers to the surface facility. The concept presumes that, where the ice is moving, the hole could be advanced by continuously melting the ice surrounding the risers to keep the surface facility positioned over the wellhead. The concept would use an approach similar to deepwater floating production platforms that are operating in many locations today.

System A would use mostly existing technology; system B would use existing technology and that currently under development. Its key components (subSea wells, multiphase pumps, seafloor separators, and reliable control systems and disconnect features) would be in use elsewhere before the year ***2020.*** System C is the most speculative, but appears feasible and could be investigated more closely once the characteristics of thick ice are better understood. Some R&D on this technology has already been done.[29]

The transportation portion of each of the above systems probably requires only a modification of existing technology or past designs.[30 31] Oil could be moved by tanker from Antarctica to ice-free land locations for shipment to markets in the Northern Hemisphere, Distances to ice-tie

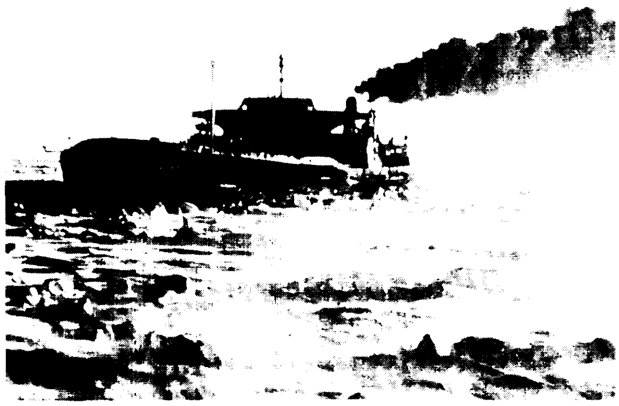


Photo Credit: *Exxon*

In 1969 the S.S. Manhatten tested the feasibility of transporting oil by ice-strengthened tanker through the Northwest Passage.

locations could range from 1,000 to ***2,000*** miles. Special icebreaking or ice-strengthened tankers and icebreakers would be used to transport oil to transfer terminals. From here the oil could be shipped to any location in the world. Pipelines could also be used to transfer oil from various points within Antarctica to loading points only along very selective routes. Hazards such as ice scouring and permafrost would have to be taken into consideration. If the hazards appeared substantial enough, new technologies might have to be developed.

An oil field in relatively deep, iceberg-free water, using System A, appears at present the most likely type of Antarctic oil field to be developed. Subsequent development, if any, might then move closer to the shoreline where icebergs would be more of a problem. Later,

[20] B. Darde and A. Lafaille, Total-CP; and P. Durando, Inst. Francais du Petrole, ''One-Megawatt Subsea Matable Electric Connector: Key to Multiphase Pump Drive Assembly—Now Field Proven,'' Offshore Technology Conference paper 5647, 1988, p. 263.

[21] M.P. Arnaudeau, Inst. Francais du Petrole, ''Development of a Two-phase Oil Pumping System for Evacuating Subsea Production Without Processing Over a Long Distance: Poseidon project,'' Offshore Technology Conference paper 5648, 1988, p. 271.

[22] H.A. Herwig and J.M. Cattanach, Ferranti Subsea Systems Ltd., ''Standardization of North Sea Multiplexed Control Systems for Ilvm-Assisted Developments,' Offshore Technology Conference paper 5670, 1988, p. 489.

[23] R.J. Emptage, Cameron Iron Works Ltd., ''A Review of the Satellite Production System (SPS) Ness Development,'' Offshore Technology Conference paper 5723, 1988, p. 367.

[24] K. Hogland, ABB-Atom Advanced Systems, and E. Nesse, Statoil A/S, ''A New Approach to Subsea Intervention,' Offshore Technology Conference paper 5728, 1988, p. 407.

[25] ''Offshore Production Without Platforms?'' *Offshore Incorporating The Oilman*, International Edition, vol. 48, No. 12, December 1988.

[26] ''Separating Separation From the Platform,'' *Offshore Incorporating The Oilman*, International Edition, vol. 48, No. 12, December 1988.

[27] 'Multiphase Pumps Delivered to Research Participants,'' *Offshore Incorporating the Oilman*, International Edition, vol. 48, No. 12, December 1988.

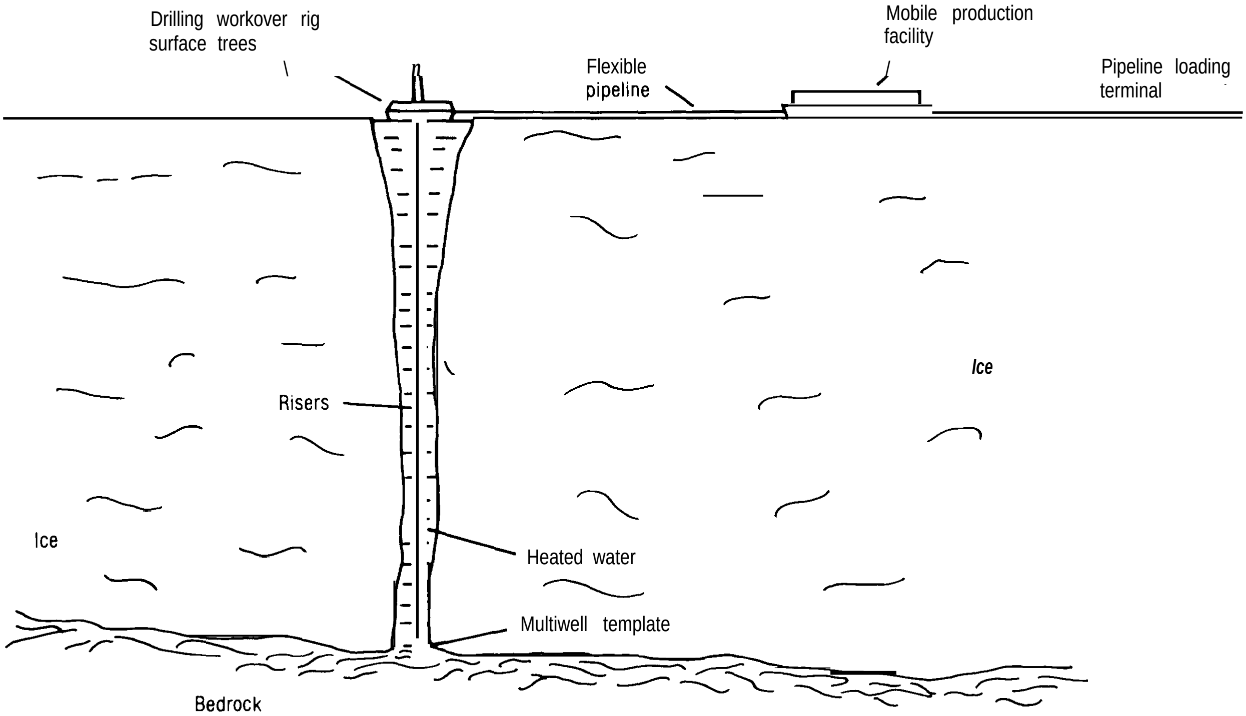
[28] K.J. Fardy, Gulf Canada Resources Ltd., and S.P. Singeetham, FMC Crop., Petroleum Equipment Group, ''Application of a Modified Subsea Wellhead System on Molikpaq, a Mobile Arctic Caisson Rig in the Canadian Beaufort Sea, Offshore Technology Conference paper 5790, 1988, p. 403.

[29] K.C. Kuivinen, Polar Ice Coring Office, University of Nebraska-Lincoln, ''Ice Drilling Technology,' paper presented at Polar Drilling Workshop, Byrd Polar Research center, The Ohio State University, Columbus, OH, Nov. 6-9, 1988.

[30] S. Gordin and D Sue-, , 'Field and Model Tests for Predicting the Icebreaking Resistance of the ARCO Arctic Tanker,' ' Arctic Oil Technology Conference, 1985.

3114~vel_ Of an Icebreak Tanker Trartsporration System for North Slope Alaskan Gas,' ' LNG Conference, Los Angeles, CA, 1986.

Figure A-5-Antarctica Development System "C" (Ice Shelf or Ice Cap)



SURCE: Deep Oil Technology, Inc., "Technology end Cost for Offshore Oil Development in Antarctica," OTA contractor report, November 1988.

drilling on the ice shelf or ice itself could be tested. Some experts, however, argue that a system mounted on the ice shelf, System C, could be the easiest to develop; more engineering studies are needed to verify this contention.

Though OTA'S most likely scenario presumes that oil development would start from seaward locations and move toward land, costs probably would change radically as developments move landward. Since it is also much more difficult to estimate costs for a hypothetical development with technologies yet-to-be tested, OTA has prepared cost estimates only for System A.

Obviously, accurate cost estimates for development of an Antarctic oil field cannot be made at present. Nevertheless, a general look at Antarctic oil production costs cart be instructive. The assumptions and resulting figures based on the System A approach can be supported by analogy to existing operations. Expert participants in an OTA workshop on oil and gas development potential considered the following cost estimates for System A reasonable. Some even considered the following estimates too high compared to present, similar operations. Experts consider the likely costs of production using Systems B or C to be much higher, but this may not be the case if more appropriate technologies are developed in the future.

System A (figure A-3) would produce the hypothetical 4-billion-barrel field in the Ross Sea, as described. Such an operation is comparable to the recently announced plans of Mobil Oil Canada Ltd. for the Hibernia field on the Grand Banks off Newfoundland. This harsh-environment field in iceberg-filled waters is planned to be built over the next few years. A large concrete gravity structure will hold the main production facilities. Three ice-strengthened shuttle tankers will transport oil to shore.

Hypothetical Development Economics

OTA prepared a brief analysis of costs and profitability of a System A operation using the above assumptions. The estimated cost of exploration, development, and transportation is given in table A-2. The analysis estimates the profitability of oil field development under various economic scenarios that might prevail in the

Table A-2--Cost Summary for Hypothetical Development of a 4-Billion-Barrei Field-(System A) (1886 Dollars)

Expenditures	$Billions
Capital costs:	
Exploration (geophysics and drilling)	1.4
Development (platforms/wells/facilities/drilling)	22.1
Transportation (tankers/terminals)	4.8
Total	28.3
Cost per recoverable barrel (approximate capital)	$7.00
Operating costs (annual):	
Production	1.8
Transportation	0.5
Total	2.3

NOTE: The above costs include delivery of produced oil to an cc-free terminal in southern South America. *Added* transportation costs to a major refinery would be comparable to that for transport from the Persian Gulf to U.S. refineries.

SOURCE: Office of Technology Assessment, 19S9.

future. The results and findings are illustrative rather than definitive. Many unverifiable assumptions about the presence of hydrocarbons and the cost of developing them had to be made, A conventional discounted cash flow model (employing a discount rate of 10 percent) was used to measure the profitability of hypothetical projects that might arise in Antarctica. It provides for an annual accounting of exploration, development, and production activities; and all associated expenditures, production flows, revenues, and tax payments for each year of a project's life.

Each project evaluated consists of an individual oil field. Project accounting allows for several dry holes prior to the discovery of a substantial oil deposit, extends throughout the field delineation, development and production stages, and ends when annual production has fallen to the point where continued extraction is unprofitable for the Operator (the economic limit). At that point the wells are plugged and the project is abandoned. The length of the project (in years) can vary depending on the size of the hypothetical deposit and the assumed level of oil prices.

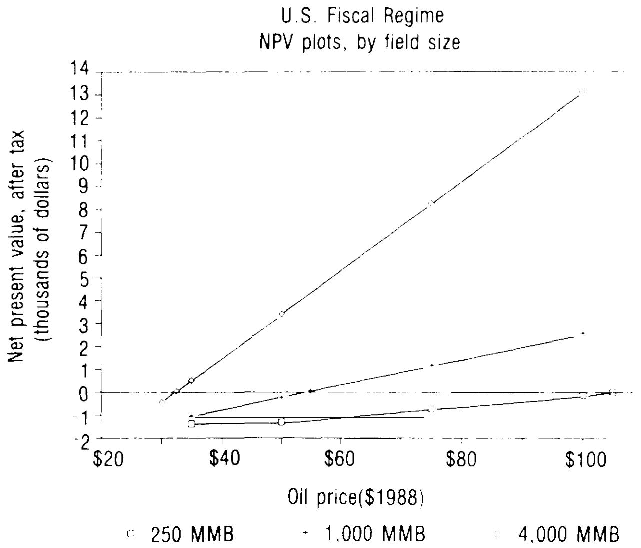
In order to evaluate the possible effect of field size on economics, three hypothetical oil deposits were evaluated, containing ***250,*** 1,000, and 4,000 million barrels of recoverable oil reserves respectively. The delineation and development programs reflect assumed individual physical characteristics of each field.

In addition to the above, model inputs include parameters that define the economic environment: world oil price, the Operator's discount rate (cost of capital), and tax rules that might pertain to future income and expenditures from Antarctic operations. The tax regime used is similar to that for offshore oil operations in the United States. The entire analysis uses constant 1988 dollars, so costs and oil prices are quoted in today's dollars, and the discount rate is measured in real terms. Subsequent inflation would affect the nominal levels of all these variables, but the net effects of these changes on profitability would largely cancel out.

The results of this modeling exercise indicate that large oil deposits (of world-class giant or larger size) could be developed in Antarctica if oil prices rise to at least double 1988 prices. Figure A-6 illustrates these results by plotting net present value (after tax) for the three field sizes in the scenarios modeled. **Only the 4-biliion-barrel supergiant field is profitable with an oil price about double the current price. The smaller fields require three to eight times current prices.**

The financial uncertainties are substantial. Will oil prices rise high enough and remain high enough to permit private operators to earn an adequate return on their investments? Box A-6 discusses four important caveats that could modify **the** results of this analysis,

Figure A-6--Oil Field Profitability



Net present value is plotted against a range of prices for three hypothetical oil fields. An oil field can be developed profitably if its net present value is greater than zero. Only the 4-billion-barrel supergiant field is profitable with an oil price about double the current price. Smaller fields would require much higher prices.

SOURCE J.L. Smith, "Profitability of Antarctic Oil Exploration and Development," OTA contractor report, December 1988.

Box A-6--Caveats

The following four caveats should be considered. They have important implications regarding the likelihood of petroleum development in Antarctica.

1. The presumed real discount rate in the analysis of 10 percent may be too low for companies contemplating large investments in highly speculative and risky projects. Although the 10 percent figure seems appropriate for investments being made in offshore petroleum provinces today, the hurdle rare for Antarctic investments could be significantly higher. The impact of higher discount rates would be to raise minimum economic prices and minimum economic field sizes, to lengthen the payback period, and to reduce the probability of substantial investments.
2. The analysis excludes the cost of most geological and seismic research that must be incurred prior to the discovery of a significant oil field. It is understood that the prospective profitability of ultimate discoveries must offset these front-end costs before sizable investments will be made in the Antarctic. Due to the long lead times that separate these early exploration costs from ultimate revenues, and the high carrying costs associated with these capital expenditures, it is safe to assume that the expectation of highly profitable oil fields will be necessary to stimulate any exploration in the Antarctic.
3. All timing assumptions (see table 2) are highly speculative, but very influential in the calculation of the profitability of individual fields. The prospect of lengthy certification or environmental permit procedures at each step will discourage private operators from attempting the process at all. Since certification and permitting procedures pertaining to Antarctica are not yet in place, it is difficult to judge the reasonableness of the time lags assumed, However, actual time lines could easily be longer.
4. The estimated cost of infrastucture in the model assumes that a single field must bear the full cost of gathering lines, transshipment terminals, and specially equipped tankers. In reality, some of these costs could be shared among several fields that might be discovered in the same area. Satellite fields, therefore, might have a lower hurdle to clear if initial discoveries cause the industry to put *some* common infrastructure in place.

OTA's analysis indicates that **the potential of Antarctic oil versus other alternatives cannot be determined with current knowledge.** Oil **from** Antarctica might *be* more or less expensive to develop than that from the Chukchi Sea or tar sands, heavy oil or oil shale, and other options. The costs to develop a particular Antarctic field will of course depend on its size, quality, and location. Some fields might be relatively inexpensive to develop, whereas others may be prohibitively expensive; the same is true for the unconventional deposits elsewhere in the world. Predictions of the costs to develop alternatives have often errored on the low side, because development costs themselves are tied to the price of oil and because proponents have portrayed their proposals in the best light.

In view of these arguments, what is the likely future for Antarctic oil development? **OTA's best guess-and it is only a guess-is that supergiant fields of 4 billion barrels or more could be developed in Antarctica by 2020 or thereabouts if such fields exist and can be found and *if* the constraints in the Minerals Convention can be overcome by a major international Operator assisted by a supportive Sponsor.**

SUMMARY

Commercial development of Antarctic oil reserves could be feasible in the next century but only if several optimistic assumptions prove out, These include technological advances; sustained, relatively high oil prices; and a reduction in excess OPEC production capacity that currently depresses the world oil market. It will also require the presence and discovery of large oil deposits, an expeditious process for resolving environmental and operating policies, and sensible and measured taxation of Antarctic oil revenues.

OTA concludes that if any one of these assumptions do not hold, oil development in Antarctica will not occur. **Under the most favorable assumptions, commercial oil development appears unlikely before three decades hence.** Early success in a concerted exploration campaign could also be critical to viable, later development.