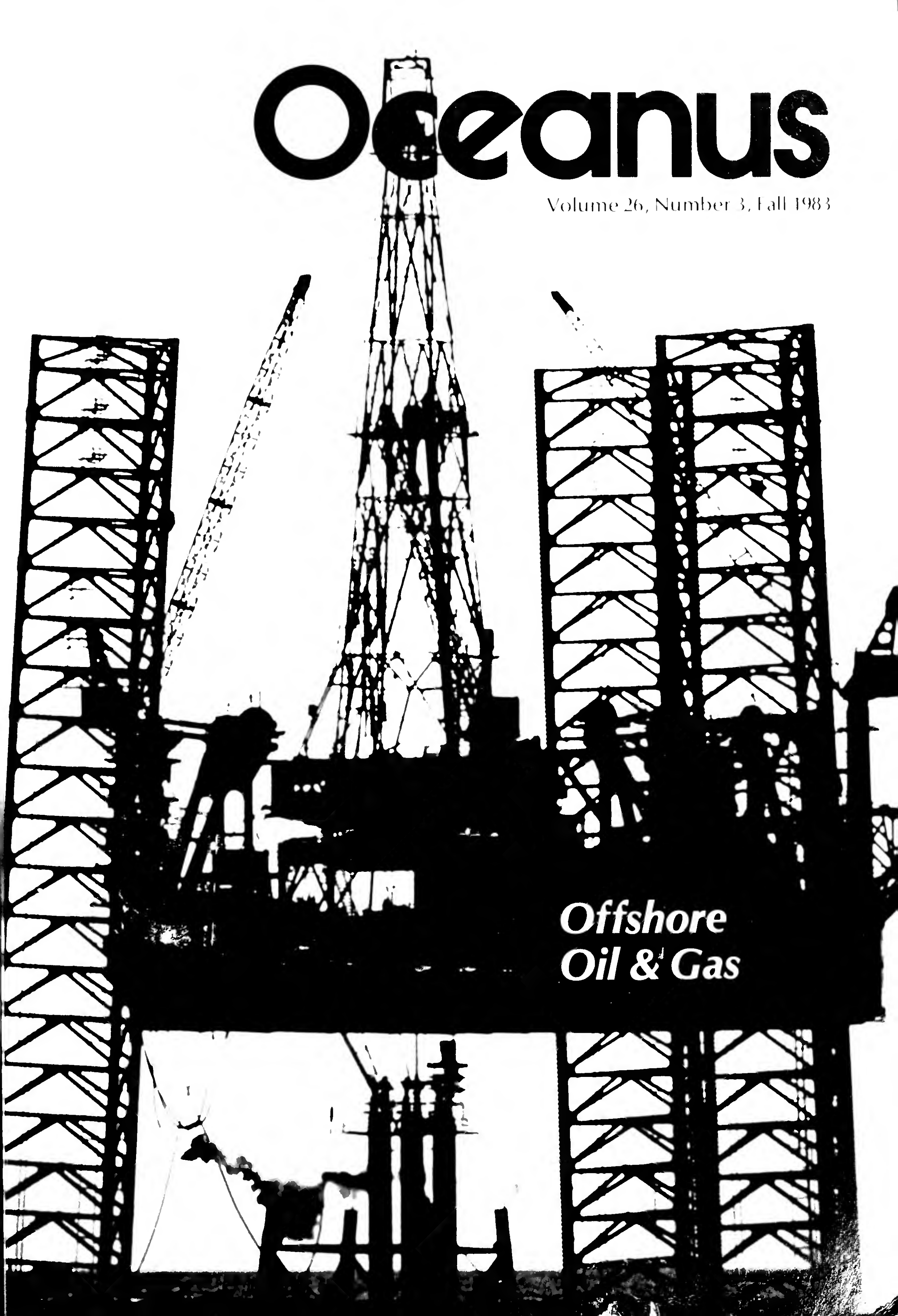
Oceanus
Volume 26, Number 3, Fall 1983
Offshore
Oil & Gas

Oceanus®

The Magazine of Marine Science and Policy
Volume 26, Number 3, Fall 1983

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Oil platform off Spain. Photo by Daniele Pellegrini, PR. Back Cover: Offshore roustabout, Madagorda Bay, Texas. Photo by Don Getsug, PR.

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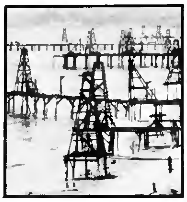
contents



profile

concerns

letters

books & films

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comment

Concerns about the potential effects of oil and gas exploration activities on Georges Bank — one of the most productive commercial fisheries areas in the world — led to the initiation of the Georges Bank Monitoring Program (GBMP) in July, 1981, when drilling first began on the Bank. The first eight exploratory wells drilled on Georges Bank were completed by May, 1982. All were classified as dry holes. We now have the results of the first year of monitoring, and, although eight wells are considered a minimal observational test, there were no biological changes in the benthic community that could be attributed to drilling activity.

The GBMP was designed to address the concerns related to the initial exploratory phase of Georges Bank development. Specifically, the objectives of the program are to "determine the fate of discharges (primarily drilling fluids and cuttings) from exploratory drilling platforms in Lease Area 42 and to assess the effects of these discharges on benthic species and communities on Georges Bank and potential depositional areas for drilling fluids and cuttings in submarine canyons and the Outer Continental Shelf south of eastern New England."

The first offering of lease tracts for exploratory drilling on Georges Bank (Lease Sale 42) took place in December, 1979. In this offering a total of 63 blocks on the Bank were leased by major oil companies or consortia. Two additional lease offerings are scheduled for the North Atlantic Outer Continental Shelf (OCS), including portions of Georges Bank — Lease Sale 52 (south-central and southwest portion of the bank) and the North Atlantic Lease Offering, set for February, 1984 (which includes the remainder of the Bank as well as areas in deeper water, exceeding 2,000 meters).

The major portion of the monitoring program — established by the Minerals Management Service of the Department of the Interior under the recommendations of the Biological Task Force for OCS Lease Sale 42 — is being performed by Battelle New England Marine Research Laboratory and the Woods Hole Oceanographic Institution. This research addresses the question of whether populations of animals living in the bottom sediments (benthic infauna) change in selected regions of Georges Bank and elsewhere during various stages of oil and gas exploration. It also questions whether these changes can be related to observed changes in the concentrations of pollutants discharged from exploratory platforms.

A recently released preliminary report — covering the first year of infauna monitoring (783 taxa of benthic invertebrates identified of which 40 percent were polychaetes) — concluded that no biological impacts from drilling activities could be detected at the 46 stations established on or adjacent to the Bank.

In a separate study, conducted by the U.S. Geological Survey (USGS), barium, a major element in drilling muds, was found in high concentrations at several stations near a drilling rig and in decreasing quantities as distance from the rig increased. Interestingly, 29 of the 46 biological stations were near this rig. Postdrilling concentrations of barium were found to be within the range of predrilling concentrations measured at other locations on the Bank. Concentrations of other metals measured were low and characteristic of unpolluted coarse-grain sediment in other Continental Shelf areas. A high level of lead was found at one station, but it was attributed to the use of tetraethyl lead in gasoline, which began in 1924. The station affected is downwind of the industrialized northeastern United States, and is considered a chronic sink for various pollutants.

The preliminary Benthic Infauna Report recommended that biological and chemical sampling continue at those stations where elevated concentrations of barium were detected. It also urged that sampling be continued at all stations in order to establish normal seasonal patterns of population fluctuations. The GBMP initially was conceived as a three-year program.

* * *

The results of another monitoring program that will be of interest to readers of this issue have recently been published. They concern the fate of *Amoco Cadiz* oil. The supertanker, after losing steerage in the western English Channel, fetched up on rocks during extremely stormy weather near the small French fishing village of Portsall, Brittany, on March 16, 1978. During the next two weeks, the entire cargo of light Arabian and Iranian crude oils and a small amount of bunker C fuel, totaling 223,000 metric tons, was lost to the rough channel waters.

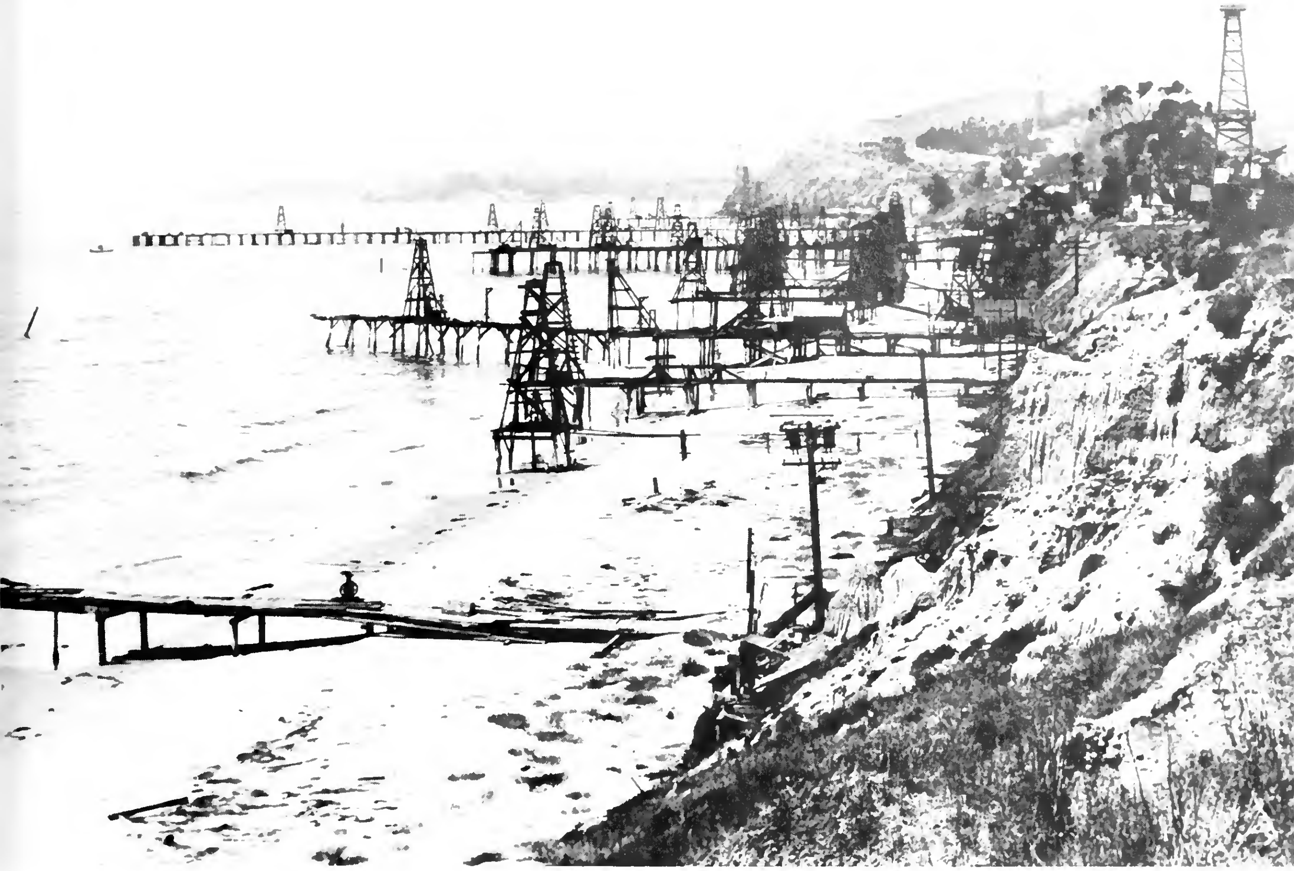
The *Amoco Cadiz* is the largest tanker spill on record. In a recent article in *Science* magazine, Erich R. Grundlach, a Senior Scientist with the Research Planning Institute in Columbia, South Carolina, along with a number of colleagues, synthesizes the extensive data on the physical-chemical fate of the spilled oil during the three years after the spill.

Grundlach and his colleagues concluded that, of the total oil lost by the tanker, 30,000 tons (13.5 percent) rapidly became incorporated in the water column, 18,000 tons (8 percent) were deposited in subtidal sediments, 62,000 tons (28 percent) washed into the intertidal zone, and 67,000 tons (30 percent) evaporated. While at sea, it was estimated that 10,000 tons of oil were degraded microbiologically.

The main conclusion drawn from the study was that, after three years, "most of the obvious effects of the spill have passed, although hydrocarbon concentrations remain elevated in those estuaries and marshes that were initially most heavily oiled."

Of the 62,000 tons of oil that came ashore, 25,000 tons were collected by thousands of cleanup workers. Six weeks after the spill only 10,000 tons remained; the most efficient cleansing agents were believed to be waves, tidal action, and microbial action. Periodic sampling of sediment in several nearby bays indicated that almost all of the oil contamination was gone within 18 months.

Paul R. Ryan



Among the first wells drilled over water are these in the Summerland field, California. Just south of Santa Barbara, this 100-acre field produced from a depth of 210 feet. The photo was taken circa 1920. (Courtesy of World Oil)

Introduction:

Offshore Oil and Gas — *Past, Present, and Future*

by John M. Hunt

The first offshore petroleum production was from extensions of existing oil fields that were discovered along the coastlines of lakes, inland seas, and oceans. Around 1897, piers were extended seaward from the coast of Santa Barbara, California, to support wells drilled in a field bordering the coast. At the same time, piled wooden trestles were being extended into the Caspian Sea from Russia's prolific coastal oil fields at Baku. In 1911, Gulf Refining built a cypress platform in Caddo Lake, Louisiana, to support a steam-driven rotary drilling rig. By 1923, piled wooden platforms were being built all along the east coast of Lake Maracaibo, Venezuela, and in the lake and marsh areas of Louisiana. Submerged barges also were used widely as drilling platforms in Louisiana, Lake Maracaibo, and the Caspian Sea. Most of these activities were in water depths of less than 25 feet.

The first completely offshore well was drilled in 1937 by the Superior and Pure Oil companies one mile off the coast of Cameron Parish, Louisiana. At the end of the next decade the Kerr-McGee Oil Company was drilling and producing oil out of sight of land in Ship Shoal Block 32 off Louisiana. By 1953, Congress had defined the ownership of United States offshore areas, and the first leases in the Gulf of Mexico were issued the following year.

During the late 1950s, drilling ships and platforms were cutting holes under water depths of more than 200 feet. By 1968, the water depths exceeded 1,000 feet. Then, in January of 1983, the drill ship *Discoverer Seven Seas* drilled a well in 5,264 feet of water, completing it at a sediment depth of 6,165 feet, in the Mediterranean Sea. Today, drilling ships can work in 10,000 feet (3,000 meters) of water.

The depths referred to previously are for conventional drilling, in which a riser system is used to circulate drilling mud and rock cuttings from the bottom of the hole up to the rig floor. In the standard riser system, a drill pipe with the rock drill mounted on the end is lowered inside a larger pipe called the riser, which extends into the seafloor. Clean drilling mud is pumped down the center of the drill pipe and out through the drill bit at the bottom of the hole. It picks up the rock cuttings that have been broken off by the bit and carries them up through the annular space between the drill pipe and the outer riser. At the surface, the mud and cuttings pass through a screen, separating the cuttings from the mud, which returns down the center of the drill pipe. Beside the drill and riser pipes, there is a third, larger-diameter pipe, called the casing, which is cemented approximately 100 feet into the seafloor to receive the drill and riser. It contains several valves in a Christmas-tree-like arrangement that can be closed by remote control. This safety feature operates when the drill encounters a deep high-pressure zone that might otherwise blow the entire string of drill pipe out of the hole.

When a hole is drilled into sedimentary rock, the pressure at the bottom of the hole normally is equal to the pressure of a column of water of the same height. Oil and gas, however, are frequently found in overpressured rocks; that is, rocks in which the pressure is one-and-a-half to two times that of a column of water. To prevent blowouts, the driller makes the drilling mud very heavy by adding barium sulfate, a powder that is heavier than cement powder. If the mud is too heavy, however, it will prevent the discovery of an oil or gas zone by pushing the hydrocarbons back into the formation so that they are not seen in the circulating mud. Consequently, the driller monitors a narrow line by keeping the mud weight slightly above the pressure at the bottom of the hole. If a sudden high pressure begins to lift the entire drill pipe, the gauge measuring the weight of the drill string will move to zero. The driller must instantly clamp shut the Christmas-tree valves and increase the weight of the mud.

In the infamous Santa Barbara oil spill of 1969, the valves were closed instantly when high pressure was encountered. The pressure was so great, however, that oil and mud broke through the unconsolidated Pleistocene sediment outside the outer well casing. Once outside the casing, there was nothing to control its movement to the surface. Today, a preventive measure is taken in dangerous high-pressure areas to avoid such spills. The outer casing is extended beyond the normal 100 feet, several hundred feet into the sediment.

The drilling ship *Glomar Challenger* of the Deep Sea Drilling Project (DSDP) has drilled holes in water depths of 23,000 feet. However, these are open holes, with no riser systems, no casings, and no means of shutting off a blowout. Seawater is pumped down through the drill pipe, after which it comes out

Lagunillas field in Lake Maracaibo, Venezuela, circa 1930. This project was the model for offshore-technology development. (Photo by C. C. McDermond/World Oil)

Breakout of Oil, Gas Supply Under the National Energy Policy Program

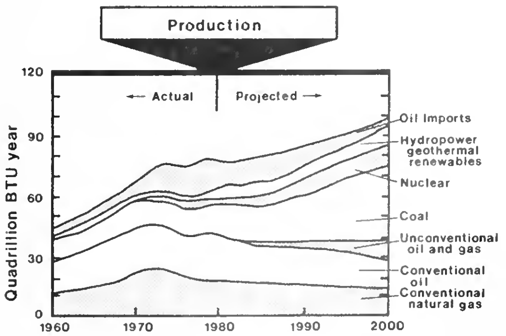
	1980 Actual	1985 Midrange (Projected, Million b/d)	1985 Range	1990 Midrange	1990 Range	2000 Midrange	2000 Range
Oil Production							
Conventional oil*	8.6	7.6	7.2-8.2	7	6.3-8.2	6.0	4.8-8.0
Enhanced oil†		0.2	0.1-0.4	0.6	0.4-1.0	1.8	1.4-2.4
Shale oil				0.2	0.1-0.4	1.1	0.6-1.6
Liquid natural gas	1.5	1.3	1.2-1.4	1.1	1.0-1.2	0.7	0.6-0.8
Subtotal	10.1	9.1		8.9		9.6	
Ranges§			8.6-9.8		8.1-10.2		8.3-11.7
Synthetic coal liquids				0.2	0.1-0.4	1.1	0.6-1.7
Production subtotal	10.1	9.1		9.1		10.7	
Ranges§			8.6-9.8		8.3-10.4		9.4-12.8
Refinery gain	0.5	0.5	0.4-0.5	0.5	0.4-0.6	0.4	0.3-0.6
Net imports¶	6.3	6.3	4.7-8.5	4.8	1.9-7.1	1.2	0-5.2
Total supply	16.9	15.9		14.4		12.3	
Gas Production		Trillion cu ft/year					
Conventional Lower 48*	19.3	17.3	16.3-18.9	16.3	13.6-18.4	13.6	10.5-16.9
North Alaska				0.8	0.7-0.9	0.8	0.7-0.9
Subtotal	19.3	17.3	16.3-18.9	17.1	14.3-19.3	14.4	11.2-17.8
Unconventional√		0.4	0.3-0.5	1.3	1-1.6	3.2	2-5
Subtotal	19.3	17.7		18.4		17.6	
Ranges§			16.7-19.3		15.6-20.6		14.4-21
Gas synthetics∝	0.2	0.2	0.1-0.3	0.5	0.3-0.6	1.4	1-2
Total domestic production	19.5	17.9		18.9		19	
Ranges§			16.9-19.5		16.1-21.1		15.8-22.4
Net imports	1	2	1-3	2	1-3	2	1-3
Total supply	20.5	19.9		20.9		21	

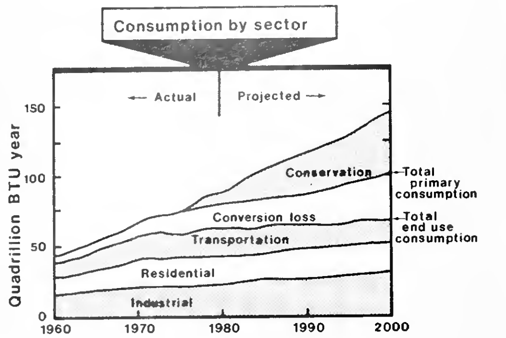
***Includes South Alaska production of about 200,000 b/d in 1980, increasing to 400,000 b/d by 2000, and North Alaska production of 1.5 million b/d in 1980 and 1.8 million b/d in 2000. †Incremental tertiary production. California heavy oil currently produced with thermal recovery techniques included under conventional Lower 48. §Ranges on totals don't equal the sum of ranges for each category because of the low likelihood that all categories would simultaneously equal their low or high value. ¶Net U.S. oil imports, excluding Strategic Petroleum Reserve and imports by U.S. territories. □Includes South Alaska production of about 200 billion cu ft/year in 1980, increasing to 500 billion cu ft/year by 2000. √Incremental production from tight sands, Devonian shale, coal bed methane, and geopressurized methane. Tight sands production from previously developed areas (900 billion cu ft in 1980). Included under conventional Lower 48. ∝Synthetic gas from oil and coal.**
Source: Department of Energy.

of the hole back into the ocean. The rock is cored rather than broken up into small cuttings. The cores are periodically pulled up through the center of the drill pipe and stored on the ship. The few cuttings obtained when the drill is not coring are swept out of the hole onto the seafloor.

No Limit

There is really no limit to the water depth in which an open hole can be drilled. There is a limit with conventional drilling, due to the tension on the riser system and the weight of the drill string. Imagine that you have a plastic straw extending from the top of the Empire State Building to the ground. Now you rotate the straw. It will twist and stretch, undergoing a considerable amount of stress. The weight of a mile-long drill pipe, plus riser, puts tremendous stress on the supporting rig, even though this is partially offset by the buoyant effect of water. It is not possible to use extremely heavy mud in deep-water drilling because there is no side support for the pipe. Inside the hole, however, the surrounding rock wall will prevent the collapse of the pipe. The heavy mud is what actually prevents high-pressure formations from blowing out. On land, the mud may weigh 18 pounds per gallon. Offshore, in thousands of feet of water, drillers may be limited to less than 10-pounds-per-gallon mud density unless several thousand feet of sediments are penetrated. This is why shallow high-pressure zones are particularly dangerous





Production and consumption under Reagan's National Energy Policy Plan (NEPP). Shaded area in consumption graph represents savings projected for conservation strategies; total end-use consumption does not include such losses as occur during production and processing. (IPE/Department of Energy)

offshore and require fail-safe systems for blowout prevention on the ocean floor, as well as casing extending deeper into the sediment.

In the last decade, oil-drilling technology advanced tremendously. But offshore blowouts are still a problem due to factors of human error — equipment failure and incompetent rig supervision. That latter factor is less critical today in the United States, since the government has become an "offshore watchdog" and industry recognizes the tremendous cost involved in oil spills. Unfortunately, in many foreign countries errors in rig operation and skimping on equipment continue to result in periodic blowouts.

Why is the drilling industry moving offshore? Because that is where the oil is. Oil is frequently trapped in anticlinal structures, which are like giant inverted saucers in the subsurface. In many countries the big anticlines on land have been drilled, but not those offshore. In 1951, the Arabian-American Oil Company drilled into a giant anticline off the shore of Saudi Arabia and discovered the Safaniya Field. Safaniya is the largest known offshore oil accumulation in the world, with recoverable reserves exceeding 25 billion barrels. For 25 years after it was discovered, this single field had more oil in it than the offshore reserves of the United States and Canada combined.

In the late 1950s, the Soviets discovered oil in an anticline in the center of the Caspian Sea. Soon, a series of wells were being constructed there, on trestles anchored in shallow water, on top of a subsurface mountain range.

Mexican geologists have identified more than 200 undrilled structures in the Gulf of Campeche alone, which may contain oil. In 1981, the Mexicans discovered 15 new oil fields, increasing their known offshore reserves to 34 billion barrels of oil and oil-equivalent gas. The Egyptians have discovered 2.5 billion barrels of oil in the Gulf of Suez by drilling fewer than 100 exploration wells into buried anticlines there. Offshore drilling in the late 1950s was confined to fewer than a dozen countries, but today active exploration is going on in the offshore areas of more than 60 countries. Nearly 40 of these presently produce oil and gas. Most recently, a major field was discovered in the Santa Barbara Channel off California.

Enormous Potential

Worldwide, the offshore potential for oil and gas is still enormous, since only a few percent of the prospective areas have been drilled. This is not due to a lack of deep-sea drilling equipment. Drilling engineers have invented a variety of drilling platforms, drill ships, subsea completion assemblies, service islands, and underwater storage tanks. Even building and servicing large underwater pipelines is routine. If you are looking for a special Christmas present for that rich uncle who has everything, for about $150 million you can buy a 500-foot, self-propelled, semisubmersible pipeline vessel that can install 20-inch pipelines in water 2,000 feet deep.

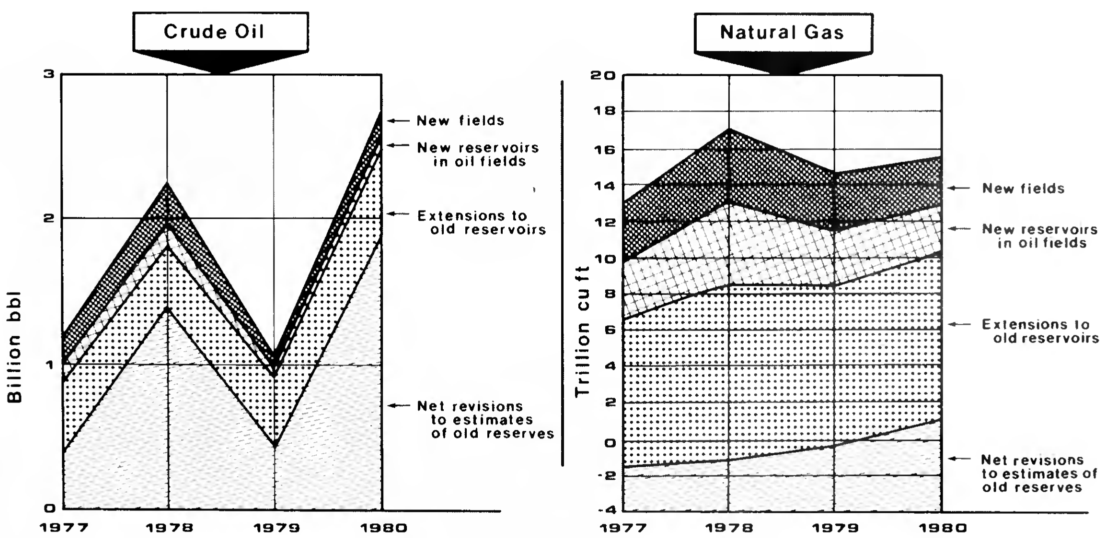
The relatively slow pace of offshore drilling, compared to that onshore, is not due to slowness in development of the technology but rather to economic, political, and environmental factors. The wells drilled on piers offshore from Santa Barbara at the turn of the century cost about $600 each, at the producing depth of 210 feet. Today, that amount of money would not even pay for the drilling permits. Offshore drilling is no longer a business for entrepreneurs. The $5 million to $15 million cost of a typical offshore "wildcat" is too much for even a major oil company to risk. Consequently, most wells are drilled by a consortium of two or more major companies.

The high exploration costs are only the beginning. If oil and gas are discovered, then the cost of a large permanent drilling platform suitable for drilling several slanted holes, plus a pipeline to carry the petroleum to shore, must be figured in. The result is that a 2,000-barrel-a-day well that would be a bonanza onshore can be uneconomic offshore. The objective of exploration is to drill as few wells as possible to estimate the total volume of recoverable oil. The estimate is then used to determine whether or not a pipeline is economically feasible. Proximity to a market is also considered. In many countries, huge volumes of the gas produced with oil are burned off continuously because there is no means of transporting the gas to a market. In some cases,

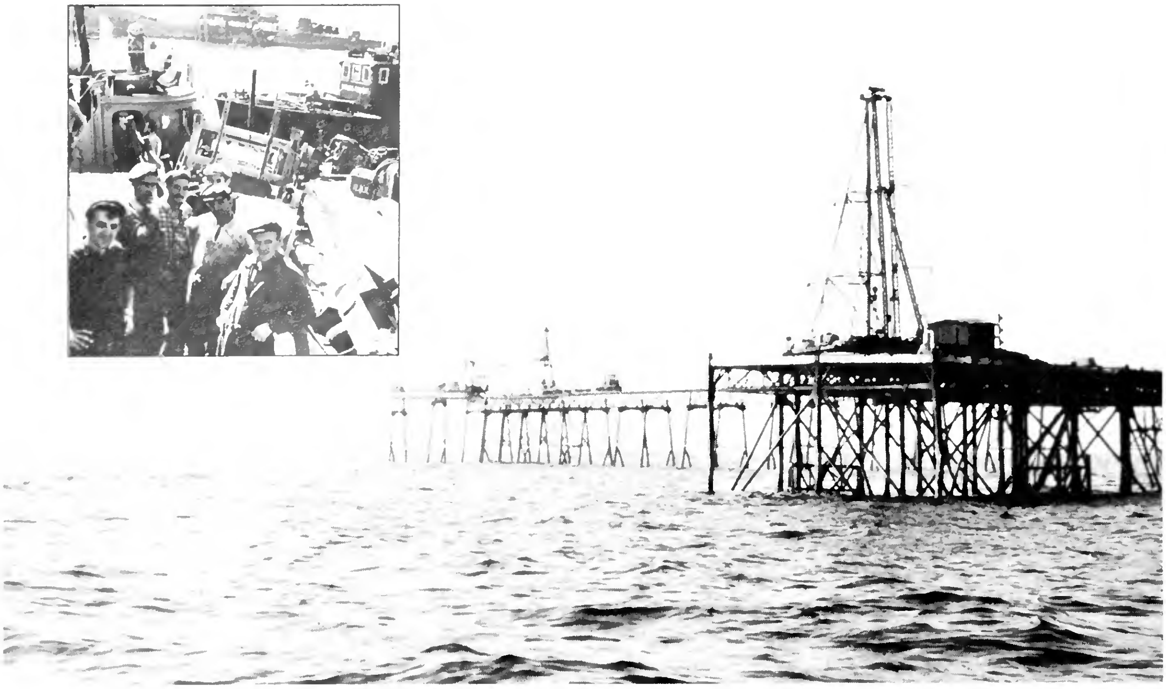
What's Ahead for U.S. Energy Prices Under the National Energy Policy Program

	Estimated 1980	Projected 1985 Midrange	1985 Range	1990 Midrange	1990 Range	2000 Midrange	2000 Range
World oil price ($/bbl)†	37	44	37-50	52	41-66	70	50-95
Resource prices							
Refined crude oil ($/bbl)	30.65	44	37.40-50	52	41.68	70	50-95
Average wellhead gas price ($/Mcf)	1.64	5.84	4.80-6.10	6.69	5.50-8.50	8.38	6.70-9.80
Average minemouth coal price ($/ton)	27.59	31.76	30.70-34.90	33.42	32.90-38.20	38.45	34.80-45.30
Delivered prices							
Residential sector							
Distillates ($/gal)	1.07	1.42	1.20-1.60	1.64	1.30-2.20	2.14	1.50-2.90
Liquid gases ($/gal)	0.63	0.85	0.60-1.10	0.98	0.70-1.40	1.27	0.80-2.00
Natural gas ($/Mcf)	4.30	7.54	6.60-8.80	8.97	7.40-11.10	10.70	8.70-12.40
Electricity (¢/kw-hr)	5.89	6.07	5.70-6.30	6.79	6.20-7.40	7.78	6.90-8.50
Commercial sector							
Distillate ($/gal)	0.96	1.30	1.10-1.50	1.51	1.20-2	1.98	1.40-2.70
Residual ($/bbl)	29.67	47.32	37-58.10	55.49	40.30-78.10	73.82	48.70-108.30
Liquid gases ($/gal)	0.62	0.84	0.60-1.10	0.97	0.70-1.40	1.28	0.80-2
Natural gas ($/Mcf)	3.51	7.60	6.50-8.50	8.65	7.10-10.80	10.39	8.40-12.10
Electricity (¢/kw-hr)	6.02	6.35	6.10-6.50	7.13	6.70-7.60	8.26	7.70-8.70
Industrial sector							
Distillate ($/gal)	0.95	1.28	1.10-1.15	1.48	1.20-2	1.93	1.40-2.70
Residual ($/bbl)	29.67	45.77	35.20-57	53.64	38.40-76.50	71.24	46.30-106
Liquid gases ($/gal)	0.62	0.84	0.60-1.10	0.97	0.70-1.40	1.28	0.80-2
Natural gas ($/Mcf)	2.90	7.10	6.10-8	8.15	6.70-10.20	9.91	8-11.60
Coal ($/ton)	41.03	42.90	30.90-56.70	46.34	33.50-63.50	52.72	35.40-73.20
Electricity (¢/kw-hr)	4.06	4.47	4.20-4.70	5.19	4.60-5.70	6.14	5.30-6.90
Transportation sector							
Gasoline ($/gal)	1.34	1.65	1.40-2	1.84	1.40-2.50	2.26	1.60-3.20
Distillate ($/gal)§	0.96	1.44	1.10-1.60	1.67	1.20-1.90	2.19	1.40-2.50
Residual ($/bbl)	29.67	45.77	35.20-57	53.64	38.40-76.50	71.24	46.30-106
Jet fuel ($/gal)§	0.99	1.33	1-1.60	1.56	1.10-2.20	2.08	1.40-3.10

*In 1981 dollars, 1981 dollars assumed to equal 1.009 times 1980 dollars. †U.S. average refiner acquisition cost of imported crude oil.
§Excludes taxes.
Source: Department of Energy.



Additions to U.S. oil and gas reserves. Revised estimates of reserves account for nearly twice the total of extensions and new discoveries. [From International Petroleum Encyclopedia, 1982, *(IPE)*]



The Russians have been drilling the Caspian Sea's prolific fields for more than 80 years. Inset shows workers at port city of Baku. (Photo by author)

the gas is reinjected into the oil field in order to maintain pressures to force the oil out. Some countries build petrochemical plants to convert the gas to industrial products.

Politics has been the major impediment to increased offshore drilling. Some Third World countries try to do their own offshore drilling, but it usually goes forward at a snail's pace because of graft and incompetence among bureaucrats. The sharp rise of oil prices in the 1970s caused many of these countries to begin offshore leasing on favorable terms in order to attract experienced oil-finders. Politics also has caused considerable confusion about offshore boundaries, which are discussed in more detail in Hollis Hedberg's article on page 9.

Environmental Concern

The third factor that has slowed offshore drilling has been environmental concern for the world's oceans. There is no doubt that oil spills in coastal waters can do considerable damage to marine life. The open oceans, however, have been subject to oil "spills" via natural seeps and fractures in the earth's surface for millions of years (see the article by Robert Spies on page 24). Fortunately, weathering processes break down this oil in a reasonable period of time. Several articles in this issue discuss the environmental implications of offshore drilling. In 1978, due to the Carter Administration's perception that we would not rely on oil in the future, only 4,000 square miles of the outer continental shelf of the United States were leased for drilling. At that rate, it would take 450 years to explore the 1.8 million square miles of prospective offshore areas of the United States. At the end of 1982, more than 40 percent of the offshore acreage of foreign countries was under lease or concession, whereas less than 5 percent of the U.S. offshore acreage was leased. These areas may hold the oil and gas for our energy needs in the next century.

How much petroleum is out beyond the coastlines? At present, the world's known offshore reserves total more than 200 billion barrels of oil or gas equivalent, which is more than a fifth of the world's total hydrocarbon reserves. There is a significant difference, however, in that onshore reserves comprise literally thousands of small fields, whereas more than 80 percent of the offshore reserves are in giant fields, containing 500 million barrels of oil or gas equivalent per field.

Undiscovered petroleum resources on the continents and continental shelves of the world are currently estimated to be around 3 trillion barrels. More than half of this is probably on the continental shelves, with additional unknown quantities under the continental slopes and rises. Despite the economic, political, and environmental problems, it is still cheaper to produce oil from giant offshore fields than from asphalt sands or oil shales.

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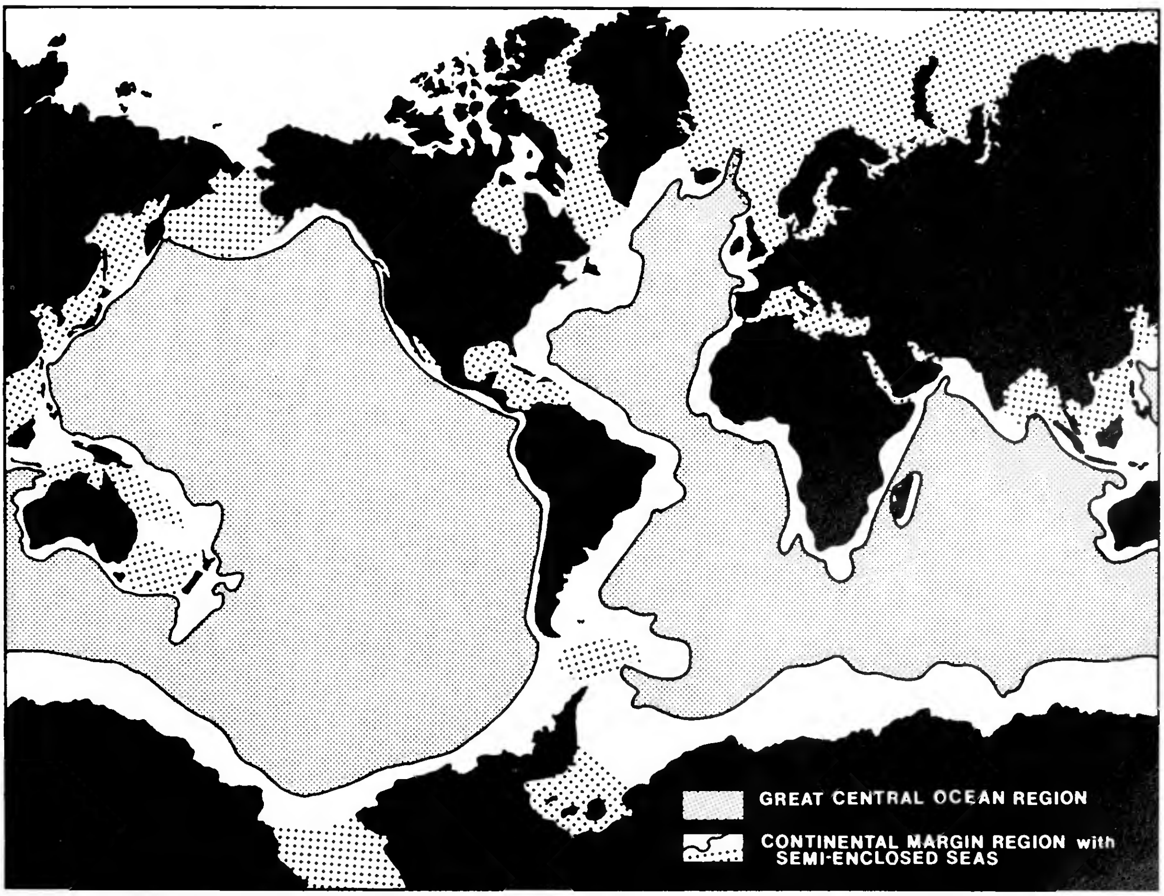
by Hollis D. Hedberg

Presently about 25 percent of the world's oil production and about 18 percent of its gas production come from offshore waters. However, practically no gas or oil yet comes from the *very deep* waters offshore, which constitute more than 80 percent of the world's total ocean and sea area.

"Deep water" is, of course, a subjective term. Thirty years ago, 50 meters was considered deep water in which to drill. Now, thousands of wells have been drilled in waters 100 meters deep and far beyond. We even have active production platforms in waters more than 300 meters deep: Shell's Cognac platform in the Gulf of Mexico (312.5 meters), and many exploratory wells drilled in 500 to 1,000 meters of water. We now know that not only the continental shelves but the moderately deep water of the upper parts of the slopes of our oceans and seas are richly promising for oil production.

In keeping with our growing familiarity with drilling and producing operations at great depths, we should, perhaps, reserve the expression "very deep water" for depths of 1,000 meters or more. In such areas, we have produced no petroleum to date and have acquired only meager direct drilling information on the petroleum potential of this vast portion of the total marine realm.

Although the words oceans and seas are often used interchangeably, for the purposes of this article, the former is defined as the Atlantic, the Pacific, the Indian, the Arctic, and the Antarctic, and



Division of world oceans from author's conception.

the latter as smaller enclosed or semi-enclosed bodies of water, numbering 40 or more, that are part of the continental margins. In considering various aspects of the petroleum prospects of the deep marine waters of the world, it is useful to distinguish between the *major oceans* and the *marginal seas*.

Records of Very-Deep-Water Drilling

Most of the geological data on very-deep-water regions come from the nearly 600 sites drilled in water depths of more than 1,000 meters by the *Glomar Challenger*. During the invaluable Deep Sea Drilling Project (DSDP) programs of the last 14 years, the *Glomar Challenger* has worked in almost all the oceans and seas of the world, doing geological, geophysical, and geochemical research. The deepest water in which the *Challenger* drilled was 7,044 meters in the Mariana Trench, and the deepest penetration beneath the ocean floor was 1,741 meters at a site in the eastern North Atlantic.

While the DSDP program has been concerned primarily with the advancement of knowledge of the rocks below the oceans and seas, much of the information gathered — stratigraphy, structure, regional geology of the sediments and, more specifically, source and reservoir character, organic carbon content, maturation status, and even direct occurrences of oil, gas, and methane hydrates — has been pertinent to the petroleum development of the world's offshore areas. However, it must be recognized that the DSDP sites were not places selected to evaluate the prospects for commercial exploitation of petroleum in deep waters. Rather, the sites were selected to *avoid* encountering oil or gas because the *Challenger* was not equipped to handle the hazards posed by oil flows and gas blowouts.

To date, only a few industry holes have been drilled in waters deeper than 1,000 meters with the specific objective of looking for commercially useful oil and gas. These holes are listed in Table 1.

Apparently, none of these industry holes can be considered potential producers. However, for initial holes in new drilling regions, such results cannot be considered discouraging; rarely do the first wells in any new region achieve production.

Requisites for Petroleum Accumulations

Several factors are frequently outlined as requisites for petroleum accumulations. Present depth of water is not in itself one of these controlling factors. Though many of the very-deep-water depositional environments on the seafloor may be unfavorable to formation of either source or reservoir petroleum deposits, it is important to remember that older underlying sediments in many of these same areas may have been deposited under quite different and more favorable conditions.

The first requirement for petroleum accumulation is a rich source of organic matter, and conditions favorable for its preservation. It appears that the bulk of the petroleum used today was created by geothermal alteration of carbonaceous matter derived from the remains of plants and animals that were incorporated in sediments. Depending on the original nature of the organic matter, different gaseous or liquid petroleums may have formed. The time required for genesis varies for different organic constituents, and the original organic matter may be more or less consumed in the process.

For source rock to be considered potentially effective as an oil producer, a minimum of 0.5

Table 1. Petroleum industry holes drilled in water depths more than 1,000 meters.

Year	Country	Company & Well Name	Water Depth
1976	Thailand	Esso — W9-E-1	1,055 m.
1977	Spain	Eniepsa — An1	1,151 m.
1978	Congo	Getty	1,325 m.
	French Guinea	Esso — FG 2-1	1,250 m.
	Surinam	Esso — A 2-1	1,160 m.
	Spain	Hispanoil, Eniepsa	1,144 m.
1979	Canada	Texaco, Shell, et al. — Blue	1,486 m.
	Spain	Eniepsa — Cabriel B-24	1,399 m.
	Spain	Getty, Grumete — C-1X	1,353 m.
	Australia	Esso Australia — Zeewulf-1	1,195 m.
	Australia	Phillips — Mercury 1X	1,142 m.
	Canada	Esso Res. — EVG C-60	1,108 m.
	Australia	Esso Australia — Resol.-1	1,087 m.
	Surinam	Elf, Shell, Eurafrep — A21	1,201 m.
1980	Britain, Rockall Trough	BNOC — 163/6-1	1,374 m.
	Australia	Esso Australia — Vinck-1	1,373 m.
	Australia	Esso Aust. — N.W. Shelf	1,373 m.
	Australia	Esso Aust. — Exmouth Plat.	1,363 m.
	Australia	Esso Aust. — E. Exmouth Plat.	1,183 m.
	Australia	Phillips — Exmouth Plat.	1,178 m.
	Australia	Esso Aust. — Sirius-1	1,173 m.
	Mauritania	Hispanoil — Ras al Baida A1	1,119 m.
1981	Australia	Phillips — Exmouth, Saturn 1X	1,177 m.
1982	Spain	Getty, Tarragona, Grumete — F-1X	1,067 m.
	France	Total, Elf, Esso — GLP-1	1,715 m.
1983	France	Total, Elf, Esso — GLP-2 (proposed)	1,200 m.
	United States	Shell — Atlantic coast (proposed)	2,073 m.

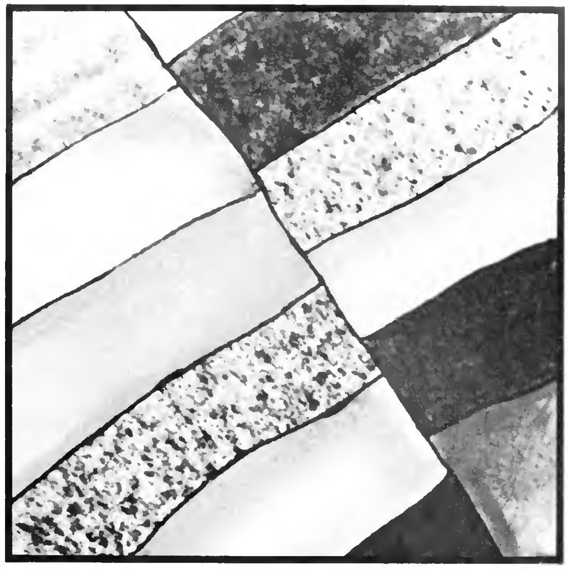
percent of organic carbon by weight is commonly considered necessary. Less organic carbon may remain in rock that has gone beyond the maturation stage, and oil, once formed, may have become gas or been completely dissipated by "overcooking" (too much thermal alteration, such that the rock has become incipiently metamorphosed). Substantial accumulations of methane gas often may have had a near-surface bacterial origin, not related to either depth of burial or temperature. Moreover, petroleum found in a given area may have had its source beds in some other area and have since migrated to its present location; conversely, the source beds in a given area may have lost, via migration to another area, the petroleum they generated.

A second requisite is a "blanket" of sediment overlying the source rock to create sufficiently high temperatures to convert organic matter to fluid petroleum. Most petroleum, other than biogenic methane, is generated thermochemically via the heat of the earth. The depth below the surface at which a petroleum source rock must be buried to attain sufficient temperature for rapid petroleum generation depends on both the geothermal gradient* of the area and the character of the organic matter. Length of time of exposure to generating temperatures is also a critical factor.

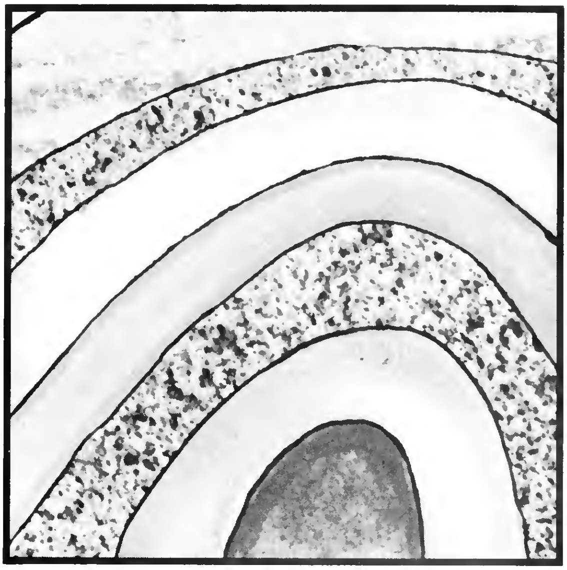
The existence of favorable conditions for expulsion of petroleum from source rock and for migration to porous and permeable "reservoir" rocks is a third general requisite. How oil and gas escape from relatively impermeable shales or other organic-rich sediments, and in what form and manner they travel to reservoir rocks, is still one of the least understood processes of oil and gas accumulation. Does oil move from its place of genesis as completely formed oil, or as various individual hydrocarbon components (precursors of oil) in solution in water or gas? Does some movement take place by diffusion or by other means, or by a combination of means at different stages? These questions still provoke controversy. Likewise, the energy source for its movement — buoyancy, compaction pressure, internal pressure due to gas genesis, clay mineral changes, aquathermal pressuring, osmosis, molecular diffusion — is controversial, and may well be various combinations of forces at different stages.

The routes followed by fluids escaping from fine-grained source rock and migrating to more permeable channels (for example, sandstones, conglomerates, permeable carbonates, fracture zones) may be intergranular, along microfractures, or by some other way or combinations of ways. The direction of escape may be upward, downward, or lateral, depending on which affords the readiest relief of pressure. The ultimate commercial reservoirs may be sandstones, conglomerates, porous carbonates, fractured cherts, weathered unconformity zones, and the like.

*The rate of increase of temperature in the Earth as a function of depth.



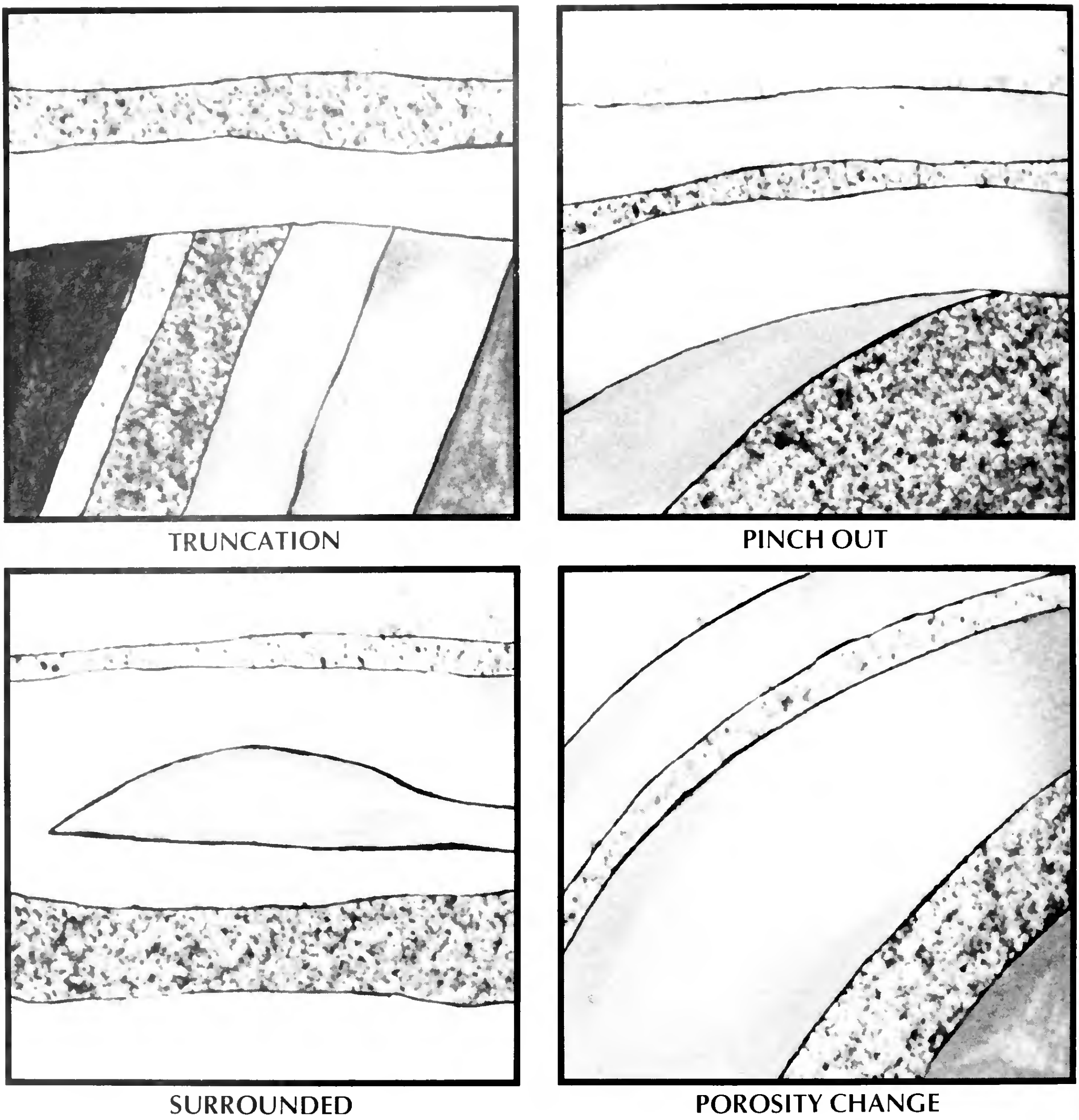
FAULT TRAP



ANTICLINAL TRAP

Two types of structural traps. Top: Reservoir rock (third layer from top on left) is surrounded by impermeable rock, preventing further migration of the petroleum. Bottom: Petroleum migrated into the upper part of the fold, or anticline, (fourth arch from bottom) and trapped beneath impermeable rock layer. (Provided by Petroleum Extension Service, University of Texas at Austin)

A fourth general requirement for substantial petroleum accumulation is to have accumulation *traps*. These may be structural, stratigraphic, or both, and of infinite variety. Adequate sealing or cover rocks are necessary if the traps are to persist. Some traps are effectively sealed for oil and not for gas, and others for heavy oil only. Among the best seals or cover rocks are shales, evaporites, methane hydrate zones, and some fault zones.



Four examples of stratigraphic traps. Top left: Inclined petroleum-bearing rock (bottom horizontal layer) is cut off by horizontal rock layer. Top right: Triangular formation (at bottom left) is pinched off gradually. Bottom left: Porous, permeable reservoir bed (center) surrounded by impermeable rock. Bottom right: Change in porosity and permeability of reservoir (large center section) leaves upper portion of reservoir (slightly shaded) impermeable. (Provided by Petroleum Extension Service, University of Texas at Austin)

A common fallacy confuses the sediment thickness needed for maturation of source rock with the much lesser thickness needed to provide sealed reservoirs to trap migrating petroleum. Many of the world's great production sites, now largely depleted, were at relatively shallow depths, where oil had migrated from deeper source rocks. Even the great Burgan field of Kuwait, because of petroleum migration, produces oil from only 900 to 1,200 meters below the surface at reservoir temperatures no higher than those of a fine summer day in Kuwait!

Finally, proper timing or sequencing of the essentials just enumerated is necessary for petroleum accumulations to occur. The best of traps, if formed after petroleum genesis and migration out of an area, will be barren. Traps exposed to post-accumulation erosion may now be empty. Rich potential source rock in which the organic matter has not yet matured into oil are of no use to us today, and source/reservoir couples that once were good but have been "overcooked" will now, at most, yield only gas, and may yield nothing at all.

Petroleum Potential of Very-Deep-Water Regions

The *great central ocean region,* constituting 77 percent of the world's total marine area, is almost entirely covered by very deep water. The *continental margins,* which lie between the central ocean region and the continental shelves, rapidly reach depths oceanward of greater than 1,000 meters. Some of the greatest water depths known in the oceans are found in the marginal trenches. The *semi-enclosed seas* of the continental margins are of quite variable maximum water depth, some never reaching more than 1,000 meters, others attaining more than 4,000 meters in their central abyssal parts.

The prospects for finding petroleum accumulations in the very deep waters of these three types of regions are as follows:

Great central ocean region. Geological prospects of petroleum accumulations in the sediments of the very deep waters of the central ocean region are generally unfavorable because of thinness of sediments, low organic carbon content, scarcity of reservoir beds, and the nearly horizontal attitude of most strata (impeding lateral migration and accumulation). Sediment thicknesses are generally less than 500 meters and reservoir sands are generally absent, or thin and of poor quality. Of 334 DSDP sites drilled in this region only two showed any direct indications of petroleum — and these, methane gas only. However, the central ocean region does have some interesting local deep-water prospects, mostly near the margins, including methane hydrate accumulations and widespread Cretaceous period (about 100 million years ago) black shale horizons.

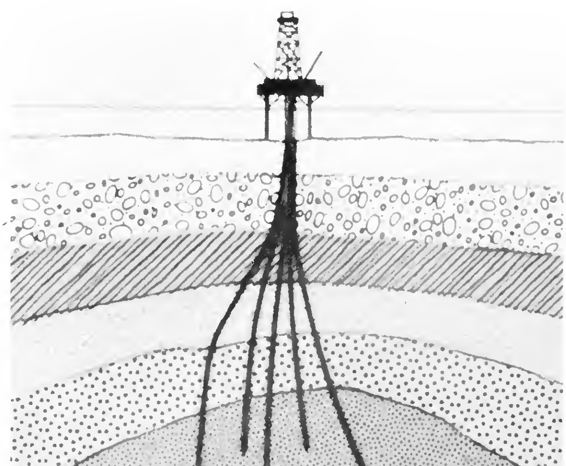
Continental margin region. This region has a diversity of features of interest to petroleum prospectors: marginal geosynclines, outer margin aprons, marginal plateau blocks, marginal trench fillings, continent-related deep-water fans, transmarginal ridges, unconformities, overlaps, and pinchouts.* There is no reason to suppose that favorable effects of such features on petroleum accumulation should cease just because the overlying water column has deepened. The continental margin region favors petroleum accumulation by virtue of thickness of sediments, presence of source rocks, reservoirs, and sealing rocks, a good probability of traps, and a generally eventful history of structure and sedimentation. Fifty-two of the 140 continental margin sites drilled to date as part of the DSDP have yielded evidence of hydrocarbons, even though the locations were chosen to avoid petroleum traps.

*The wedging out of a stratum; commonly used in connection with the wedging out updip of a sand layer into a shale to form a stratigraphic trap for petroleum accumulation.

Semi-enclosed seas of the continental margin. The restricted seas of the continental margin, of which about 40 have been recognized, are among the best prospective areas in the world for petroleum. Proximity to land and large rivers has provided them with thick layers of sediment with relatively rich accumulations of both terrestrial and marine organic matter, even in their central parts. Their restricted nature favors limited circulation and preservation of organic matter, as the result of reducing conditions on the bottom, or because of rapid burial by sediments. Favorable reservoirs are to be expected in sediments of deltaic, turbidity-current, or reef origin. They are generally situated in tectonically mobile environments, where fold and fault structures and repeated unconformities are common. The restricted character of marginal seas also has favored the formation of sealing evaporites, and many are already known to be characterized by diapiric structures.*

The borders and shelves of many of these semi-enclosed seas are already the sites of abundant petroleum production (such as the Gulf of Mexico, Persian Gulf, Caribbean Sea, Mediterranean Sea, Caspian Sea, and the North Sea). The very-deep-water central portions of these same basins also may hold abundant petroleum accumulations. A recent study of the

*A domal or anticlinal structure in which the overlying rocks have been ruptured and the core has been squeezed out; common in evaporites, shales, and other plastic rocks.



Directional drilling is often used to produce several wells from a single offshore platform without moving the equipment. (Provided by Petroleum Extension Service, University of Texas at Austin) central part of the Gulf of Mexico by the United States Geological Survey (USGS) estimates that there are 22 billion barrels of oil in place in some 152,000 square kilometers of the central Gulf. More than 75 percent of this area lies under water depths exceeding 3,000 meters.

Of 101 DSDP sites in semi-enclosed marginal seas for which organic carbon determinations are available, 58 had organic carbon concentrations, at least locally, of more than 0.5 percent and 29 had indications of oil, gas, or methane hydrates.

Drilling in Very Deep Water

Though we stress that present depth of water at a site is in no way an indicator of the prospects of petroleum accumulation there, the influence of water depth is quite another story when it comes to actually finding petroleum and producing it. Only a few years ago, the prospect of drilling wells and producing petroleum in water thousands of meters deep seemed only an idle dream. Today, as noted earlier, we not only have actively producing platforms in as much as 312 meters of water, but have drilled nearly 30 exploratory wells for oil at more than 1,000 meters water depth. A glance at the trade magazines these days shows the oceans filled with an amazing and bizarre assortment of huge, strange creations — drillships, barges, jackups, submersibles, and semi-submersibles — for offshore drilling. Of these, many are designed for drilling in deep or very deep water. The drilling industry has steadily and rapidly increased the water-depth range of its capabilities and equipment. As to what the limits are, the attitude seems to be, "If there's enough oil there, we'll find a way to get it."

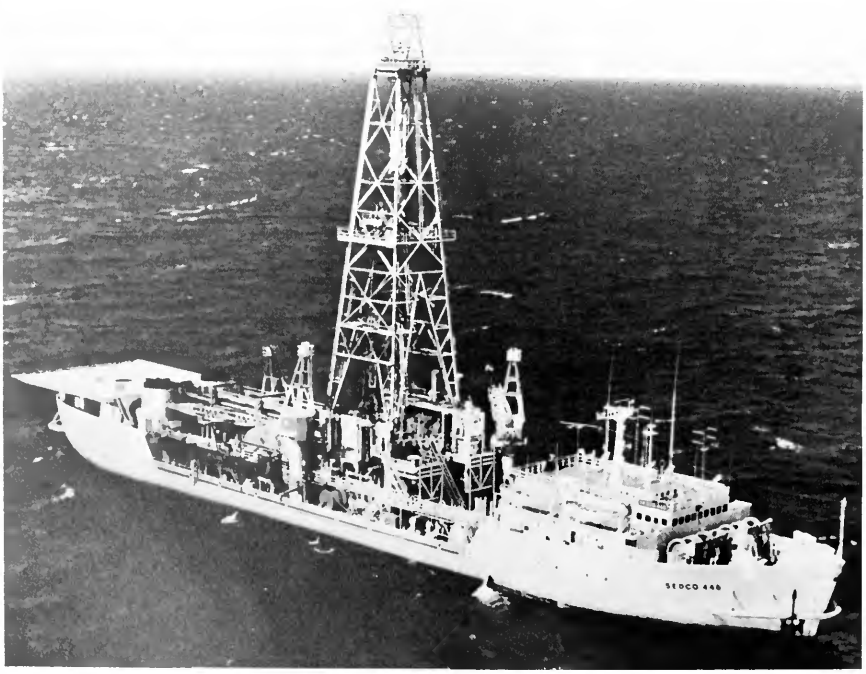
The costs will be enormous indeed, because of the problems of deep water, the remoteness from land bases of some of the more promising very-deep-water sites, and the hazards of weather, currents, and ice that must be faced. As an example of costs, it is estimated that the two-well program of Total-Elf-Esso at depths of 1,200 meters in the Gulf of Lyon in the Mediterranean Sea will require an expenditure of about $100 million. Shell and partners will likely spend between $30 million and $50 million to drill a well in 2,073 meters off the Atlantic coast of the United States, 120 miles southeast of Atlantic City.

Obviously, with costs and problems such as those envisaged, no one will drill in very deep water for minor accumulation targets. Only prospects of major, prolifically productive fields will justify the needed investments. But there is no reason to doubt that such prospects exist.

Problems With the Law of the Sea

Serious obstacles to exploration and development of petroleum prospects in the very deep waters of the world's oceans and seas may emerge unless the Law of the Sea (LOS) Convention is drastically modified. Several of its provisions — such as the creation of boundaries between coastal states and international jurisdiction over mineral resources — appear ill-advised.

The Law of the Sea Treaty, as presently proposed, fails to provide a sound and definite basis for drawing the limit between coastal-state and international jurisdiction over mineral resources along the outer edge of the continental margin where it extends more than 200 nautical miles from shore. In effect, this uncertainty means that



The Sedco 445, among the most experienced deep-water drillships in the world. (Courtesy of Sedco) exploration will be deterred over large areas of the continental margin. There are two formulas for determining boundaries allowed by the Law: the first is based on the impracticable measure of the thickness of sediments as a function of distance from the foot of the slope; the second involves the difficulty of drawing directly a precise base-of-slope boundary, with no provision for a guiding, internationally approved *boundary zone* within which each coastal state could establish its own precise boundary.

No oil company is going to risk the huge amount of money required for a well in these very deep waters without clear demarkation of a national boundary. Hence, the region affected by the dubious boundary — which may be many thousands of square miles in area and commercially significant — becomes valuable to no one.

A reasonable boundary formula, outlined long ago, would give coastal states jurisdiction over mineral resources out to the approximate foot of the continental (or insular) slope, plus an oceanward-adjacent boundary zone of a uniform width (to allow for uncertainties in fixing the exact position of the foot of the slope), within which each state would establish a precise boundary. This coastal-state jurisdictional area would exist in addition to the Exclusive Economic Zone (EEZ) proposed in the Law, which grants coastal states jurisdiction over both living and mineral resources out to a distance of 200 nautical miles beyond the base line from which the territorial sea is measured. President Reagan declared a 200-mile EEZ for the United States on March 10 of this year, after having decided last year that the United States would not become a party to the LOS treaty.

The Law of the Sea Convention fails to live up to its implicit promise to give to coastal nations jurisdiction over the mineral resources of the entire continental margin. Instead, it assigns to an International Authority the central parts of some of the potentially richest petroleum areas of the continental margin — the central parts of some of the semi-enclosed marginal seas, such as the Gulf of Mexico, the Barents Sea, and the Bering Sea. A more equitable arrangement would be to divide jurisdiction over mineral resources in semi-enclosed seas, which are properly part of the continental margins, among bordering countries. Each bordering state should control the shelf and slope adjacent to its shore; the entire central area beyond the base of the slope would be divided equitably among them.

The treatment of islands in the Law of the Sea Convention is also defective. Shelf/slope islands are properly assigned jurisdiction out to the base of the continental slope on which their mother country stands; improperly the Convention also gives them the double benefit of claiming such additional areas as lie within 200 nautical miles of their shores, whether or not this extends their territory beyond the base of the slope. Island dependencies situated on the continental shelves or slopes of semi-enclosed seas within the continental margin should not control territory beyond the foot of the shelf/slope platform on which they stand. The mother countries should not be allowed to use such islands to claim jurisdiction beyond the continental slopes of semi-enclosed marginal seas.

West of the Pribilof Islands in the Bering Sea, the United States should not claim a 200-nautical-mile jurisdiction zone extending beyond the normal limits of the outer edge of the Bering Sea margin into the very deep water of the central Bering Sea, on the basis of these islands. The United States, as a bordering nation, should receive an appropriate share in the very deep water of the whole central Bering Sea on the principle of an equitable division of the central deep-water area of marginal semi-enclosed seas. Similarly, Mexico should not claim a 200-nautical-mile jurisdiction zone extending north beyond the foot of its slope into the very deep water of the central Gulf of Mexico on the basis of small reef islets near the outer edge of its shelf. Instead, Mexico should receive its appropriate share of the deep central part of the Gulf of Mexico under a standard provision for equitable division of the central portions of the semi-enclosed seas in their entireties among the bordering nations.

One could point out many other defects with respect to boundaries in the Law of the Sea Convention (in articles 76, 121, and 123, and elsewhere), and in such counterproductive provisions as royalty penalties on costly production from the very deep waters of the central ocean region, where penalties are least appropriate. Hopefully, these defects can be remedied before the treaty is fully ratified. The matter of jurisdiction over the very-deep-water continental margins is pivotal. These concerns may seem unimportant now, but, inevitably, they will assume greater importance as technology continues to make these regions more accessible and petroleum reserves dwindle. The issues should be addressed now, while there is still time.

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Early example of seismographic exploration in the Gulf of Mexico, involving sonic measurement of underwater explosions. (Fritz Henle/Photo Researchers, Inc.)

Although the last two decades have seen major advancements in marine geological and geophysical research, a reorientation of research directions is now in order.

The 1950s and 1960s were periods when new techniques were developed to explore the ocean floor and what lies beneath it. These techniques were utilized in a massive exploration of oceanic geology. Large quantities of data were obtained. The late 1960s and 1970s saw the utilization of these data in developing the theory of plate tectonics: a major step in understanding the geology of the earth was achieved. This marked a change in research emphasis — from data gathering to synthesis, from technological innovation to development of elaborate models.

Synthesis and modeling are, of course, important, but the point has been reached where further progress will come from new observations based on new techniques and experiments rather than from synthesis of existing observations. Experiments have to be conducted not simply to choose between existing models, but to obtain new information in areas not fully explored or with precision not available earlier. These, in the serendipitous way that science often moves, will lead to the development of new models rather than testing of old ones.

"Passive" Continental Margins

Perhaps nowhere is the need for new experiments and information more acute than in the study of continental margins. It is important to explore the "passive" continental margins, such as the margin off the East Coast of the United States, because these margins mark the sites of the initial breakup that led to the separation of America from Europe and Africa.

A major obstacle to understanding these areas is the presence of a very thick deposit of sediments over the crust, formed about 190 million years ago during the first opening, and hiding what went on at this very important time in earth's history.

One of the principal tools used to explore the geology of the continental margins is seismology. Sound waves produced by explosions or other sources of sound travel into the earth and on their return, by reflection or refraction, are observed by sensitive detectors. Older seismic methods simply do not work too well in these areas, at least in part because the seismic waves are seriously attenuated and scattered by the thick cover of sediments, which weakens and distorts the seismic "image" of the subsurface.

Some new seismic techniques have been developed recently, which borrow technology from industry and theory from university researchers. These techniques are enabling us to explore deeper into the earth and with much greater precision than was possible with the older seismic methods. But these techniques, which require high-quality equipment for data acquisition and processing, are too expensive to be routinely employed by the academic community. Major advances in marine geology and geophysics will depend on new technology, but lack of money is presenting the most potent deterrent to growth in this field.

One way for university researchers to obtain more money is to team up with industry to explore areas of common interest, such as the passive margins. In addition to the possibility of new experiments, a cooperative effort might make existing seismic data that industry has obtained on the continental shelves available to academic institutions. These data, though obtained by industry for prospecting for hydrocarbons, could be of immense help in solving regional geologic-research problems. At present, academic institutions are able to obtain these data only by buying them at high prices.

New Seismic Techniques

The seismic reflection common-depth-point technique is the method most used by industry for prospecting on continental margins. With some modifications, this method could deliver better information about deep geological structures and properties of rocks. Such information is valuable in both industrial and academic research. The common-depth-point technique is shown in Figure 1. With this method, a ship carrying a source of sound (which is "fired" at constant, specified intervals) tows a streamer, typically about 3,000 meters long. The streamer carries sound detectors grouped in a number of "active sections." The sound reflected from the boundaries of subsurface rock layers is received at the active sections; by recording and displaying these signals appropriately subsurface rock layers can be imaged.

One can see (Figure 1, bottom left) that reflections from the same subsurface point can be received at each of the active sections (only three are shown here — typically there are 36 or 48) provided the sound that originated at the proper "shot point" is selected. If the sound signals at each of the active sections are added together, the combined signal will be appreciably greater than if a single active section had received the reflected sound.

One important detail has to be kept in mind before the sound signals at the different active sections can be summed. As Figure 1 (bottom left) shows, the paths traveled by the sound to the various active sections are different. Correspondingly, the time required for the reflections to arrive at the different active sections varies (Figure 1, top right). A correction, known as the moveout correction, must be applied before the sound signals are added together.

The moveout correction depends on the speed of sound in the subsurface-rock layers. Since this is not known beforehand, it is determined by trial and error in such a way that the totaled reflection signals yield the maximum value. This procedure, by enhancing the reflected signal, makes it easier to detect poorly defined rock-layer boundaries and also determines the speed of sound in these layers, which gives important clues about the nature and composition of the subsurface rocks.

It also is reasonable to expect that as the streamer is increased in length, deeper and less-well-defined layer boundaries will be detected, since more seismic signals at a greater number of active sections will be summed up. Moveout will be

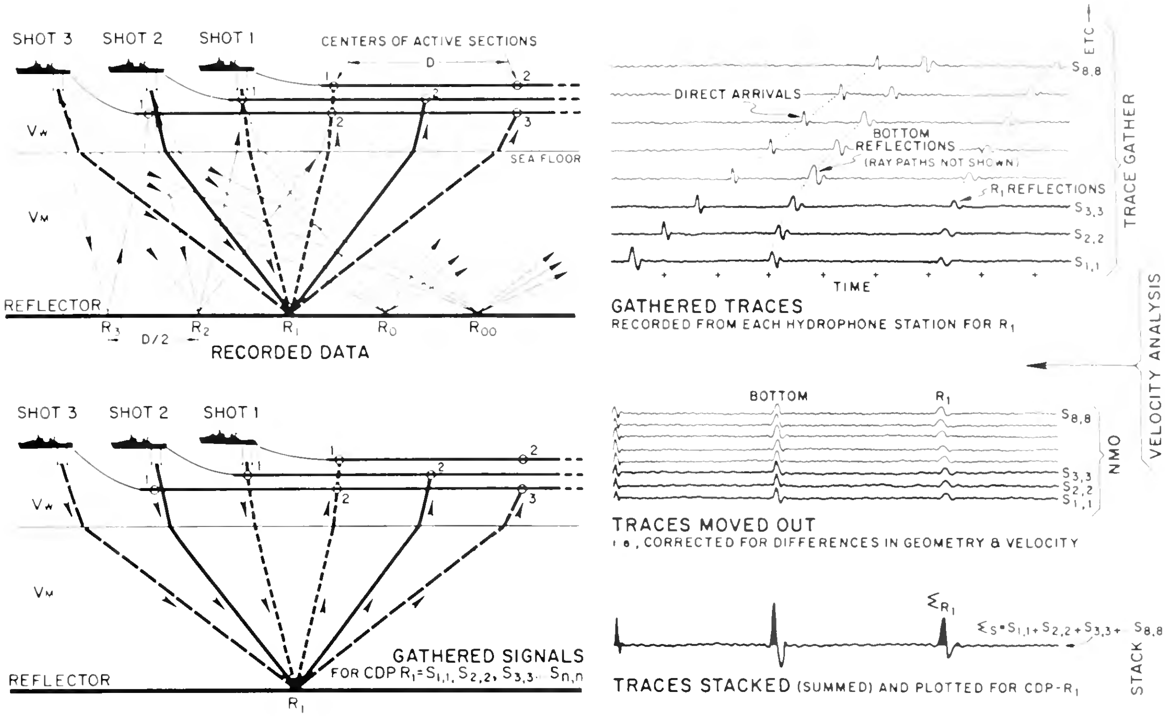


Figure 1. In the seismic common-depth-point technique, the echo-sounding method of detecting subsurface layers is improved considerably by towing a streamer that carries a number of sound "detectors" instead of just one.

increased, so the speed of sound in the rock layers will be determined more precisely.

There is a physical limit, however, to the length of streamers that can be towed behind a ship. Peter Buhl and Paul Stoffa of Lamont-Doherty Geological Observatory suggested an ingenious method whereby employing more than one ship greatly increased the effective length of the streamer. Figure 2 shows this for two ships on the same course, both carrying sound sources and towing streamers. If the distance between the end of the streamer of the lead ship and the front end of the streamer of the following ship is equal to the length of each streamer, then, by firing shots alternately from sound sources on each ship, the sound waves reflected at a common subsurface point are received along a distance that is three times the length of each individual streamer. In effect, a long *synthetic* streamer three times the length of a normal streamer has been created. Ships from three oceanographic institutions carried out an even more elaborate experiment off the U.S. East Coast, the Long Aperture Sizing Experiment (LASE). They detected deep rock layers better than would have been possible with single-ship streamers.

A second experiment (associated with LASE) utilized two ships moving away from each other (Figure 3). This is termed "expanded spread profiling" and allows reflections to be received from various rock-layer boundaries below the common mid-point (CMP). In addition, it enables sound waves that travel large horizontal distances in deep layers to be received when refracted. The speed of sound in various rock layers was determined with much

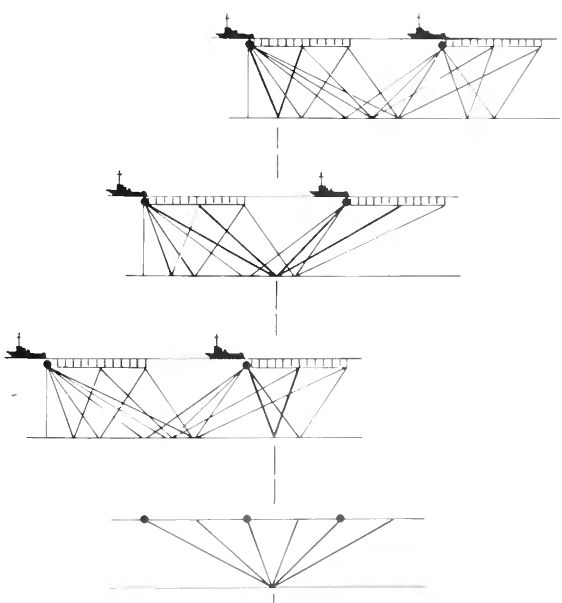


Figure 2. A very long streamer, which is difficult to tow behind a ship, can be effectively replaced by using two ships, each with its own "noise" source and streamer carrying seismic detectors. The advantages of a long streamer — better imaging of subsurface layers and accurate determination of the speed of sound in deep layers — can be achieved by the two-ship technique.

The R/V Hollis Hedberg *has been outfitted with state-of-the-art seismographic instrumentation for deep-water exploration projects conducted by the Gulf Oil Company. (Courtesy of Gulf)*

greater precision than had been possible hitherto.

For oil prospecting, especially in areas where there are no wells, or very few, the speed of sound thus determined gives valuable clues about the nature of rocks that are present. However, this experiment requires two ships, fully equipped with seismic instrumentation, which is very expensive. It seems that probing the passive continental margins with this technique in projects jointly conceived by academic and industry scientists could prove fruitful for both groups.

The Satellite Altimeter

Another recently developed technique of considerable interest to both parties involves an instrument called the satellite altimeter. This instrument can, very precisely, measure the distance of a satellite from the sea surface in the manner of an echo sounder measuring the distance from a ship to the bottom of the ocean. If the satellite is tracked very accurately, the altimeter will yield the varying height of the ocean surface.

In the absence of waves, there are two principal causes for surface distortion. One is ocean currents, which tend to pile up the water in certain areas. The Gulf Stream, for example, can distort the surface by a meter or more. The other principal cause of surface distortion is density differences within the earth that distort the gravity field and thus affect sea level, which is a surface of equal gravity potential. This is shown in Figure 4, where the introduction of a body of high density raises the height of sea level above the body. In actuality, because the density variations are more complex, the distortions of the sea-level surface also are more complex. But by mapping this surface with the altimeter we can deduce the gravity field and obtain the gravity anomalies.

To anyone who has made measurements of gravity at sea aboard a ship, requiring several months to map an area, the fact that similar information can be obtained by a satellite in a fraction of the time is staggering. It should be noted, however, that at present resolution via satellite is not as accurate as resolution via surface ship.

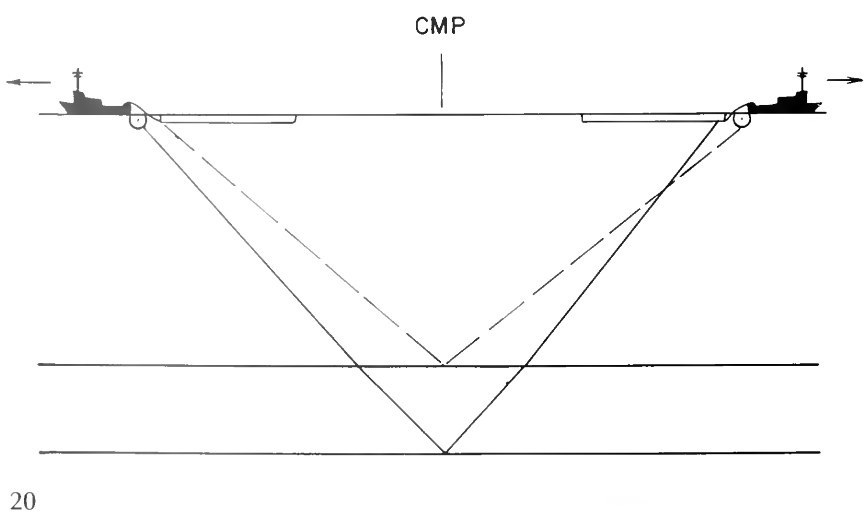


Figure 3. Another two-ship seismic technique, in which the two ships move away from each other, is very useful for obtaining accurate information about the speed of sound in rock layers at great depth below the common mid point (CMP).

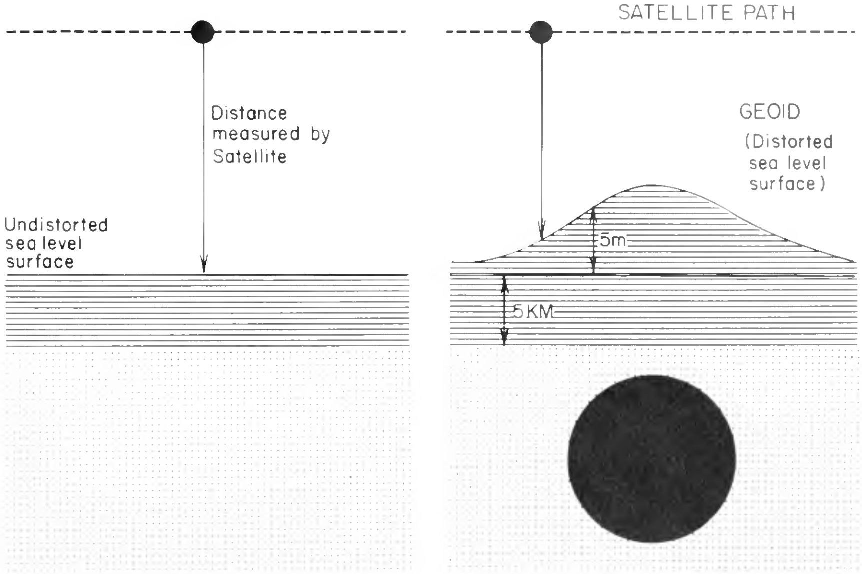


Figure 4. The gravity field produced by a dense buried body distorts the sea-level surface above it. By accurately measuring the height of the sea-level surface from a satellite with an instrument called the altimeter, the variations in height of this surface can be determined and the buried body can be detected.

A gravity map of a part of the Norwegian Sea that Gisle Groenlie of Norway and I constructed is presented at the top in Figure 5. This was based principally on data obtained during more than six cruises in the *Vema*, representing a total time of about 18 months over approximately seven years. Bill Haxby of Lamont-Doherty constructed a gravity map of the same area (Figure 5, bottom) based on satellite-altimeter data collected in about a month's time. The similarity between the two maps constructed from completely different kinds of data is striking.

It also is instructive to compare the gravity field with the morphology of the ocean bottom. In deep water, it is the bottom topography that gives rise to the largest variations in the gravity field. Thus, the satellite-altimeter data provide information about bottom morphology that is especially important for exploring remote areas. Where the ocean bottom is flat, it is the subbottom features that give rise to variations in the gravity field. The satellite altimeter, therefore, has the capacity to detect subbottom features. This is of particular interest to industry for reconnaissance studies over sedimentary basins in remote parts of the world's oceans — particularly over continental margins.

The precision of altimeter measurements and of satellite tracking will have to increase considerably before the subsurface features can be defined with enough precision to be really useful for detailed hydrocarbon prospecting. But this again represents an area where new and expensive technological innovations can be useful to industry and university scientists alike.

Other Technological Innovations

Another significant technological development is the acoustic imaging of the bottom. While the development of side-scan sonars in shallow waters has been under way for a long time, the development of side-scan sonars in deep waters has been limited. Pioneered at the Institute of Oceanographic Sciences in Wormley, England, Geological Long Range Inclined Asdic (GLORIA) is towed behind a ship in a stable configuration to prevent rolling and pitching. The sound beams emitted by the transducers carried in GLORIA emit sound at a frequency of about 6 Hz. The horizontal beam width is 2½ degrees and the vertical angular beam width is 30 degrees. At a depth of 5,000 meters, the seafloor about 30,000 meters to each side can be scanned by GLORIA. With this new technology, sonic images of substantial areas of the ocean floor can be obtained in rather impressive detail in a relatively short time. GLORIA and other side-scan sonars will undoubtedly serve as important reconnaissance tools in conducting geological studies in the oceans in the future.

An example of technological innovation that did not materialize is the Ocean Margin Drilling Project (OMDP). Proposed as a successor to the highly successful Deep Sea Drilling Project (DSDP), to be funded jointly by the National Science Foundation and by industry, a principal objective of OMDP was to drill into the thick sedimentary layer of the continental slope off the East Coast. The project was of great interest to academic scientists because the nature of the sediments deep under the continental slope is largely unknown. It was of interest to oil companies because it promised information about the oil potential under the continental slope. The project also would have encouraged the development of techniques for drilling in deep water (with safety precautions).

The Ocean Margin Drilling Project never went forward. The project would have been expensive and neither industry nor the academic community was anxious to spend large amounts of money in areas beyond its own interest. If cooperative ventures such as this are launched in the future, both industry and academic researchers must develop an

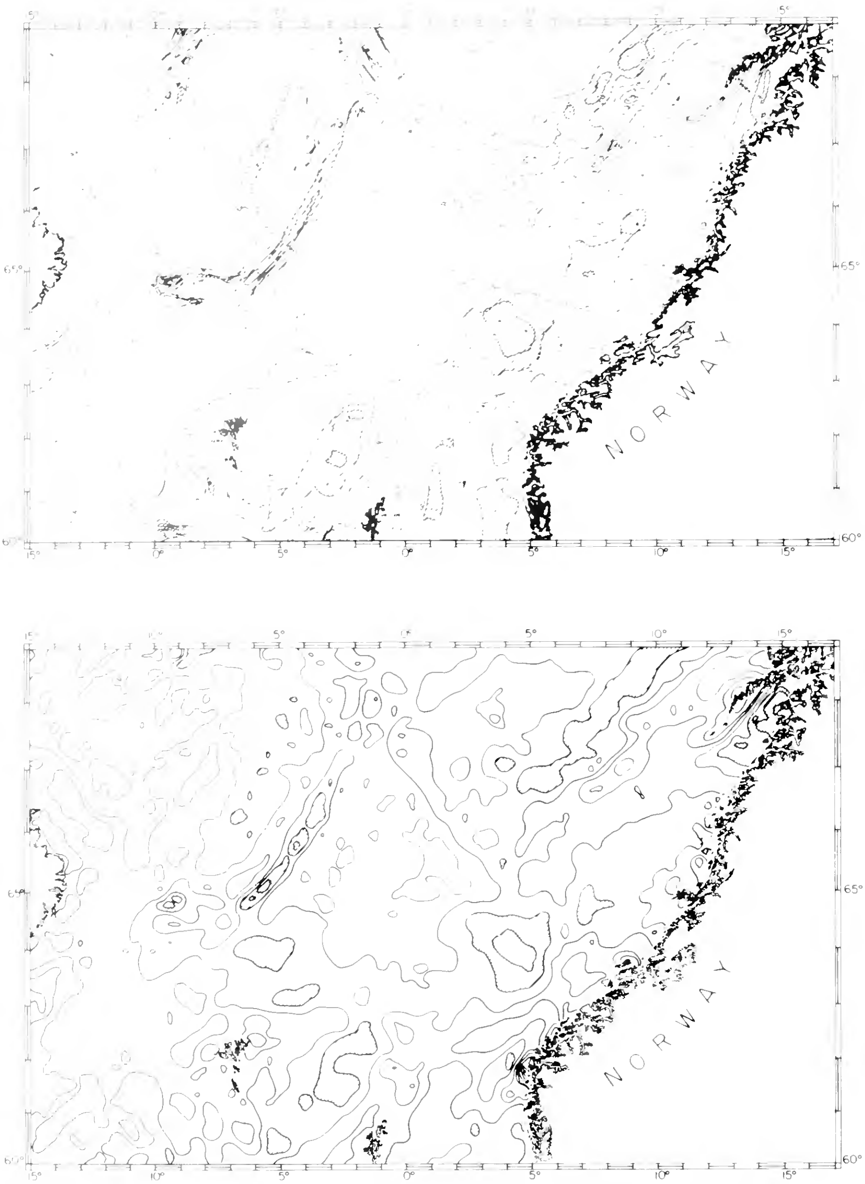


Figure 5. Satellite altimeter measurements can map the distortions of the sea-level surface (Figure 4). These distortions can be transformed mathematically to describe the variations of gravity on the sea surface. Top, a gravity map of a part of the Norwegian Sea constructed by making conventional gravity measurements by a surface ship gravimeter for a total period of about 18 months in the Norwegian Sea. This can be compared to a gravity map, bottom, obtained from satellite altimeter measurements during a period of a few weeks.

understanding of each other's problems and motives. Trust and understanding are essential for the success of future cooperative projects. These will only develop if projects are launched and successfully carried out.

Manik Talwani wrote this article while serving as a consultant to the Gulf Research and Development Company, where he now is employed as Chief Scientist. He is a former Director of the Lamont-Doherty Geological Observatory at Columbia University in New York.

Natural Submarine Petroleum Seeps

by Robert B. Spies

Oil has been seeping naturally from the earth into the sea for thousands, if not millions, of years. Arabian and Syrian tribesmen fought in Biblical times over asphalt slabs that floated up from the bottom of the Dead Sea, and Paleolithic man used natural tar to fix spear points to shafts. Now, natural petroleum seeps are attracting renewed attention as the search for oil moves further and further offshore. Scientists at the University of California at Los Angeles (UCLA) are using mass spectrometry techniques to study small amounts of organic material taken from long cores deep in the Santa Barbara Basin. They have convincing evidence that petroleum has been seeping into the southern California bight for tens of thousands of years. Meanwhile, geochemists are busy towing sophisticated "sniffers" and low-frequency seismic profilers along our continental shelves to pinpoint small seeps, which may indicate undiscovered petroleum resources. And one oil company — Atlantic Richfield (ARCO) — has capped a major natural seep and is transporting the oil to shore — an operation that allows it to install another platform rig without worsening local air quality.

Characteristic gas bubbles denote seepage area in the Isla Vista region. Presence of animal and plant life in the immediate vicinity of natural seeps has allowed for extensive testing of the short- and long-term impacts of oil in the marine environment. (Photo by author)

The Nature of Seepage

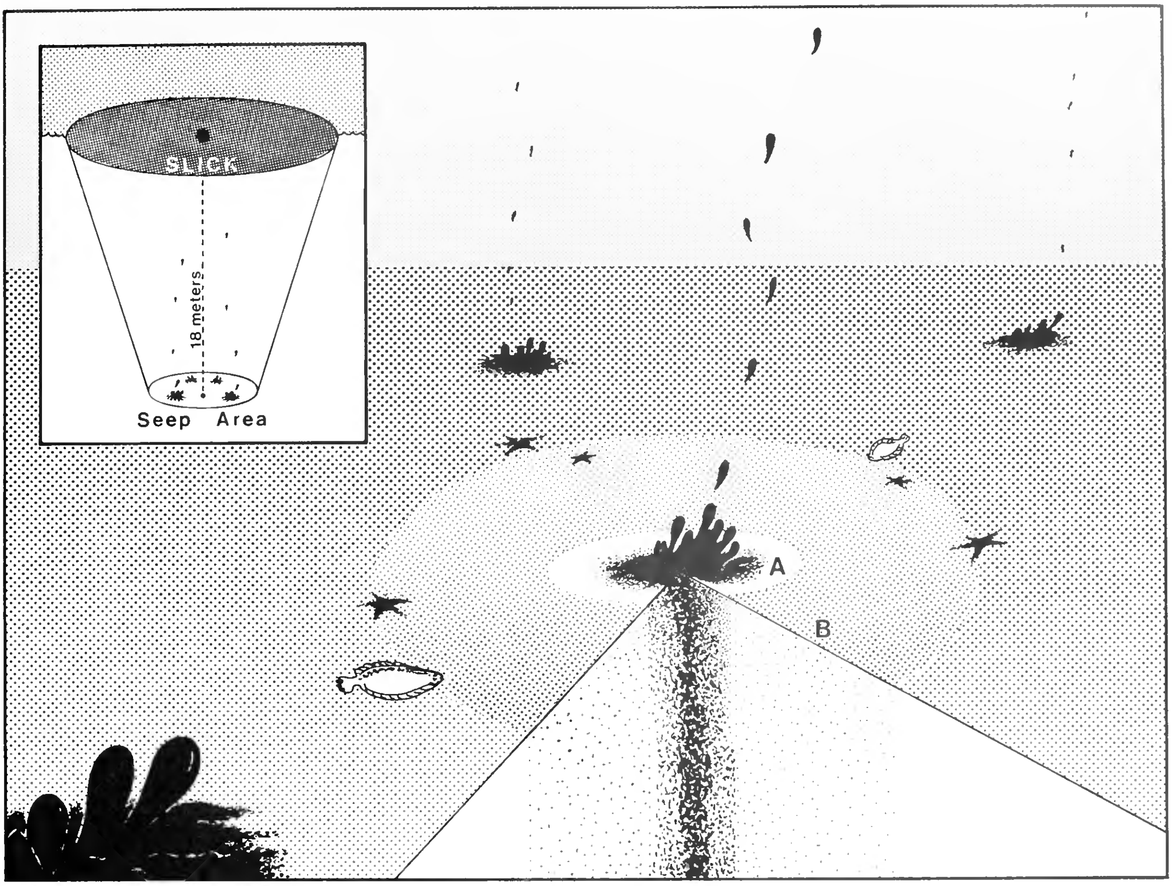
Whenever oil- or gas-bearing geological strata are uplifted, eroded, or fractured, petroleum can reach the earth's surface. Along some southern California beaches a combination of uplifting and erosion during recent geological history has exposed sandstones formed in ancient seas. Asphalt oozes out of the beachfront cliffs on warm summer days. Further offshore, tectonic activity has resulted in faults that penetrate shales and into petroleum-bearing strata, allowing oil and gas to migrate up toward the ocean floor through a thin sand layer and into the water. The water, in turn, penetrates the oil reservoir, resulting in a water-washed, partially degraded petroleum, rich in hydrogen sulfide and asphalt and low in straight-chain hydrocarbons.

Evidence of seeps varies from the thousands of small, intermittent streams of bubbles along the southern California continental shelf, to the oozing from blocks of tar several meters thick and more than 400 meters long in the shallow waters of the western Santa Barbara Channel. The boil of the vigorous petroleum seep being trapped by ARCO could be seen clearly from aircraft landing at the Santa Barbara airport. From a submarine 60 meters below the water surface, it was observed that the force of the escaping gas and oil from this seep had formed craters in the ocean floor ranging from 1 to 5 meters in diameter.

Distribution and Detection of Seeps

Although the Santa Barbara Channel contains the most prolific seeps known, they occur throughout the world. Offshore areas of Alaska, Australia, Canada, Mexico, the Persian Gulf, Trinidad, and Venezuela contain seeps. These are not as apparent as those around Coal Oil Point in the Santa Barbara Channel, where oil slicks nearly always can be seen. Seeps are more difficult to detect in deep water or in remote offshore areas — often there are no visible clues on the water's surface. In deep water, gas bubbles may dissolve completely before reaching the ocean's surface; oil, which often is only slightly buoyant, can lose enough of its low-molecular-weight components to seawater to become neutrally or negatively buoyant, in which case it will never float to the surface to form a slick.

When seepage is not evident on the sea surface, small bubbles or dissolved petroleum deep in the sea can be identified and analyzed. Seeps have been located in Alaska's Norton Sound, off Baffin Island in Canada, and near Venezuela by means of



Isla Vista study area off Santa Barbara: 18 meters deep, the seep area is 1,000 square meters, and contains between 1 and 2 dozen "hot spots," where oil is actually bubbling out of the ocean floor. The resulting oil slick, approximately 4 times the size of the seep area, drifts to westward because of wind and current. A: within ½ meter of a hot spot — essentially in it — pore water (that found in the spaces between sediment particles) hydrocarbon concentrations range up to 1.2 parts per million, and marine life is inhibited. B: 20 meters from the hot spot, pore water hydrocarbons range between 45 and 100 parts per billion; here, animal life is more abundant than in comparison, non-seep areas.

gas chromotography — chemically measuring dissolved gaseous and light liquid hydrocarbons. Many small seeps along the coast of southern California were located either by a towed "sniffer," which analyzes the infrared absorption of gaseous hydrocarbons as they leave the sea surface, or high-resolution, low-frequency (3.5 kiloHertz) seismic profiling, whose signals reflect characteristically off small gas bubbles. Seismic profiling also can detect gas-charged sediments, a hazard to siting offshore platforms.

Estimating Rates of Seepage

Accurate estimation of seepage rates is a difficult task, at best. Presently, most estimation efforts are being done by geophysicists, who are attempting to calibrate their seismic profiling methods, and by oceanographers, who are constructing hydrocarbon budgets for the sea.

There have been only a few attempts to measure directly the gas and oil leaked by seeps. In 1969, scientists from the University of California

Isla Vista oil seep located at 18 meters water depth off the coast of Santa Barbara. This tar mount, one of dozens in the area, oozes oil in fingerlike projections at several points. The diameter of the mount varies from 20 to 30 centimeters. (Photo by author) at Santa Barbara correlated data from aerial photography and surface-slick sampling and calculated that the seeps around Coal Oil Point released 50 to 70 barrels of oil into the sea everyday. In 1982, industry-funded research used a manned submersible, Nekton Corporation's *Gamma*, to place volumetric gas samplers over single vents. The patchy distribution and intermittent nature of seepage makes any projection of these measurements into regional seepage-rate estimates very unreliable. The rate of oil seepage is sensitive to the passage of storms; presumably, lower barometric pressure accounts for increased flow rates during storms. Seeps also are very sensitive to tidal height, and flow rate may be inhibited by as much as 20 to 30 percent with each foot of tidal increase.

On a worldwide basis, estimates of seepage rates have been little more than educated guesses based on various assumptions. In 1974, at the Esso Research Production Company in Houston, R. D. Wilson developed an estimate of the global rate of natural oil seepage. Wilson's geological model incorporated structural features, earthquake activity, and thicknesses of the continental margins, as well as available flow-rate data for high-, moderate-, and low-potential areas. Assuming normal distribution of flow rates within each area, Wilson estimated that the range of seepage rates extended from 0.2×10^6 to 6.0×10^6 metric tons a year; he considered 0.6×10^6 metric tons a year to be the most probable rate. This estimate, representing 10 percent of the oil annually entering the oceans, also appeared in the 1975 National Academy of Sciences Report, *Petroleum in the Marine Environment*.

Preparing a revision of the 1975 report, Keith Kvenvolden of the United States Geological Survey (USGS) recently revised that figure downward. Relying on assumptions about the size of present oil reserves and the uniformity of seepage rates throughout geological history, Kvenvolden estimates that the annual seepage rate is between 0.02×10^6 and 2.0×10^6 metric tons.

Petroleum Seeps as Natural Laboratories

Not only are petroleum seeps important sources of hydrocarbons to the world oceans and indicative of potentially recoverable resources, they also are excellent laboratories for observing the effects of crude oil and natural gas on marine life. As study areas, oil seeps offer distinct advantages over spills, polluted estuaries, offshore platforms, and laboratory aquaria and microcosms. Unlike large spills, which are unpredictable and characterized by decaying effects, large natural seeps are relatively permanent sources of chronic contamination. Whereas in contaminated estuaries the effects of oil are masked by those of metals, pesticides, and such exotic organic compounds as hydrocarbons of pyrolytic origin, observed ecological changes in the vicinity of offshore seeps can be attributed directly to crude oil. Seeps also provide for the worst-case analysis of crude-oil contamination of sediments, since hydrocarbon levels in sediments around offshore platforms usually are so low that the ecological effects of oil cannot be distinguished from

Air Pollution Trapped on Ocean Floor

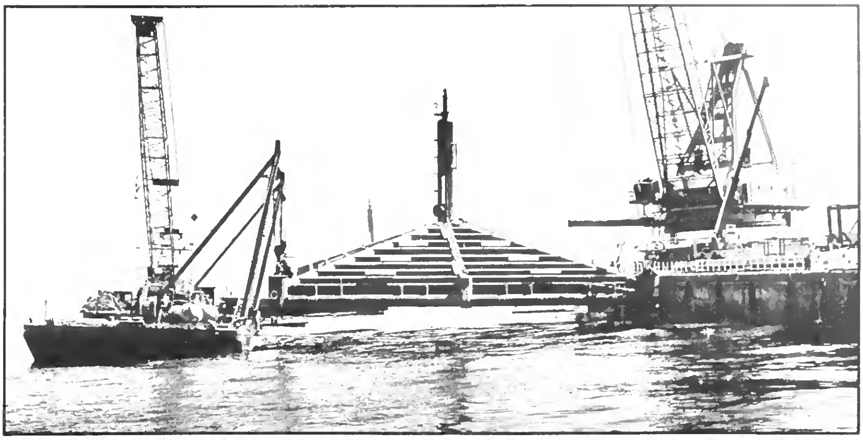
An ambitious experiment to trap natural-gas seeps from the ocean bottom off Coal Oil Point (near where Dr. Spies is conducting his field studies) started in September, 1982, when Atlantic Richfield Company (ARCO) lowered two 100-foot-square metal pyramids 220 feet under the surface of the ocean. They are 1.5 miles offshore, 10 miles west of Santa Barbara near the University of California campus.

Atop the steel tents are flexible hoses connected to pipelines leading to gas-processing plants onshore. ARCO hoped to collect 500,000 cubic feet (three tons) of reactive hydrocarbons daily as an offset against air pollution it would generate from offshore drilling rigs in the area.

Santa Barbara County requires that any new source of air pollution in the county or within three miles offshore be offset nearby by a 120 percent reduction of the same kind of pollution. If the offset is in a different kind of pollutant, the reduction must be 200 percent.

ARCO has found new, rich oil areas in an offshore field that it has been producing for some time. The company intends to drill more delineation wells and eventually put up one or two additional platforms. Onshore pollution offset opportunities were virtually exhausted when ARCO devised the concept of reducing air pollution from natural sources offshore.

Aerial view of transport barge and marine cranes used by ARCO to carry its two pyramid "caps," now in place over major seeps at Isla Vista, off the Santa Barbara coast. (Photo by Steve Malone/Santa Barbara News Press)



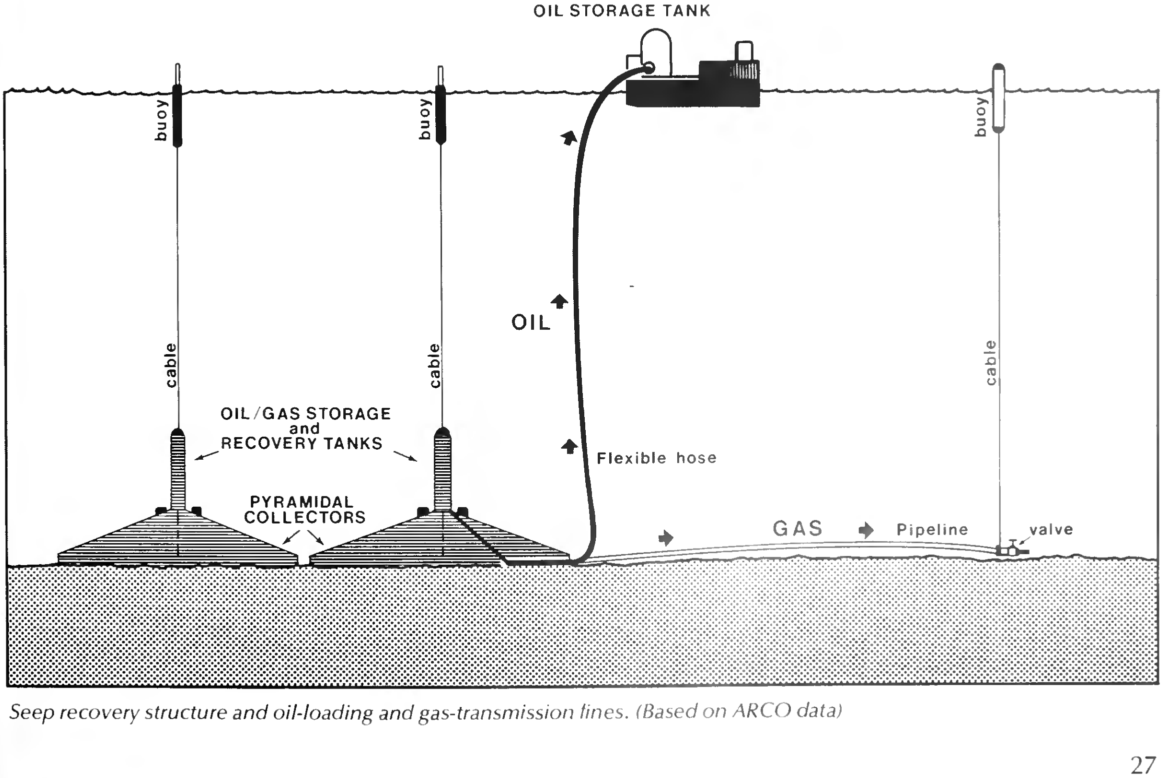
Steel pyramids are lowered by marine cranes in September, 1982, as part of ARCO's natural-seep containment project in the waters off the coast of Santa Barbara. (Photo by author)

During the first 10 months, the ARCO shrouds did not trap 500,000 cubic feet of natural gas per day — they collected one million cubic feet! And these six tons are composed of only the reactive hydrocarbons; ARCO officials claim that these constitute 15 percent of the total volume. The remainder is methane, which is not considered reactive by the county's Air Pollution Control District (APCD). The APCD is interested primarily in reactive gas that turns to photochemical smog when exposed to sunlight.

North American Weather Consultants and the county's APCD believe that about 25 percent of the county's hydrocarbon air pollution originates in offshore gas seeps. Some oil comes up into the gas traps, too, but that amounts to only 100 barrels a month in emulsion that is 85 percent water. This is put through the oil-processing plant simply as a means of disposal.

ARCO is trapping more polluting gas than is required as offset for its own drilling projects, and is "banking" the rest for sale to other oil companies who also have drilling projects pending but no place to turn for offsets. Obviously, the two 350-ton gas traps are doing well where they are, but seeps have a tendency to migrate. The ARCO seep containers can be lifted and moved to new locations if these seeps prove to be transient.

Robert Sollen



Seep recovery structure and oil-loading and gas-transmission lines. (Based on ARCO data) other human and natural factors. Laboratory aquaria cannot replicate the complexity and randomness of ecological changes that can occur in the ocean. In work with microcosms — small isolated parts of ecosystems — distortion of advective forces, nutrient limitation, wall effects, and the frequently low rate of control treatments leave some doubt about how fully transferable results are to the real world.

Aware of many of these advantages, a small group from my laboratory set out in 1975 to study the Isla Vista seep near Coal Oil Point in the Santa Barbara Channel. Our first objective was to compare the bottom-dwelling communities of organisms in the area around the seep to a nearby area without seepage to document the effects of fresh crude oil.

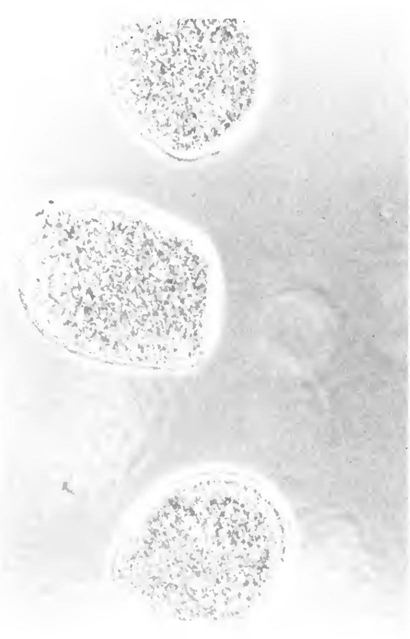
Findings and the Future

Much to our surprise, we found very similar kinds of animals in both areas (with a few exceptions), but, in the seep area, the number of animals was always much greater. After this initial discovery, we made numerous dives in both areas and carried out field and laboratory experiments to understand this phenomenon. Subsequently, we formulated a number of hypotheses to guide our continuing investigations of marine life in and around the seep.

The first is our hypothesis of organic or trophic enrichment. We postulate that the dense animal communities in oil-seep areas, at the bases of their food webs, are supported by fast-growing populations of hydrocarbon-degrading and associated microorganisms. We corroborated this hypothesis by correlating microbial biomass with fresh oil in sediments, then tracing petroleum carbon through the food webs, using naturally occurring, stable-isotope ratios and carbon 14 abundances. The utilization of fossil hydrocarbons by seep organisms is indicated by a depletion of carbon 14 in their tissues relative to the comparison area. Microorganisms are very important in the natural turnover of elements — the cycles of matter — that support life in general. The carbon and sulfur cycles are involved in passing petroleum energy into the food web.

Our second line of inquiry derives from an adaptation hypothesis. We posited that, exposed to petroleum seepage for thousands of years, southern California marine organisms might have developed special adaptive traits for dealing with petroleum. Short-term adaptations of this sort are common among fish, characterized by inducible hydrocarbon-metabolizing systems that operate mainly in the liver. Many invertebrates have similar, but less well-characterized systems. However, no strictly long-term adaptations to petroleum are known to occur. To test for possible adaptations, we exposed sea star embryos from various populations to petroleum. The growth of sea star embryos was inhibited equally by seep petroleum regardless of their parents' histories of exposure to oil. Similar results were obtained with a series of adult organisms by Richard Caldwell of Newport, Oregon. More recently, we compared the metabolism rates of radiolabeled hydrocarbons among sea stars from Coal Oil Point and those of sea stars from the less-contaminated waters of Monterey Bay in northern California; we found no differences.

Although there is no solid evidence of long-term adaptations to petroleum among invertebrates in the areas of seeps, we have measured short-term increases of hydrocarbon-metabolizing enzymes in two species of flatfish found in the petroleum seeps. These inducible enzymes function by oxidizing foreign molecules as they enter the flatfish's body. While this allows the flatfish to successfully detoxify some pollutants, there are a number of pollutants whose metabolic products can be more harmful than the parent compounds — possibly leading to lesions and various disorders affecting reproduction. This



Sea star embryos in both photographs are of same age. The growth of those on the left was inhibited by exposure to petroleum. Similar results are witnessed in adult organisms. (Photo by author) probably is more of a problem for estuarine fish, which are exposed to greater quantities of hydrocarbons of pyrolytic origin that contain large amounts of single-ring, polynuclear aromatic hydrocarbons — the metabolic products of which are harmful.

The possibility of marine-organism adaptation to chronic pollution and, in this particular case, to hydrocarbons in southern California, appears to be worth further investigation. Such research might help resolve the disparity between the observed effects on life in natural oil seeps and the effects of oil spills as recorded on the East Coast of the United States, where damage to marine life has been the norm.

A third aspect of our research concerns the relative toxicity of seep oil to marine organisms, and the concentrations of petroleum hydrocarbons in sediments, pore water (interstitial water), and the water column in the seep environment. Seep petroleum is geochemically altered before it reaches the ocean, which raises the possibility that it may not be as toxic as other kinds of crude oil. We tested this hypothesis by exposing developing sea star embryos to water-soluble fractions of several crude oils. We found that seep oil was more toxic to the embryos than two Santa Barbara crude oils, and as toxic as Prudhoe Bay crude oil. Our measurements of hydrocarbons in the water column beneath the slick produced by the seep corroborated the previous results, indicating less than 10 parts per billion of dissolved liquid hydrocarbons; this is less than is generally thought damaging to marine life. However, down in the sediments, pore-water concentrations of hydrocarbons can range from 45 to 100 parts per billion in areas where marine life is dense, and as high as 1.2 parts per million where seepage is very intense and marine life is inhibited.

It seems obvious to us that the patterns of animal life around oil seeps are similar to those around sewage outfalls. Near the source, conditions are toxic to most animals, but microbial activity is very high; farther away, where the organic material is more dilute, animal life can be stimulated by the extra organic carbon.

Future research projects will examine the possible subtle effects of petroleum on settlement, growth, and reproduction of marine organisms in seep sediments. The ultimate goal of these and many other pollution-research programs is to determine whether or not there are significant effects on marine animals resulting from long-term, low-level exposure to pollutants: Are our anxieties about man's increasing utilization of the continental shelves justified?

Robert B. Spies is a marine scientist with the Lawrence Livermore National Laboratory, Environmental Sciences Division, University of California at Livermore.

Using chemical tracer techniques, several studies in southern California have shown that the natural seeps account for most of the bothersome beach tar that plagues West Coast bathers. (Photo by Steve Malone/Santa Barbara News Press)

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The Prudhoe Waterflood

By mid-1984, the Sadlerochit oil-producing formation in Prudhoe Bay, Alaska, will be flooded with an annual average of 2 million barrels per day of seawater. Approximately one million barrels of produced water — the discharge associated with oil-production operations — also will be distributed into the formation.

The operation involves injection of water into petroleum reservoirs beneath the seafloor in order to displace the residual oil and move it toward a recovery wall by force of the pressure of the water. This effort is aimed at increasing the output in the "second-recovery stage" from the nation's largest oil-producing field.

The proportions of the $2 billion project are unprecedented. Material and equipment commitments were initiated in early 1981 to ensure mechanical completion and start-up by mid-1984. The waterflood facilities will provide for the withdrawal, treatment, heating, and injection of water from the Beaufort Sea.

The offshore seawater treatment plant (STP) is a 600-foot-long facility that is mounted on a barge. Built in Korea, the total cost of the STP alone exceeded $350 million. The Atlantic Richfield Company subsidiary ARCO Alaska transported the STP to Alaska this past summer. It was installed at the end of a 2½-mile causeway in approximately 12 feet of water.

Once in operation, the STP will heat extracted seawater to 40 degrees Fahrenheit. This heated water will be filtered, deaerated, and pumped through two low-pressure, insulated pipelines to the end of the existing West Dock causeway. From there, the seawater will be carried to one of the two onshore seawater injection plants at the ARCO site.

At the injection plant, the water will be received at the intake manifold, heated to a maximum temperature of 80 degrees Fahrenheit, and rerouted to an inlet tank. Booster pumps will then deliver the seawater to the main injection pumps for discharge to a high-pressure manifold. Both the booster and main pumps will be equipped with waste-heat recovery units.

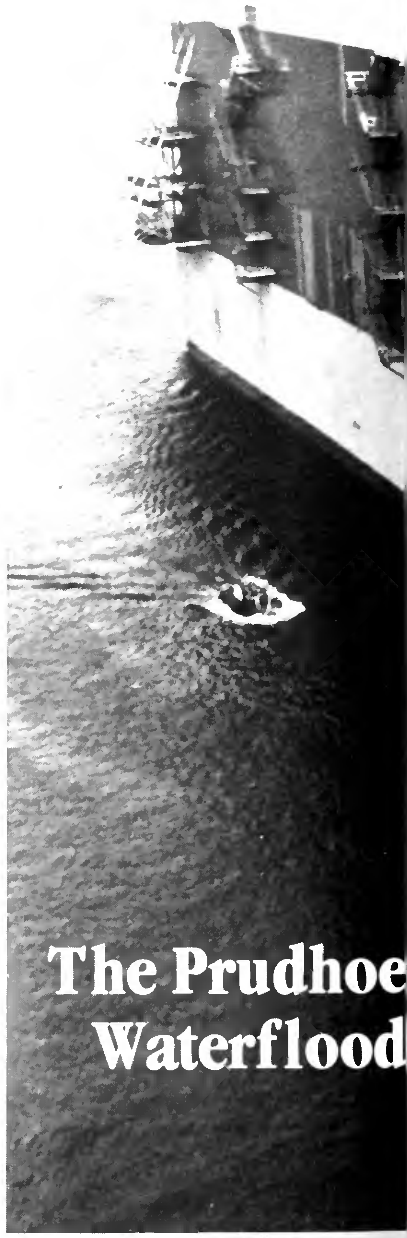
The pressurized water will be either routed from the injection-plant manifold through nearby well sites, or transferred to intermediate manifolds for distribution to outlying production centers. The produced water from each oil-production center will be similarly distributed.

All material filtered out of the seawater will be returned to the Beaufort Sea. As an extra precaution, angled screens will be installed to divert marine life entering the equipment into a recovery system from which it will be returned to the sea. The STP also will be equipped with sampling and observation instruments for studying the marine life.

The injection process to be used is straightforward. Raising the temperature of the seawater will help prevent freezing in the injection plant's reservoir. Heat for this process will be recovered from the injection-pump turbine and exhaust gases. From the inlet tank, suction is provided to four turbine-driven booster pumps, which will pressurize the seawater to meet the requirements of the main injection pumps. Before distribution to the actual drill sites, this water will be further pressurized to the average discharge pressure of 300 pounds per square inch at which the plant was designed to operate.

Chemical incompatibility between the produced water and the seawater makes it necessary to install flanges, or valves, at all interfaces to ensure the two fluids are not inadvertently mixed. Microprocessors connected to a central computer in the injection plant control the entire injection system, which is powered electrically via a new substation and backed up by a diesel-fired emergency generator.

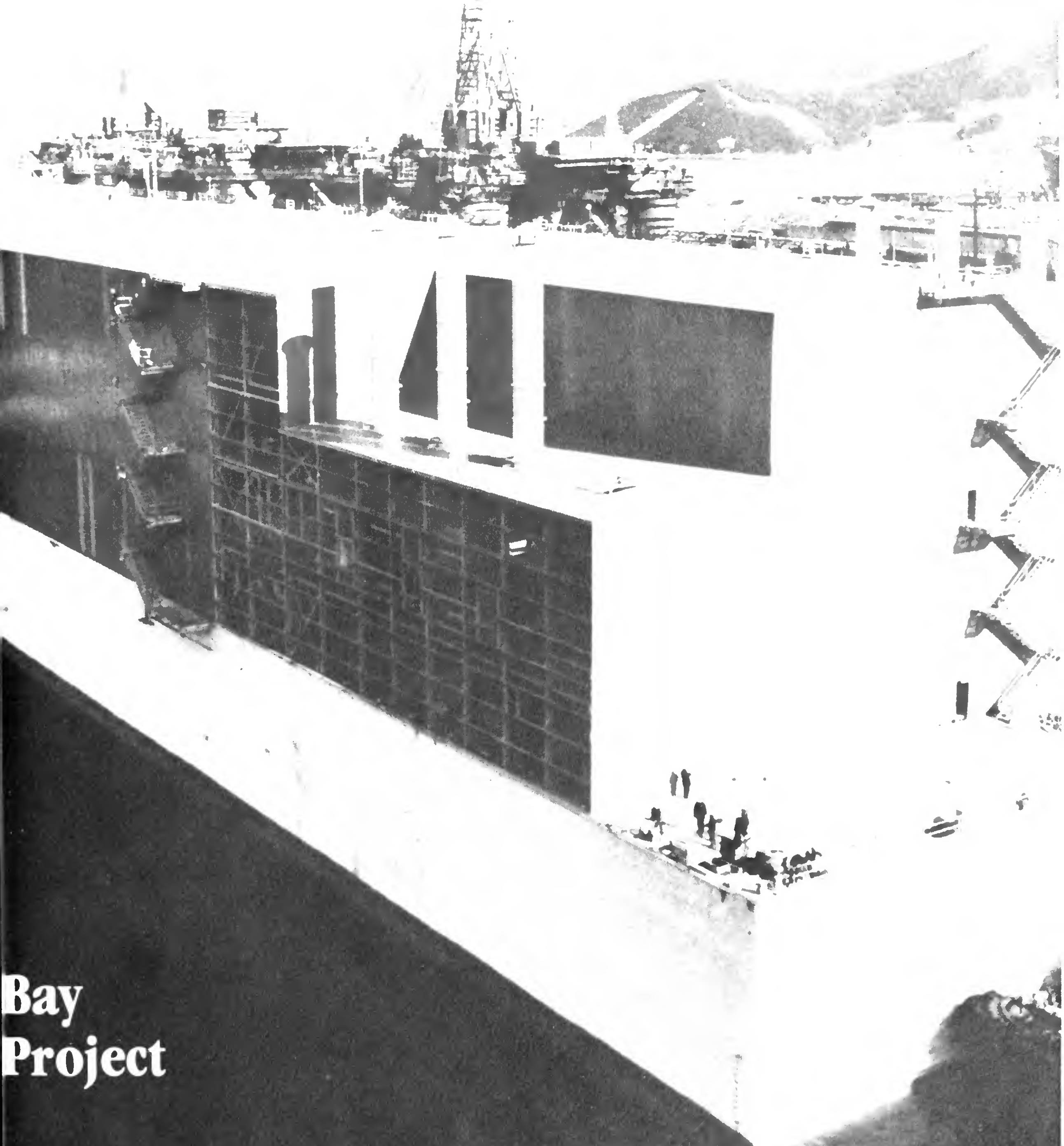
In addition to the unique design and transport concepts, the Prudhoe Bay project must be able to withstand severe environmental hazards after the structures are in place,



particularly the threat of freezing. Freeze protection will be ensured at three stages in the operation.

Initially, water will be injected at 15 sites on the east side of the field. New construction at each site will involve a methanol/water tank, a small control module for power supply, and freeze-protection

Bay Project

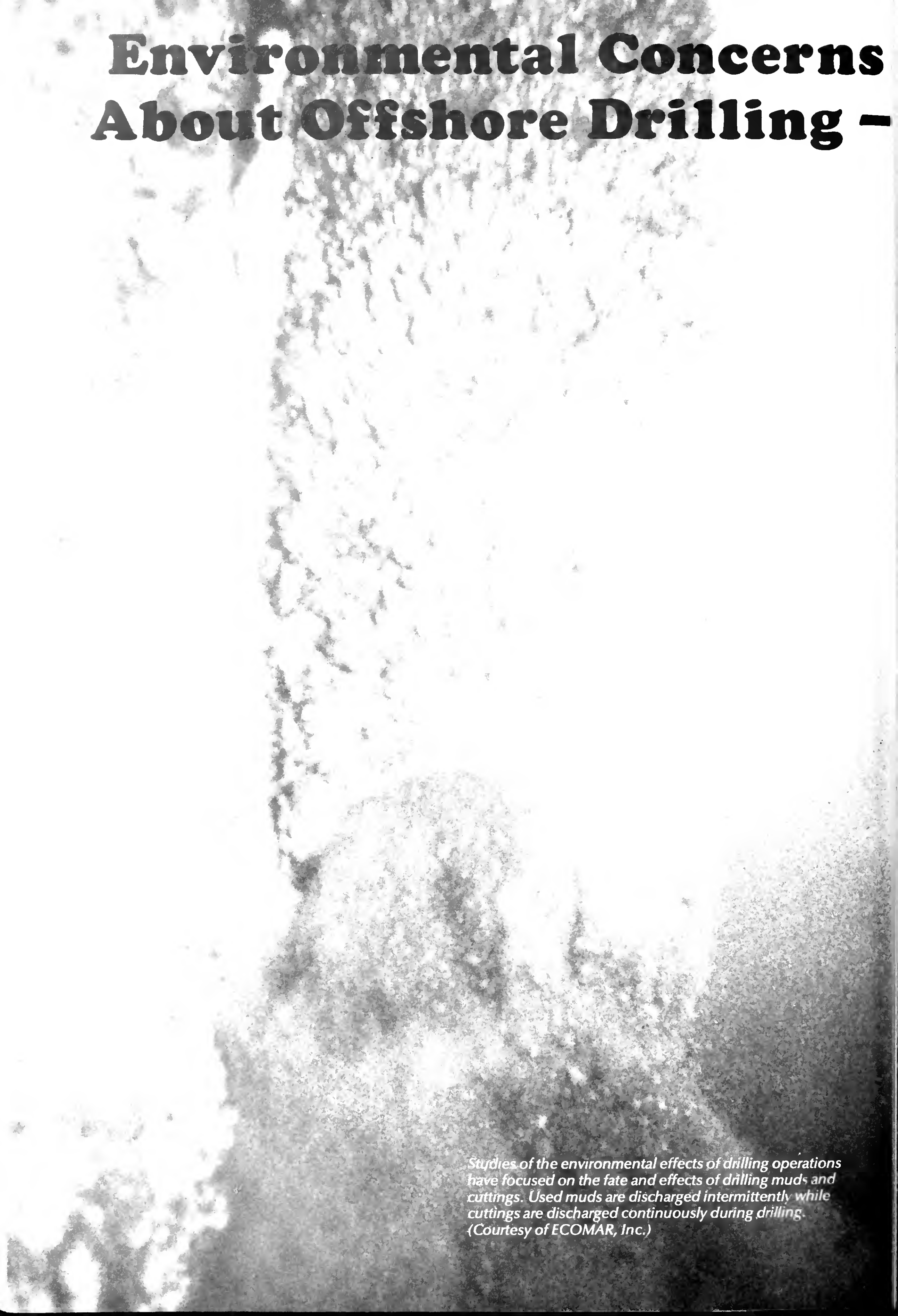


The 600-foot-long seawater treatment plant is pictured at dockside in Korea before beginning its journey to Prudhoe Bay, Alaska. The barge-mounted facility weighs nearly 30,000 tons and will be in operation at ARCO Alaska's West Dock facility in mid-1984.

assemblies. All waterflooding will be accomplished by converting existing well lines from oil-producing service to waterflood service.

The schedule presently calls for expansion of the waterflooding project in 1986, at which time additional manifold facilities will be required to service injection operations at drill sites not included in the first flooding. ARCO Alaska believes that its unique design and delivery plans will make it possible to ensure that the nation's most prodigious field can be produced for maximum output with maximum safety — for as long as possible. ■

Environmental Concerns About Offshore Drilling –



Studies of the environmental effects of drilling operations have focused on the fate and effects of drilling muds and cuttings. Used muds are discharged intermittently while cuttings are discharged continuously during drilling. (Courtesy of ECOMAR, Inc.)

Muddy Issues

by Charles A. Menzie

During the last decade, concern mounted over the environmental effects of waste disposal in our atmosphere, land, freshwater lakes and rivers, groundwater, and oceans. At the same time, awareness of the general lack of information available to judge the effects of particular disposal activities increased. This made it difficult to quantify problems and place them in perspective. There was a general sense that we were polluting the environment and endangering ourselves — that we knew little about the short- or long-term effects of such actions. As a result, a considerable number of studies were initiated on a wide range of waste disposal and siting issues. Some of these are highly visible issues: nuclear-power plant sitings and hazardous-waste disposal. Others remain less well-defined and have not captured much attention, including nonpoint source discharges of agricultural and urban runoff to inland water and coastal systems.

Environmental issues associated with offshore oil and gas operations have been, and to some extent remain, highly visible and controversial. This is evidenced by the considerable amount of testimony received in public hearings, and by the extensive number of field and laboratory studies conducted during the last decade. There is a wide range of environmental issues associated with oil and gas operations, including marine-environment, atmospheric, and socioeconomic impacts. At present, atmospheric impacts associated with emissions from offshore operations are of concern along coastal California where operations are near shore and the prevailing winds onshore. Socioeconomic issues, meanwhile, are of particular importance in Alaskan waters where there is concern over the impacts of development on local human populations and cultures.

Effects of Routine Discharges

Drilling fluids (muds), drill cuttings, and produced waters (the discharge associated with oil-production operations) are the most significant discharges associated with offshore oil and gas operations (Table 1). The quantities of these discharges vary. During exploration, drilling is conducted to determine the nature and extent of potential oil and gas reserves. These operations are usually short, involve a small number of wells, and are generally conducted from mobile platforms or vessels. Drilling muds and cuttings are discharged during exploration. Once oil and gas is found, development begins, which involves the drilling of 10 to 30 wells, usually from a fixed platform. Since more wells are drilled, a larger volume of drilling muds and cuttings are discharged during development than during exploration. Once the drilling unit used in development is removed, extraction of hydrocarbons from underground formations begins. This extraction process may involve discharges of produced water, or brine effluent.

Concern over the environmental effects of drilling and produced-water discharges resulted in a large number of laboratory and field studies. Recent research was presented at the 1980 Symposium on the Fate and Effects of Drilling Fluids and Cuttings held in Florida. The results presented at the symposium varied with the type of drilling mud under investigation. Laboratory toxicity studies were conducted on water-based drilling muds, which presently are disposed of in U.S. coastal waters; other toxicity studies were performed on muds that were not permitted for disposal in U.S. coastal waters. Even among water-based muds, there was variability in the composition of the major drilling-mud components. This, in turn, led to variability in the toxicities of the materials. In some respects, the situation was that of comparing apples and oranges: general statements concerning toxicity and the potential effects of drilling fluids were not conclusive because of the differences that exist among these materials.

In an effort to provide more useful information on the toxicity of drilling muds, the operators exploring for oil and gas on the outer continental shelf in the mid-Atlantic and Georges Bank areas were required to do bioassays for eight generic mud types. A testing protocol was developed and approved by the Environmental Protection Agency (EPA). In new regions, testing is to include the original test species and other organisms representative of the region. In addition, new drilling muds proposed for use must be tested.

A review of the results of acute-toxicity testing on drilling muds was undertaken for the EPA by Gary Petrazzuolo. A total of 303 toxicity tests was performed. In his review, Petrazzuolo noted that tests had been completed on at least 35 drilling muds or components where there had been exposure to 48 marine species, including representatives of phytoplankton, copepods, isopods, amphipods, gastropods, decapods, bivalves, echinoderms, mysids, polychaetes, and fish. Petrazzuolo concluded that, for the drilling fluids and species tested, the acute lethal toxicity of drilling muds is very low. He did note that some groups, including phytoplankton and copepods, were more sensitive than, say, polychaetes and isopods; that larval-like stages were generally more sensitive than adult forms; and, that moulting animals were more sensitive than intermoult animals.

Other laboratory procedures have been used to examine the sublethal effects of drilling muds. These include a variety of physiological, biochemical, and behavioral studies. Some of these

Table 1. Categories of major discharges from offshore oil and gas operations.[a]

Discharge category	Exploration	Development	Production
Drilling fluids[b]	Well depths less than 3,050 m		
(Total additives to water-based systems and volumes discharged)	520-709 tons/well 417-1,094 m³/well	7,090-21,279 tons/platform	
	Well depths greater than 3,050 m	10,940-32,820 m³/platform	
	672-2,118 tons/well 900-4,800 m³/well		
Drill cuttings[c]	823-1,285 tons/well	9,000-27,000 tons/platform	
Produced water[d]	——	——	0-2,709 m³/day per platform; 884 m³/day was the mean flow for 10 platforms; in Gulf of Mexico
Deck drainage[e]	53 m³/day	53 m³/day	No information
Sewage[e]	5.3 m³/day	5.3 m³/day	0.7 m³/day

[a]Seawater discharges such as cooling waters are not included. Drilling fluid additives are in dry weight.
[b]Discharges of drilling fluids are based on information summarized by Petrazzuolo (1981) for five wells drilled in the Gulf of Mexico and one in the mid-Atlantic bight. Discharges during development were estimated by using the highest value for exploration wells less than 3,050 meters in depth (709 tons/well) and multiplying by an assumed number of wells per platform (10-30).
[c]Drilling cuttings discharges for exploratory drilling are based on four case studies with well depths ranging from 1,650-4,980 m. Drill cuttings discharges for developmental drilling were estimated by using a value of 900 tons/well and multiplying by an assumed number of wells per platform (10-30).
[d]Values based, in part, on information presented in Jackson, and others, 1981.
[e]Based on information provided by oil companies.

m = meters
m^3 = cubic meters

are difficult to interpret in terms of the significance of the response and their relationships to actual exposure concentrations in the field; behavioral studies have been informative. Sublethal effects have been observed in situations where drilling muds were applied directly to hard corals, though the dose could not be quantified. Behavioral effects also were observed or inferred when drilling fluids were applied directly to sediments.

In work done by Marlin Tagatz's laboratory at Gulf Breeze, on Pensacola Bay, Florida, there was evidence that the recruitment of colonizing, benthic invertebrates is reduced where sediments are covered with layers of drilling muds. This could indicate either disruption of physical or chemical cues important for larval settlement or a direct avoidance response to the presence of the material. In another study carried out by Jelle Atema at the Marine Biological Laboratory at Woods Hole, Massachusetts, juvenile lobster behavior was observed to be modified as a result of the presence of drilling muds on sediments. Whether these kinds of effects would actually occur in the field would depend on the amount of drilling discharges that accumulate on the sediment surface. It is not likely to occur in high-energy areas, but it is a possibility in low-energy areas where deposition is promoted.

Field observations on the effects of drilling discharges have been made in most continental-shelf areas of the United States. These studies show that during bulk discharges of drilling muds and cuttings the plume tends to separate into an upper plume, which is carried away from the drilling rig, and a lower plume which descends rapidly to the seafloor. The upper plume contains a relatively small percentage of the total discharged materials and is rapidly diluted in the water column. Some of the finer material may accumulate on and be transported along pycnoclines (the transitional area between surface waters and very deep waters). Most of the discharged solids descend rapidly to the seafloor. With regard to environmental effects, the short- and long-term fates of this material are more important than those associated with the lighter upper plume.

Seafloor Studies

At present, research on the fate and effects of drilling fluids and cuttings is focused on the benthic environment. This is consistent with the observation that the bulk of the material discharged descends rapidly to the seafloor. Physical alterations of the seafloor have been examined using underwater television cameras, side-scan sonar techniques, diver observation, and examination of cores. Accumulations of solids and cuttings piles on the order of 50 to 150 meters in diameter around well sites have been observed in the less turbulent regions of the Gulf of Mexico and in the mid-Atlantic outer continental shelf. Accumulations were not observed in the more turbulent environments of Tanner Bank off California or Cook Inlet, Alaska. In the Cook Inlet area, however, investigators did find cuttings entrained in the sediments, the result of extensive sediment motion associated with strong tidal currents in that area. In the southeast Georgia embayment, small patches of drilling muds, tens of centimeters in diameter, were observed on the seafloor immediately following bulk discharges. However, these patches dispersed within a 24-hour period, as revealed by follow-up photographic surveys. In relatively low-energy areas, including regions in the mid-Atlantic outer continental shelf, discharge accumulation could still be observed a year after completion of drilling.

Although a broad range of trace metals has been analyzed in sediment samples in the vicinity of well sites, barium is the only metal that can be found consistently at elevated concentrations following drilling. This is probably a function of the large quantities present in the drilling muds. The magnitude of elevated barium concentrations depends on the quantity of discharges as well as the nature of the local benthic environment. In relatively quiet areas, as are found in the mid-Atlantic and Gulf of Mexico, barium concentrations in the upper few centimeters of sediment were significantly elevated at the well site, and decreased to background levels at distances of 1,000 to 3,300 meters from the well site. By contrast, measurements made in such high-energy areas as the southeast Georgia embayment and Cook Inlet indicate that barium concentrations were not significantly elevated in the sediments. Preliminary information from Georges Bank, a relatively high-energy environment, suggests low levels of barium in the immediate vicinity of an exploratory well (see page 2).

Expressed concerns regarding the accumulation of trace metals in benthic organisms and fish around drilling operations were addressed in both field and laboratory examinations. Overall, only limited accumulations of selected metals were observed.

Direct effects on biological communities around drilling operations have been observed in relatively low-energy environments, where discharged materials settle and accumulate. In high-energy areas, materials are rapidly dispersed and the effects are minimal. A recent study of the mid-Atlantic outer continental shelf noted that cuttings and other debris accumulated on the bottom as a result of exploratory drilling attracted certain species of bottom-dwelling fish. The density of fish and crab populations increased greatly throughout the area studied after drilling operations. One year after the termination of drilling operations, comparatively large numbers of hake (a demersal fish) were still present in the immediate vicinity of the drilling well. The populations of crabs and other decapods, although still larger than they were before drilling, had decreased.

While the number of mobile megafauna and fish increased in the mid-Atlantic area during and after drilling, the abundance of infauna — animals that normally live in the sediment — decreased. We attributed this to a combination of natural and discharge-related factors.

Several observed effects seem to be related to changes in the sediment environment. The densities of polychaete worms were reduced in areas of elevated clay content. It is believed that the excess clay resulted from either the initial spudding* of the well or the subsequent discharge of clay cuttings

The benthic environment in the immediate area of an exploratory well in the mid-Atlantic. Fish attracted to the area swim over an area characterized by well cuttings. (Photo by author)

from the hole, rather than from drilling muds. The densities of brittle stars were much lower in the 100-meter radius of the drilling operations immediately after drilling and a year later. This, too, may be the result of sediment alterations. We suggested that these effects might be traced to diminished larval recruitment in response to the altered sediment environment in the area. Many benthic invertebrates are planktonic and have some ability to select the sediments on which they will eventually settle. If those sediments are chemically or physically altered, they may be less attractive to larvae; this is consistent with interpretations of the laboratory studies carried out by Tagatz and Atema, which were described earlier.

A benthic monitoring program to assess the effects of the limited exploratory operations is being conducted on Georges Bank. Preliminary results indicate no adverse biological effects, though barium levels have risen slightly in sediments around the exploratory operations. These findings are not surprising as Georges Bank is a relatively high-energy environment.

Production Operations and Produced Water

After the necessary drilling operations have been completed, extraction of hydrocarbons can begin. There has been limited work done on the toxicity of produced waters to marine organisms. A series of bioassays was carried out on produced water from the Buccaneer Field in the Gulf of Mexico using brown and white shrimp, barnacles, and a species of small fish. Generally, toxicity was low except when biocides that had not been scavenged from the system were present. Additional information on the potential toxicity of produced water can be gained

*The initial drilling of upper layers of sediment that involves deposition of cuttings directly on the seafloor.

from studies of water-soluble fractions of oil (which contain hydrocarbons similar to those found in produced water) and treated ballast water. Toxicity studies performed on ballast-water treatment effluent from Port Valdez, Alaska, by the National Marine Fisheries Service (NMFS) revealed that the treated effluent contained light, aromatic hydrocarbons in the range of 1 to 16 parts per million (ppm). This approximates the levels of light aromatics observed in produced waters from the Gulf of Mexico and off the West Coast of the United States. In these tests, conducted with a number of adult and larval fish and invertebrates, water-soluble fractions of oil and ballast water exhibited low toxicity. The concentration of effluent in the test water had to reach 10 percent (100,000 ppm) before proving lethal to at least half the organisms over a period of 96 hours.

Although acute toxic effects appear to be low, chronic lethal and sublethal effects (behavioral impacts) must be considered. Chronic exposure to organisms in the water column could occur in areas where there is continuous input and discharged hydrocarbons are not rapidly removed from the system. The potential for hydrocarbon buildup in the water column is greater in semi-enclosed coastal embayments with limited flushing than in offshore regions. In both cases, the rate of dilution, advection, and other losses such as evaporation and sedimentation, must be considered before judging whether or not there would be chronic effects on animals living in the water column.

Hydrocarbons that become associated with the sediments are a more likely cause of chronic exposure; the sources for such hydrocarbons include produced water, oil spills associated with transfer operations, and leaks in pipelines. Several studies suggest that the lighter aromatic hydrocarbons, such as naphthalene, are surrendered more readily by the sediments than are the polynuclear aromatics. However, because produced water may be discharged continuously, hydrocarbons with lighter and higher molecular weights can accumulate in sediments and affect benthic organisms.

Accumulations of hydrocarbons have been recorded in sediments around production platforms. This generally occurs in shallow-water regions or low-energy environments. In high-energy areas, where sediment transport occurs and dilution and transport in the water column is rapid, accumulations occur only — if at all — in the immediate vicinity of the discharge. Discharged hydrocarbons may accumulate at low levels in animals living in the vicinity of production platforms. In the Gulf of Mexico Buccaneer Field study, for example, petroleum hydrocarbons were found in barnacles, fish, shrimp, and other organisms. Fish that fed on the platform fouling community contained higher concentrations of hydrocarbons than those that fed in the water column; there was no evidence of biological magnification of these hydrocarbons through the food web.

Benthic infauna may be reduced in abundance in the immediate vicinity of production platforms with produced-water discharges as seen in Buccaneer Field and Trinity Bay. In Trinity Bay, within 15 meters of the discharge, the sediments were almost devoid of benthic infauna. The numbers of both species and individuals increased with distance, out to 600 to 1,500 meters from the platform. Investigators concluded that persistent low levels of the light aromatic hydrocarbon naphthalene apparently restricted many species. Other hydrocarbons not measured in the study also might have contributed to the effects on these invertebrates.

Many contaminants, such as heavy metals and hydrocarbons, have a high affinity for particulate material and tend to accumulate in sediments. Subsequent resuspension and transport of bottom materials, then, determines the degree to which near-field or far-field effects occur. In high-energy areas, discharged materials are rapidly resuspended and transported away from well or production sites. As a result, the material is spread over a larger area. In low-energy areas, high concentrations of discharged materials remain near the well site for long periods, increasing the likelihood of affecting the local benthic environment. Clearly, the effects of routine discharges depend on *what* is discharged, *where* it is discharged, and *how much*.

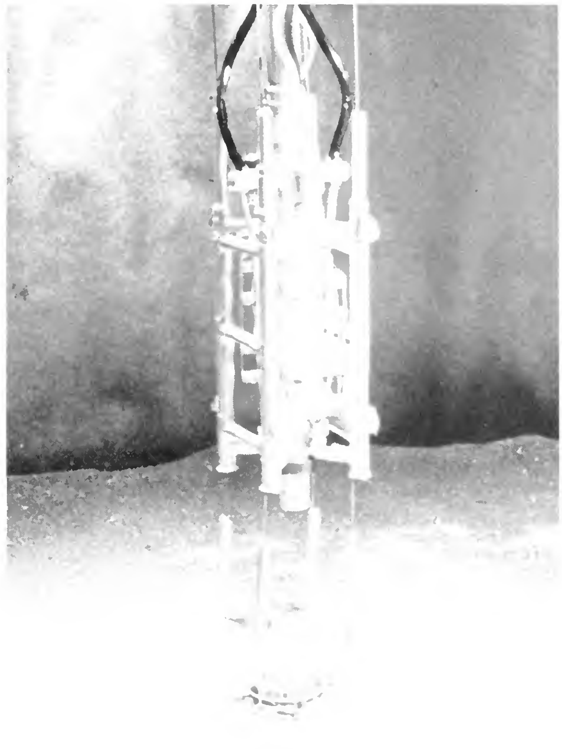
Accidental Oil Spills

Perhaps the greatest environmental concern with offshore oil and gas operations is that of oil spills. Accidents can cause oil spills: well blowouts, platform collapses or collisions with ships, pipeline ruptures, problems with transfer of oil and gas between facilities, and fires and explosions. Well blowouts that resulted in large oil spills include the 1969 Santa Barbara, California, the 1977 Ekofisk North Sea, and the 1979 Ixtoc 1 Gulf of Mexico spills.

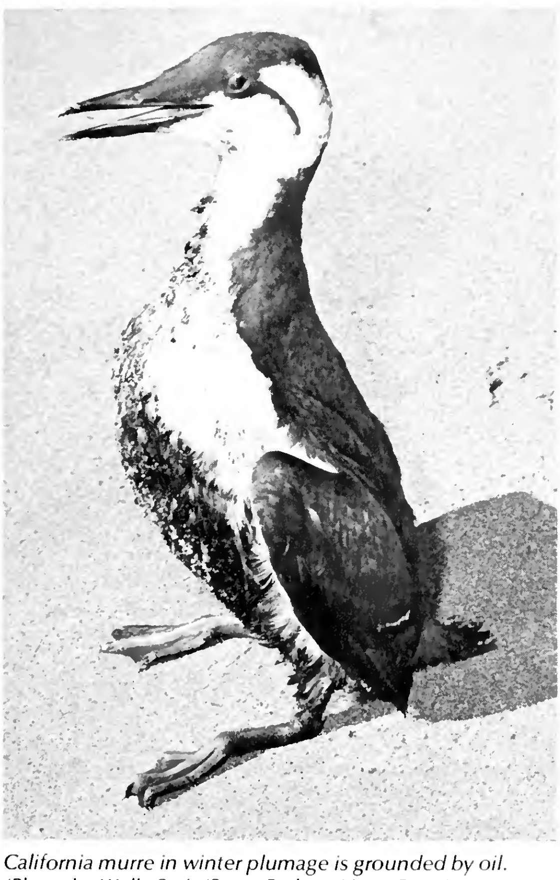
Data on oil spills collected and published by the U.S. Coast Guard show that tank ships, tank barges, and pipelines are the most significant sources of oil spills by volume. Offshore petroleum-production facilities generally contribute only a small percentage of the total volume of oil spilled. Other significant sources of oil to marine environments are nonpoint source discharges, river inputs, tanker discharges, and natural oil seeps. In a 1981 National Academy of Sciences report it was estimated that 120,000 metric tons of oil are released to the oceans each year as a result of all offshore oil and gas operations; this amounts to about 2 percent of the total annual input.

When oil spills occur in the open sea there may be immediate effects on planktonic organisms and seabirds at the surface. Dispersion of oil at sea reduces the likelihood of hydrocarbons reaching the sediments in toxic amounts. In shallow, low-energy embayments, tidal flats, and estuaries, the impacts of oil spills are apt to be more severe. There can be immediate effects on nearshore marine bird populations, benthic invertebrates, and fish. Mortality rates among birds coated with oil is particularly high as the result of loss of waterproofing, loss of buoyancy, and dehydration. Spilled oil also may be incorporated into the sediments, with chronic effects on benthic populations and demersal fish. Acute lethal effects of oil on marine organisms may result initially from the lighter aromatic hydrocarbons. These hydrocarbons tend to be lost quickly. However, hydrocarbons with higher molecular weights are more persistent; they can be incorporated into the sediments, where they have the potential to affect populations over longer periods of time. Few quantitative estimates are available on the fate of oil that has entered the ocean due to large spills. However, estimates for the 223,000 metric ton spill from the *Amoco Cadiz* supertanker indicate that 13.5 percent was rapidly incorporated into the water column, 8 percent was deposited in subtidal sediments, 28 percent washed into the intertidal zone, and 30 percent evaporated (see page 2).

According to a 1981 report by the Interagency Committee on Ocean Pollution Research, Development and Monitoring (COPRDM), oil-impacted sites generally recover and re-establish populations similar to those existing prior to the spill within less than 10 years. However, recovery rates of local bird or mammal populations with low reproductive rates may be slower. The oil and gas industries, in cooperation with the U.S. Coast Guard, are developing techniques and procedures for containing and cleaning spills, and thereby reducing the effects of oil spills.Oil-spill cooperatives, such as Clean Seas, Inc., Clean Gulf Associates, and Clean Atlantic, Inc., have been established in the United States to respond rapidly to accidental oil spills in their respective geographical areas. Special training facilities have been established to teach well-control methods so that blowouts can be prevented and controlled.



A subsea blowout-preventer stack is lowered to the wellhead on the seafloor. Essentially a large high-pressure valve, the device can be remotely controlled. (Provided by Petroleum Extension Service, University of Texas at Austin)



California murre in winter plumage is grounded by oil. (Photo by Wally Stein/Santa Barbara News Press)

Offshore Platforms as Artificial Reefs

Observations around platforms off the coast of California, in the Gulf of Mexico, and around the drilling rigs off the East Coast consistently indicate that these platforms act as artificial reefs, harboring rich fouling communities of sea anemones, barnacles, bryozoans, starfish (some of very large size), and other invertebrates. Fish populations around these structures increase dramatically, including favored sport fish, such as red snappers in the Gulf of Mexico. As a result, platforms have become popular areas with sport fishermen.

As biological material develops on the structures of platforms, it falls to the seafloor and provides nutrition for benthic invertebrates and demersal fish populations — in particular, large numbers of starfish, crabs, and certain bottom-feeding fish. Whether or not these platforms actually increase the overall production of marine life is speculative. They do provide surface areas for fouling communities that would not otherwise inhabit a particular marine environment, and the organisms associated with these communities

Offshore platforms serve as artificial reefs, developing rich fouling communities of reef-like organisms and attracting fish and crustaceans. (Courtesy of ECOMAR, Inc.)

provide a source of food for the more mobile fish and crab populations. The structures themselves provide a physical habitat that attracts many of the mobile species.

Summing Up

Offshore oil and gas operations generally are carried out in an environmentally safe manner. Observed effects usually are restricted to benthic environments located in shallow or low-energy areas and the immediate vicinity of operation. Oil spills are most detrimental in nearshore areas, especially where coastal bird populations may be affected; large oil spills, however, are rare and techniques are being developed to prevent them and to control them and mitigate their impact.

As industry, the general public, and environmental advocates learn more about the actual effects of offshore operations, the concerns and controversy regarding such operations should be alleviated somewhat. Hopefully, this will make it possible to direct attention and funds toward more critical, though less visible, marine-pollution problems, such as nonpoint source discharges to coastal systems. Still, it is essential to maintain environmental safeguards to ensure that offshore operations continue to be carried out in an environmentally sound manner and to monitor periodically the effects of these operations.

Charles A. Menzie is Manager of the Environmental Services Department at EG&G Environmental Consultants, Waltham, Massachusetts. His research has focused on the fate and effects of wastes disposed of in estuarine, coastal, and offshore environments.

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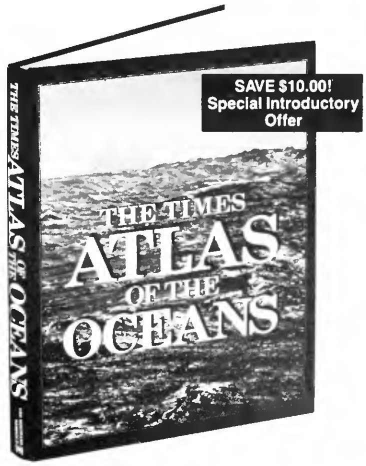

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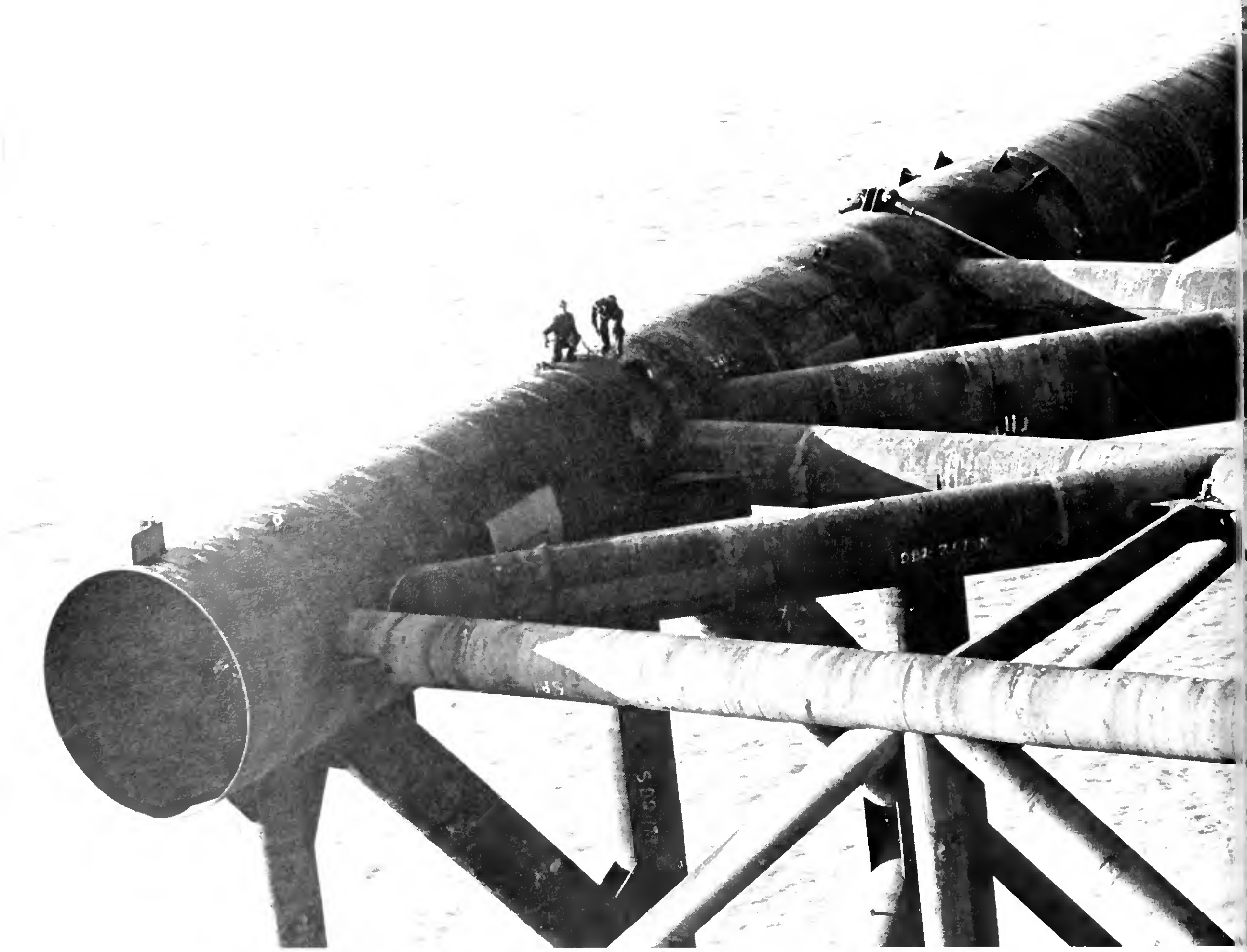
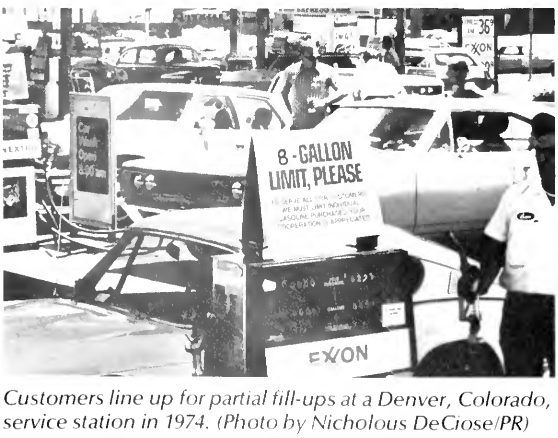


A 4,000-ton drilling platform is readied for sinking to the bottom of the middle ground shoals of Cook Inlet, Alaska. (Photo by Joe Rychetnik/PR)

How Undiscovered Oil Is Estimated



Customers line up for partial fill-ups at a Denver, Colorado, service station in 1974. (Photo by Nicholous DeCiose/PR)

by John Steinhart and Mark Bultman

As the oil glut persists and the natural-gas bubble envelops us, energy recedes from the headlines. It seems like only yesterday, but it was during 1981 that projecting oil and gas availability was a growth industry, absorbing the efforts of government agencies, academics, consultants, and many industry analysts. In the pause before gas-station lines focus media attention on these predictors once more, there is a chance to see how much agreement about future U.S. oil availability has been achieved by professionals in the earth sciences.

Only a decade ago, estimates from reputable geological analysts had a range of a factor of 10 for ultimately recoverable oil. Flanked on either extreme by doomsayers, cornucopians, eager talk-show hosts, and impact-seeking journalists, what visionaries there may have been were easily obscured by these battalions of nuts and cranks. Economists marched to their own, different drummer: with the market as mecca, they seemed to assume that the oil supply was infinite. Confrontation over this point elicits rapid denial, followed by muttering about substitution or technology. Economists have their own lunatic fringe, including one who argues that if we don't know how much oil there is, well then, the supply must be infinite.

Much attention has been focused on the amount of ultimately recoverable oil that remains beyond presently measured reserves. This amount consists of two parts: (1) extension of known fields via developmental drilling; and (2) further new discovery in areas not yet exhaustively explored. This second category is the most contestable, and often is further divided into the small discoveries in well explored areas (most of the discoveries in the onshore, lower 48 states are now of this sort) and frontier areas where little or no exploration has been done. The offshore regions of the United States (including Alaska) constitute the largest frontier area remaining, although some sites in the Gulf of Mexico and off the coast of California are already mature.

Yet, even if consensus could be reached in terms of the amount of ultimately producible oil, we wish to know more. For example, we need to know when, and in what quantities, this oil can be delivered. By now a market believer will object: Surely this is a matter determined by the price. The objection is correct, in that dramatic price fluctuations will elicit a response in terms of amounts produced, albeit a sluggish response, as we saw in the late 1970s. One enlightening, though incidental, result of M. K. Hubbert's work for the United States Geological Survey (USGS) with production and discovery histories was the illustration of the remarkably constant 10- to 11-year lag between discovery and production during the last 50 years despite constant change in the oil industry. Price fluctuations are remedial, but they also carry their own diseases. The proportion of inflation, recession, or any other undesirable economic impact that should be ascribed to abrupt changes in energy prices is debated, but few doubt the reality of these impacts. The oil industry itself, by virtue of its sheer size, is capable of provoking general economic dislocation.

Moreover, there are real physical limitations on the rate at which oil can be supplied as the remaining frontier areas are explored. When the amount of oil added to reserves from new discoveries is small relative to the amount of oil remaining in fields already in production, oil can be supplied only in ever decreasing amounts. The extraction rate is limited by the physics of fluid flow through porous media. The good news is that there will be substantial domestic oil production a century from now. The bad news is that much less domestic oil will be produced. In order to quantify the amounts, some sense of how much oil remains must be gained.

The estimation of what to expect from future discoveries has been simplified somewhat by the understanding of the size distribution of oil fields. Figure 1 shows the breakdown of quantities of oil discovered according to field size. It is striking that three-quarters of all discovered oil is in giant fields of more than 100 million barrels; only 8 percent is found in fields smaller than 10 million barrels. The giant fields, because of their size, have been easy to locate once exploration has begun in a new area. This history of onshore oil discovery in the 48 states, when organized by field size, shows clearly the progressive dominance of smaller fields in the discovery process (Figure 2). When production history is divided into two groups — giant fields and all others — the giant-field dependency shows quite clearly (Figure 3). The largest field in the United States — Prudhoe Bay in Alaska — accounts for the temporary reversal of the 1970 to 1976 oil-production decline. Our giant-field dependence continues. Almost half (45 percent) of our proven oil reserves is in just five fields, and four of these were discovered before 1932 (see Table 1). Prudhoe Bay alone accounts for 30 percent of proven reserves. The four giant fields discovered before 1932 are already well into steady decline. Even Prudhoe Bay is expected to begin its long decline in the late 1980s; water flooding for secondary recovery (see page 30) at Prudhoe Bay is about to begin.

The dependence on very large fields is a worldwide phenomenon. The four largest fields

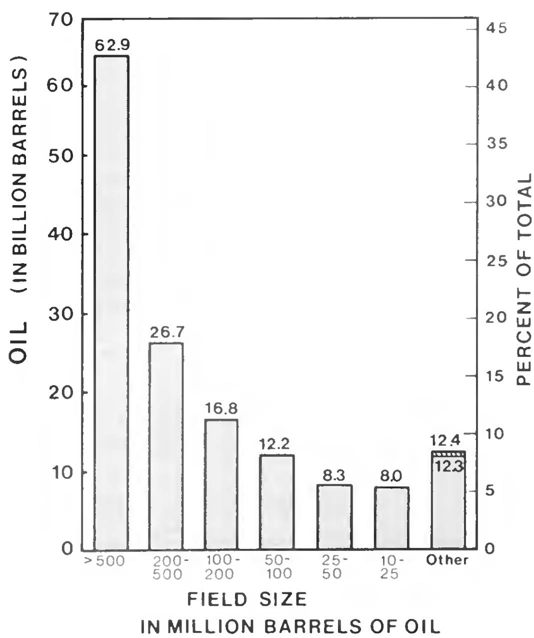


Figure 1. Distribution of crude oil by field size. (From Nehring, 1981)

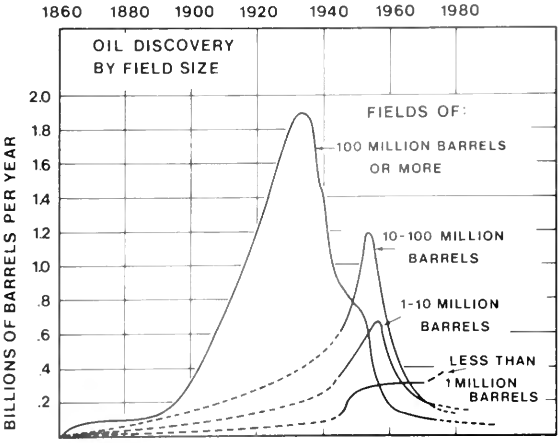


Figure 2. Discovery history of oil according to field size. (From Menard, 1976)

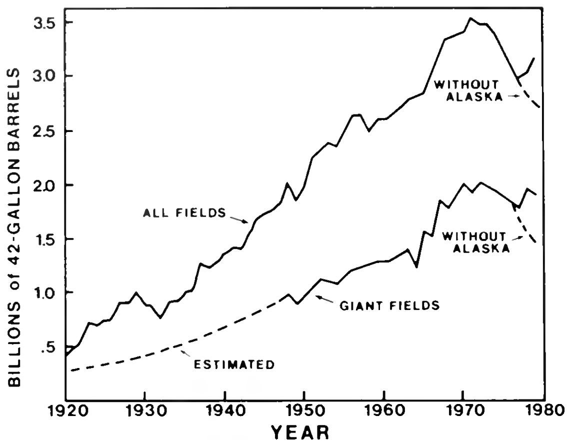


Figure 3. U.S. historical oil-production showing giant-field dependence. (From Steinhart and McKellar, 1982)

account for 20 percent of world oil production, and 481 of the 22,000 known fields contain more than 80 percent of known reserves. A. A. Meyerhoff of Tulsa, Oklahoma, discussed the implications of this large-field dependence in "Economic Impact and Geopolitical Implications of Giant Petroleum Fields" published in *American Scientist.*

Estimation of undiscovered oil depends heavily on the degree to which the content or the existence of giant fields can be predicted. Most of the oil in frontier areas is in these very large fields, and if our predictions about those are nearly right, it is a simple matter of increasing the totals somewhat to allow for the numerous small fields that may be found later.

It is on this point that some participants disagree. There are industry people and public officials that reject estimation; many others have faith that the large fields will be found. Hubbert once asked a geologist responsible for some of the largest estimates of future oil discoveries why his estimates were so large. The geologist said that the oil has to be there because we need it. Other believers represent versions of the old-time wildcatter: a person who does not believe will not be long in the wildcat drilling business. Although defensible as a personal conviction, this faith in the unlikely has infected some business and government leaders, including the Secretary of the Interior and the Assistant Secretary for Minerals and Resources.

Faith and hope notwithstanding, estimates of undiscovered oil resources are developed in two general ways: historical-trend analysis and geological analogy.

Historical Trend Analysis

The best known practitioner of historical-trend analysis is Hubbert. In 1956, he accurately predicted the peak of U.S. oil production in 1970 and its subsequent decline. Despite intensive analysis since, Hubbert's projection is the only example of an accurate prediction made well in advance with a defined, repeatable technique.

Most historical analysis begins with the simple observation that production of a finite resource starts at zero, grows for a time, peaks in a mature phase, and ultimately declines. The problem then becomes how to fit a curve to that history, and identifying constraints on future production and discovery. Obviously, such a technique works best with a resource for which the art of exploration is well advanced. There is no argument about production in the past. The constraints are known: (1) the total produced must equal the production plus reserves, and their extensions (enlargements on known reserves) plus undiscovered producible amounts, and (2) the last phase of production must be continuously declining as it approaches depletion. This second constraint means that we know the shape of the "tail" of the curve. However, the onset

Table 1. The five largest oil fields in the United States.

Field	Location	Year of Discovery	Production as of 1/1/83	Proven Reserves as of 1/1/83 (All quantities in billions of barrels)	Estimated ultimate recovery
1. Prudhoe Bay	North Slope, Alaska	1968	2.67	6.76	12 ± 2.0
2. East Texas	East Texas	1930	5.18	1.27	7.5 ± 0.5
3. Wilmington	California	1932	2.07	0.33	3.5 ± 0.5
4. Midway-Sunset	California	1912	1.55	0.42	3.0 ± 0.5
5. Yates	West Texas	1926	0.92	1.03	3.0 ± 0.5

of this phase is signaled only when reserves and their extensions are much more prominent as remaining resources than as new discoveries. This phase should be expected when about 10 to 20 percent of total, ultimately producible amount of oil remains.

Hubbert used the logistic-growth curve* for his projections, which occur widely in systems with growth limits. C. L. Moore also used a Gompertz curve* with an additional parameter for his estimates. J. J. Wiorkowski dealt with the curve-fitting problem by relying on a generalized family (the Richards function*) of curves, which includes both the logistic-growth and Gompertz curves as special cases. Although formal goodness-of-fit statistics may be determined for the curve fitting, they reveal little about the accuracy of the derived oil estimates. Nevertheless, U.S. oil-discovery and production data fit the same logistic-growth curve quite well thus far (Figure 4). There is no implied, inevitable history destined by such a fit. Some depletion histories for U.S. resources fit logistic curves (anthracite coal, for example), and some do not (bituminous coal and mercury, for example).

H. W. Menard's work with random exploration drilling models makes use of historical-discovery data in a different way. The computer could generate many "might-have-been" histories of random-drilling searches and determine how rapidly the presently known oil fields would have been discovered. Knowing that oil is concentrated in the largest fields helps, because large fields are the most likely to be found by a randomly located drill hole. But one could also suppose, along with J. D. Moody and others, that there remain undiscovered, on the land of the lower 48 states, 50 more giant oil fields. Since these fields must be in the localities examined during the history of oil exploration, a random-drilling program would have found almost all of them by now. There are a few who believe this. At heart, oil-company executives do not: it would be an easy matter for a few large companies to end all costly exploration on the lower 48, fire their expensive staffs, and mount a random-drilling program that would pay off with all the certainty of the house take at Las Vegas tables. The more obvious explanation is that these giant fields do not exist in well-explored areas. It is possible, after work with random-drilling models, to believe that a large number of undiscovered giant fields exist only if one also believes that the scientific search for oil by geologists and geophysicists consistently results in decisions to drill in the wrong places.

A model proposed by L. J. Drew, J. H. Schuenmeyer, and D. H. Root in 1980 describes the discovery process in partially explored basins, and can be used to predict the size distribution of future discoveries in a given basin. No geological assumption need be made, since the parameters of the model are obtained directly from the historical drilling record. Projections of ultimate yield are made

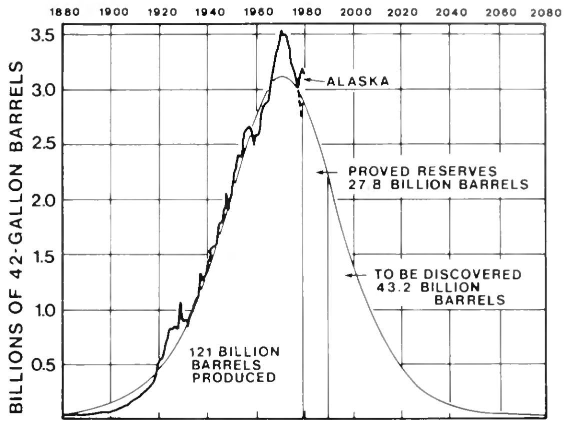


Figure 4. Annual U.S. oil production with logistic-depletion model fitted. Curve was fitted to production data for 1930 through 1979. (From Steinhart, 1979)

possible by the progressive exhaustion of possibilities as a result of continued exploratory and developmental drilling. Clearly, the large targets — which contain most of the oil — are first identified by the drilling. The authors point out that the area-exhausted model has been used in the Denver basin with much success. Using only pre-1956 discovery and drilling data, the model correctly predicted the size distribution from 1956 to 1974.

These historical-trend analyses were tested on the Los Angeles Basin, using historical data terminating in 1920 and at the end of each succeeding decade. All converged with the present estimates; the random-drilling model, which was not really devised for this purpose, was less stable, and the Gompertz curve used by C. L. Moore converged very slowly for purely mathematical reasons. The area-exhausted model, devised for basins, was exceptionally stable and converged early. The success of these projections is all the more surprising because neither the production or exploration histories of the Los Angeles Basin especially resemble the generalized curves they fit.

There are other variations and combinations of historical-trend analysis. Figure 4 illustrates results for aggregate U.S. oil production. Several facts are apparent. First, by separating Alaska (mainly Prudhoe Bay) from the trend, it is clear that only the enlargement of the area under consideration and production from the largest U.S. field ever found have slowed the decline in production. Second, the most vigorous criticism of these analyses — that they take no account of price impacts — is not cause for rejection of the results. The Great Depression, when oil prices dropped to 50 cents a barrel, shows clearly enough in the production history, but is not very important in the overall production circle, however cataclysmic it may have been to the industry.

Too little attention has been devoted to the advantages offered by historical analyses of this type. The ability to repeat the analysis with different fitting procedures allows for checks not possible with judgmental geological estimates. Comparison of Figure 4 with other such estimates suggests that

*These statistical formulas are growth curves, which represent activity as it increases over time.

Offshore rig near Santa Barbara, California. (Photo by Joe Munroe/PR)

variations of ± 20 percent can arise from choice of fitting procedures. Implicitly, these methods contain the collective geological judgments of the past which, in turn, rest on more disaggregated data than any single geological estimate. In addition, only historical-trend analyses compensate for future technological change. Embedded in the data is the history of technological advance in the oil industry. Implicit in the projections is a continuation of this advance. Even the historical expansion of available areas is so embedded. It took a super giant like Prudhoe Bay to show as a dramatic aberration.

Geological Analogy

Geological analogy has a very simple underlying concept. If a virgin area, A, has a similar geology to an already quite developed area, B, then the petroleum potential of area A is similar to that of area B, which has already been determined. The problem is that many areas with quite similar geologies have quite different resource potential.

Estimation of petroleum potential through geological analogy has become more sophisticated than simply looking for accumulations of sediments with structures that might contain oil. Analogies based solely on sediment volume or areal extent of sedimentary rock accumulations have been made in the past and often have resulted in absurdly large estimates of oil potential. Such estimates can prove to be spectacularly wrong. For example, the eastern Gulf of Mexico off Florida, thought by some to have enormous oil potential, has yielded very little oil, despite large thicknesses of sediments and some large structures like the Deslin Dome. Clearly something was missing.

In order for commercial quantities of oil to be present, a series of conditions must have been met, in a particular time sequence. First, sufficient organic material must have been present and incorporated into the sediments as they were deposited. This organic material must not be oxidized (as would happen, for example, to decaying plant remains on the forest floor). Second, the organic-rich sediments must be buried deeply enough and long enough for petroleum to be produced in the source rock. Such source rocks are said to be thermally mature. Third, the oil must be forced out of the source rocks and migrate into reservoir rocks with sufficient pore space (porosity) to store the oil and enough interconnectedness among the pore spaces (permeability) to make future extraction possible. Fourth, these reservoir rocks must be contained by superposed impermeable rocks in a spatial geometry that traps the oil in the reservoir. Finally, these oil traps must not be breached by later structural deformation or erosion. Natural oil seeps, which led to the discovery of many early fields, show that this breaching does occur.

Each of these necessary conditions present somewhat different problems and, unless substantial geological data is available for the area to be evaluated, judgment and imagination play a considerable role. Even if all the necessary conditions are met, oil will not be found unless the conditions have occurred in proper sequence and with adequate time duration. The time factor cannot be specified very exactly and is difficult to evaluate. The North Slope of Alaska, the North Sea, and the offshore of Mexico's East Coast yield to these methods, but the same methods failed in the Outer Banks of the offshore regions of California, the Baltimore Canyon, central Iraq, and the eastern Gulf of Mexico.

Despite these objections, much of the effort to estimate the presence and size of undiscovered oil reserves has been devoted to geological-analogy methods. Some estimates of this sort must be correct since nearly every possible outcome has been predicted by someone. Because the estimates depend on basic geological judgments, the estimates stand as conclusions; they cannot be checked, they can only be accepted or rejected. Sadly, it appears that public officials seem to choose those estimates that suit their own wishes and programs.

The difficulty can be illustrated by contrasting two lengthy and ambitious recent estimates. G. L. Dolton and others provided the latest in a long series of estimates of ultimately producible oil emanating from the USGS. Although this USGS estimate is not so wildly optimistic as those of a decade ago, it is still among the largest of recent efforts. Specifically, Dolton and his colleagues conclude that there is a 95 percent probability that *more than* 64 billion barrels of undiscovered recoverable oil remain. An even more ambitious, basin-by-basin study done by the Rand Corporation in 1981 concludes that there is a 90 percent probability that *less than* 32 billion barrels of producible oil remain to be discovered. Not only do the estimates not overlap but, if the limits met formal statistical requirements, the two results could not happen. Closer inspection of the reports shows that the probabilities also are subjective estimates and thus carry no more information about actual limits than the (subjective) average values.

Comparison of the disaggregated estimates between Rand and the USGS shows that the major disagreements arise not from extensions to proven fields or, as might be expected, in the relatively unexplored areas in the offshore frontier, but in the onshore areas of the lower 48 states. The USGS concludes that 48 billion barrels are likely to be discovered in these well-explored areas. The Rand study estimates less than 5 billion barrels, which is typical of many estimates. One cannot help but wonder if the desire to lease controversial areas stimulated these improbably large estimates.

The least known areas that remain are the continental slopes. There has been extensive production offshore until the 1950s in water depths up to 200 meters. This is the continental shelf, geologically similar to the continent, but underwater. The water depths on the slopes range from 200 to more than 2,000 meters. Little exploration data and only a few holes exist to limit the imagination in this area. Different sedimentary processes operate here and sediment materials also differ. Opinions vary wildly among analysts, a majority holding that the slopes will yield little or no commercial oil, and a significant minority that is quite optimistic. Even so, the most optimistic experts assembled by the USGS estimate an upper limit or a 6-year supply roughly equal to the Prudhoe Bay field.

It comes down to this: the only well-defined and repeatable (and occasionally successful) methods project a rather bleak future for U.S. oil discovery. They cannot encompass areas with no exploration; thus, optimists and pessimists can make their own guesses. But some restraint is in order. It was very unusual to find even one field as large as Prudhoe Bay in U.S. territory, given the distribution of world oil. The possibility that another will be found is very unlikely, indeed. The offshore frontiers in Alaska (especially the Beaufort Sea) and some California offshore areas represent the most significant possibilities. Lease bonus bids may represent the collective opinion of the oil industry at present. Merger and acquisition data show that proven reserves of oil sell for about $5 to $10 a barrel. Bids of $2 billion for Beaufort Sea leases suggest the industry is expecting to find oil in amounts of a few hundred million to a few billion barrels there. Other frontier bids for much smaller amounts, or the lack of bids, suggest much less optimism about the existence of large amounts of undiscovered oil.

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Land rig installed on man-made island in Alaska. (Provided by Petroleum Extension Service, University of Texas at Austin)

Domestic Options to

by Don E. Kash

The issue of offshore oil and gas production was propelled onto the public agenda by two events in the late 1960s and early 1970s. An oil-covered bird in its death throes, pictured on the cover of *Life* magazine at the time of the Santa Barbara oil spill in 1969, heralded the beginning of broad public consciousness that offshore oil development holds environmental risks. Long lines at gasoline stations following the Arab oil embargo of 1973 symbolized the need for more domestically produced oil.

Looking back over the last decade, it is difficult not to view the struggle over offshore oil development as a microcosm of a much broader set of concerns involving the "energy crisis" on the one hand and the raised environmental consciousness of Americans on the other. This is because industry and government experts believed that offshore areas held the greatest potential for large new reserves of oil, while environmentalists saw coastal ecosystems as fragile and petroleum-resource development as a direct threat to those ecosystems. Moreover, since most of the offshore oil was federally owned, it was an energy resource uniquely susceptible to pressure from a broad range of political interests.

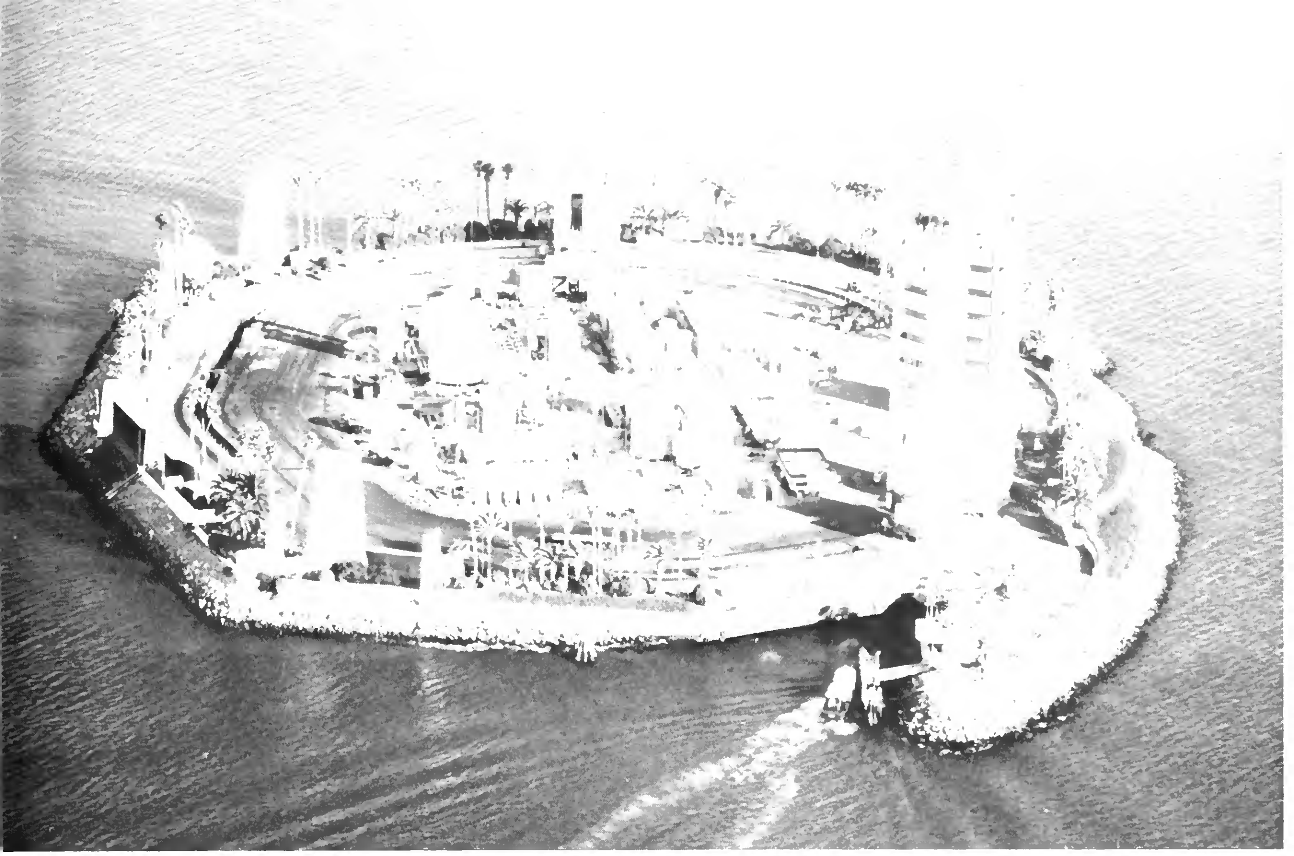
A decade after the oil embargo, Secretary of the Interior James Watt's leasing program, which offers the industry one billion offshore acres from which to select tracts, has reinvigorated the energy-versus-environment struggle. The pattern of continuing controversy over offshore oil and gas has given impetus to the search for domestic energy alternatives.

All Sources Needed

The either/or character of the debate about energy under the oceans is unfortunate. In truth, the nation needs to pursue both offshore oil and other domestic liquid-fuel sources if it is not to become increasingly dependent on imports.

Offshore areas are an attractive potential source of petroleum. The United States Geological Survey (USGS) estimates that roughly a third of the undiscovered recoverable oil and gas resources in the United States is located under coastal waters. And it is widely believed that those waters hold the most likely prospect of giant oil fields — fields with sufficient productive capacity to make a difference in the nation's future oil-supply situation. In fact, in the case of the deep-water and Arctic environments, only very large, highly productive oil fields will be able to justify initial development costs.

To appreciate the issues that surround offshore energy development, a distinction must be



"Beautified" artificial island for oil and gas operations located in Long Beach Harbor, California. (Photo by Steve Proehl/PR)

Offshore Oil and Gas

made between the nation's situation with regard to oil and that regarding natural gas. At present, the nation's gas supply situation is one of surplus, and many estimators believe this surplus may continue for some years.

Conversely, there is serious and pervasive uncertainty about the future of domestic oil supplies. Most estimates suggest the United States will remain heavily dependent on oil imports for the foreseeable future unless substantial new domestic supplies are developed. Projections of continued heavy import dependence result from the expectation that domestic petroleum production will steadily decline, even with substantial discoveries offshore.

The Congressional Office of Technology Assessment estimates that, with conservation and fuel switching (by electric power plants, for example), we may, by 1990, be able to cut our oil consumption by as much as 1.8 million barrels a day. These savings, plus possible savings of 0.6 million to 1.3 million barrels of oil per day from improved efficiency in the transportation sector, are based on real optimism. Unfortunately, such oil savings roughly parallel estimates of the decline in domestic petroleum production. Simply stated, if one takes both optimistic projections of oil conservation and optimistic projections of new discoveries of oil, including substantial discoveries off U.S. coasts, import dependence remains constant.

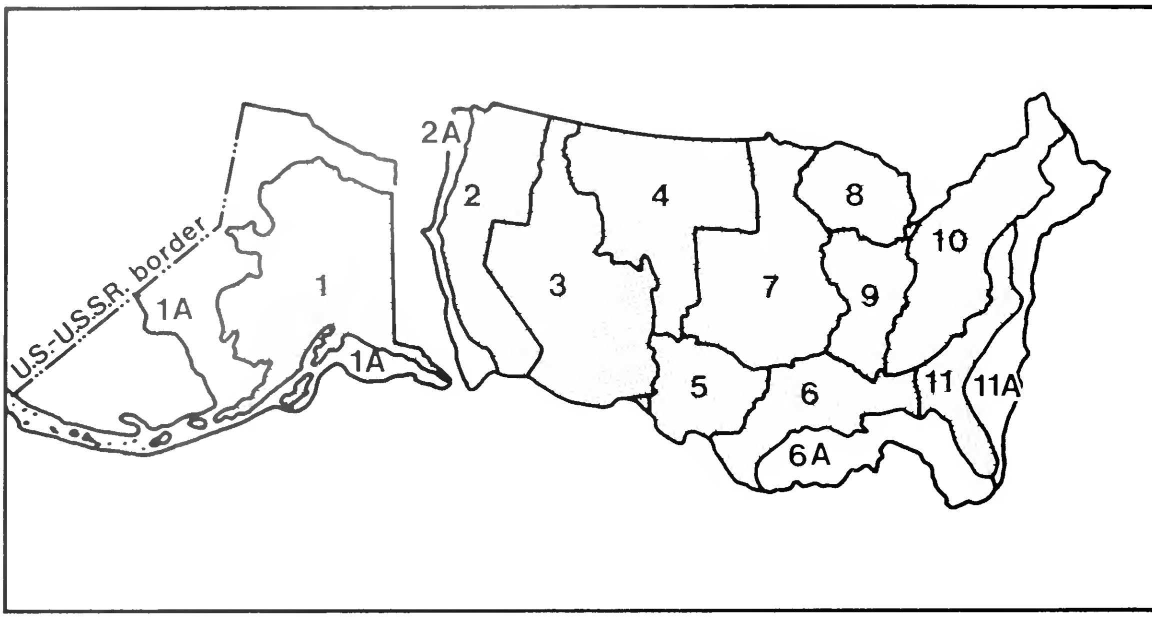
The fundamental and seemingly intractable problem for the United States is its inability to switch to nonliquid fuels for transportation. Transportation uses 60 percent of the nation's oil, but no alternatives exist. Similarly, the estimated one-quarter of our oil used in the manufacture of products — a highly valued use — is unlikely to shrink.

In 1982, as a result of major conservation achievements and a serious economic recession, U.S. consumption of oil declined from a peak of 19 million to 15.3 million barrels a day. Domestically produced petroleum supplied 10.2 million barrels a day, and imports or existing stocks supplied the other 5.1 million barrels a day. The nation was roughly one million barrels a day less dependent on imports in 1982 than it was at the time of the embargo.

The Office of Technology Assessment expects domestic production to drop from 10.2 million barrels a day to 7 million barrels a day by the year 2000. That projection assumes continued development of offshore oil fields.

If the nation's production picture is to be turned around, it will require the discovery of more Prudhoe Bays. Without the large oil fields beneath Prudhoe Bay, Alaska, domestic production in 1982 would have been only 8.7 million barrels a day instead of 10.2 million. The easiest way to characterize the nation's domestic oil-production

Estimated Undiscovered Domestic Oil and Gas Reserves



Onshore regions	Crude oil (billion bbl) Low	High	Mean	Natural gas (trillion cu. ft.) Low	High	Mean
1 Alaska	2.5	14.6	6.9	19.8	62.3	36.6
2 Pacific Coast	2.1	7.9	4.4	8.2	24.9	14.7
3 Colorado Plateau & Basin and Range	6.9	25.9	14.2	53.5	142.4	90.1
4 Rocky Mountains and northern Great Plains	6.0	14.0	9.4	29.6	69.0	45.8
5 West Texas and eastern New Mexico	2.7	9.4	5.4	22.4	75.2	42.8
6 Gulf Coast	3.6	12.6	7.1	56.6	249.1	124.4
7 Midcontinent	2.3	7.7	4.4	22.9	80.8	44.5
8 Michigan basin	0.3	2.7	1.1	1.8	10.9	5.1
9 Eastern Interior	0.3	1.9	0.9	1.2	5.0	2.7
10 Appalachians	0.1	1.6	0.6	6.4	45.8	20.1
11 Atlantic Coast	0.1	0.8	0.3	0.1	0.4	0.1
Total onshore	41.7	71.0	54.6	322.5	567.9	426.9
Offshore regions (shelf and slope)						
1A Alaska	4.6	24.2	12.3	33.3	109.6	64.6
2A Pacific Coast	1.7	7.9	3.8	3.7	13.6	6.9
6A Gulf of Mexico	3.1	11.1	6.5	41.7	114.2	71.9
11A Atlantic Coast	1.1	12.9	5.4	9.2	42.8	23.6
Total offshore	16.9	43.5	28.0	117.4	230.6	167.0
Total U.S.	64.3	105.1	82.6	474.6	739.3	593.9
Lower 48 onshore	36.1	62.0	47.4	288.6	525.9	390.3
Lower 48 offshore	8.7	25.1	15.8	66.1	148.2	102.4

Source: International Petroleum Encyclopedia, 1982

Undiscovered resources as estimated in 1980 by USGS for conventionally producible oil and gas. Low and High totals based on 95% and 5% probabilities, respectively, of discovering more than listed. *Figures do not add due to rounding. ±Resources recoverable only with technology for exploitation of Arctic ice-pack regions. (IPE/USGS)

situation is to note that, at a production level of 10.2 million barrels a day, the nation uses 3.7 billion barrels of domestically produced oil each year. Just to sustain production at that level, then, the United States has to discover the equivalent of a new Prudhoe Bay oil field every three years. Even with substantial success offshore, few observers expect that kind of discovery rate.

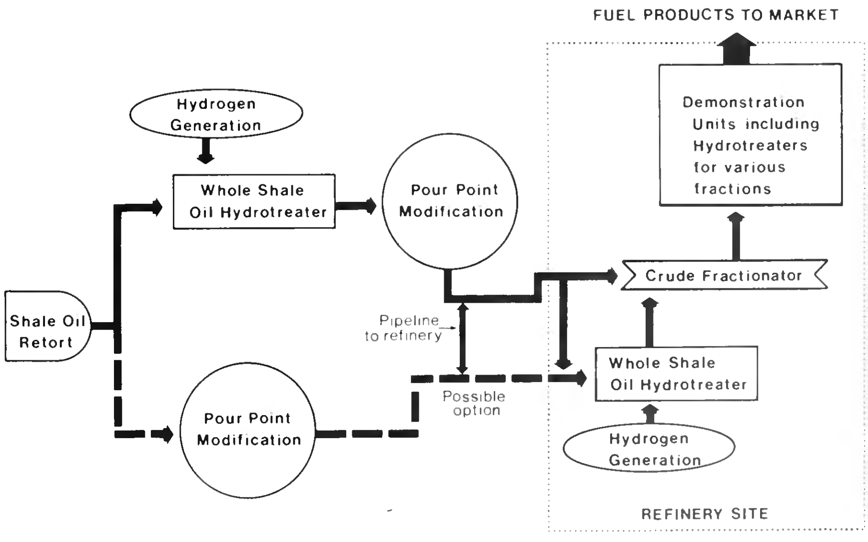
The Alternatives Outlook

Two potentially large sources of liquid fuel stand out as other possible options. One is liquid synfuel from coal and oil shale. The other is liquid produced from natural gas. Coal and oil shale synthetic-liquid technologies have been tested on a small scale, but there is basic disagreement among experts concerning when liquid fuels from these technologies can be made available and what they will cost.

The uncertainty surrounding synthetic-liquid technologies flows from our inability to predict the problems that will be associated with scaling synthetic-fuel production plants up to commercial size. No science of scaling up exists. The only way to determine how effectively such plants will work, what their costs will be and, of equal importance, what their environmental impacts will be, is to build and test them on a commercial scale.

Commercial synthetic-liquids plants are very expensive. Estimated capital cost per plant is somewhere between $3 billion and $5 billion. Constructing such a plant requires a long lead time and large-scale technical, economic, and managerial capabilities. With long lead times and high costs, even the largest energy corporations have found it difficult to justify the risks — witness the shutdown of the Exxon Corporation's Colony Oil Shale Project in Colorado. Corporate managers must be influenced by not only the great technical, economic, and environmental uncertainties associated with such plants, but also by the unpredictability of the future world price of oil. Because capital investment is so large, poor performance in any part of a plant, including emissions and environmental controls, could make it a financial disaster. Should a synfuels plant operate at only 50 percent of its design capacity, the cost of the output liquids could be 60 to 70 percent higher than estimated.

Unanticipated environmental problems could be equally costly, and the environmental impacts of

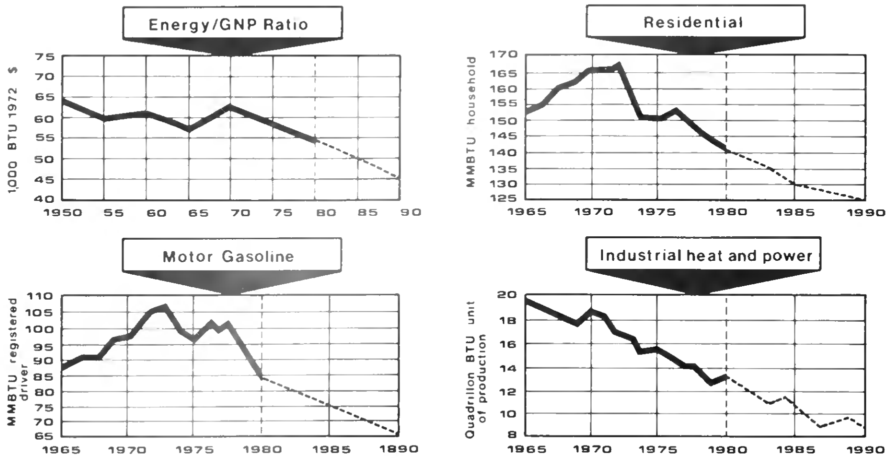


Shale oil upgrading/refining options. Boxed area denotes processing that cannot be accomplished onsite. (IPE)

Comparison of Properties: Shale Oil and Conventional Petroleum

	API gravity	Sulfur (wt%)	Nitrogen (wt%)	Pour point °F.
Raw shale oils				
Surface retorting	20	0.7	2.0	70-90
Modified in-situ retorting	25	0.6	1.3	50
Petroleum crudes				
Alaskan North Slope	27.5	1.0	0.04*	30
Rocky Mountain low sulfur	39	0.2	0.03*	7
Rocky Mountain high sulfur	26	2.3	0.01*	0
California (heavy)	19-24	1-2	0.1-0.3*	-5 to 90

***Nitrogen contents for petroleum crudes based on 525 °F. to 1,000 °F. cuts.**
Source: International Petroleum Encyclopedia, 1982.



U.S. energy conservation. During 1970s, conservation became a major energy source. Consumption dropped dramatically, while GNP grew, proving that conservation need not reduce economic growth. Dotted lines represent projections for future trends. (IPE/Shell Oil)

synthetic-fuel plants will be significant. For example, a 50,000-barrel-a-day oil shale plant will consume roughly 25 million tons of shale per year. That is, each plant will require a mine roughly equal in size to the largest surface coal mine in the United States. Producing one million barrels a day of liquid petroleum from shale, or 1/15 of the amount of oil consumed in the United States in 1982, will require 20 huge mines. The risks associated with commercializing synthetic fuels from coal parallel those associated with oil shale.

The second potentially large-scale option involves converting natural gas to liquid fuel for transportation. The economic and environmental risks associated with this option are much smaller than for synthetic fuels. In the case of liquids from natural gas, however, uncertainties exist concerning whether there will be sufficient quantities of natural gas to supply its traditional markets and also supply the feedstock for liquid-fuel production. Although some observers believe there are huge, economically viable, new quantities of gas to be had from unconventional and very deep sources, there is no consensus on this point.

Clearly, the most unconventional (some would say "far out") theory is that which argues the abiogenic origins of gas. This theory holds that at the time the earth was formed, huge quantities of primordial gas were captured. Those making this argument suggest that much of the natural gas we use is from outgassing.* Were this theory to be proven, the gas potential of the United States might be huge, but for most petroleum geologists, this theory smacks of *Alice in Wonderland*.

More conventional estimators of huge gas resources argue that large quantities exist deep in the earth's crust below 15,000 feet. Discoveries of gas in such areas as the Deep Anadarko Basin of western Oklahoma have provided support for this theory, but there is nothing resembling agreement on the quantities existing at these depths.

Finally, there are estimates of huge quantities of gas to be had from such sources as the tight sands** running along the Rocky Mountains. In this case, the experts' disagreement is not so much over the quantities of gas contained in these sands as over our ability to develop technologies that will allow it to be economically produced. Gas-resource estimates are thus shot through with controversy and uncertainty.

Should the optimists be proven correct, natural gas could become a major domestic feedstock for synthetically made liquid fuels. At present, however, there are no large-scale plants in existence in the United States that can convert natural gas into liquid transportation fuels. The development of commercial-scale plants with such capability might provide the nation with a "backstop." Such technology offers an additional benefit. There are, around the world, reserves of gas not presently available to the world energy market because of our inability to efficiently transport natural gas. If commercial plants could economically convert natural gas into liquids, the world's supply of liquid fuels would be much larger and more diverse.

High Risk

At present, all of the alternative liquid-fuel options involve such high risk that it is unreasonable to expect the private sector to carry out the necessary tests to determine their feasibility. If the nation is to have any alternative domestic liquid-fuel supply options, it seems clear that a federally supported effort will be required. A federal program aimed at underwriting a demonstration program for the production of liquid fuels, on a scale of somewhere between 250,000 and 500,000 barrels a day, would have potentially large benefits for the nation. Certainly those benefits are large if one of the objectives is national security. Unfortunately, the Synthetic Fuels Corporation, established by Congress in 1980 to promote commercial synfuels development, has done little to develop liquid-fuel alternatives to oil. This was, perhaps, to be expected, given the current administration's opposition to government initiatives and subsidies.

It is important to emphasize that a federally supported alternative-fuels program should not

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*Gas escaping from deep in the earth.

**Geologic formations characterized by low permeability that impede the movement of naturally occurring gas to wells.

imply detailed government management. Quite to the contrary, government efforts to pick winner technologies and manage them so that they ultimately function in the commercial marketplace generally have not been successful. Federal subsidies for an alternative-fuels demonstration program such as that suggested here should be handled so that the government absorbs the major portion of the economic risk and leaves the management of the project to the individual private-sector concerns that will build and operate the plants. One attractive approach to such a subsidy program would be to have government simply provide a guaranteed market at a guaranteed price for the products of synthetic-fuel plants. Under such an arrangement, if the price of imported oil went above the negotiated price established for alternative fuels, there would be no extra cost to the government. Should the price of alternative fuels be higher than that of imported oil, the government would pay the difference.

It must be emphasized that the goal of an alternative-fuels demonstration program is to provide the nation with an alternative to heavy dependence on imported oil. The achievement of that goal also will require the pursuit of offshore oil. The justification for federal support of liquid-fuel alternatives must be viewed in the same way that one views the premiums paid for insurance.

The nation's situation with regard to liquid fuels makes it inappropriate to talk about a choice between offshore oil and gas development and alternatives to such development. There is a clear need for both.

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Acknowledgment

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ABOUT THE EDITOR: Maurice L. Schwartz received advanced degrees, including the Ph.D. at Columbia University. He has been a professor of geology at Western Washington University since 1968. Additionally, he is currently an adjunct professor at the Institute of Coastal Studies, Nova University. He is the Editor of SPITS AND BARS and BARRIER ISLANDS, volumes 3 and 9, respectively, of the Hutchinson Ross Benchmark Papers in Geology Series.

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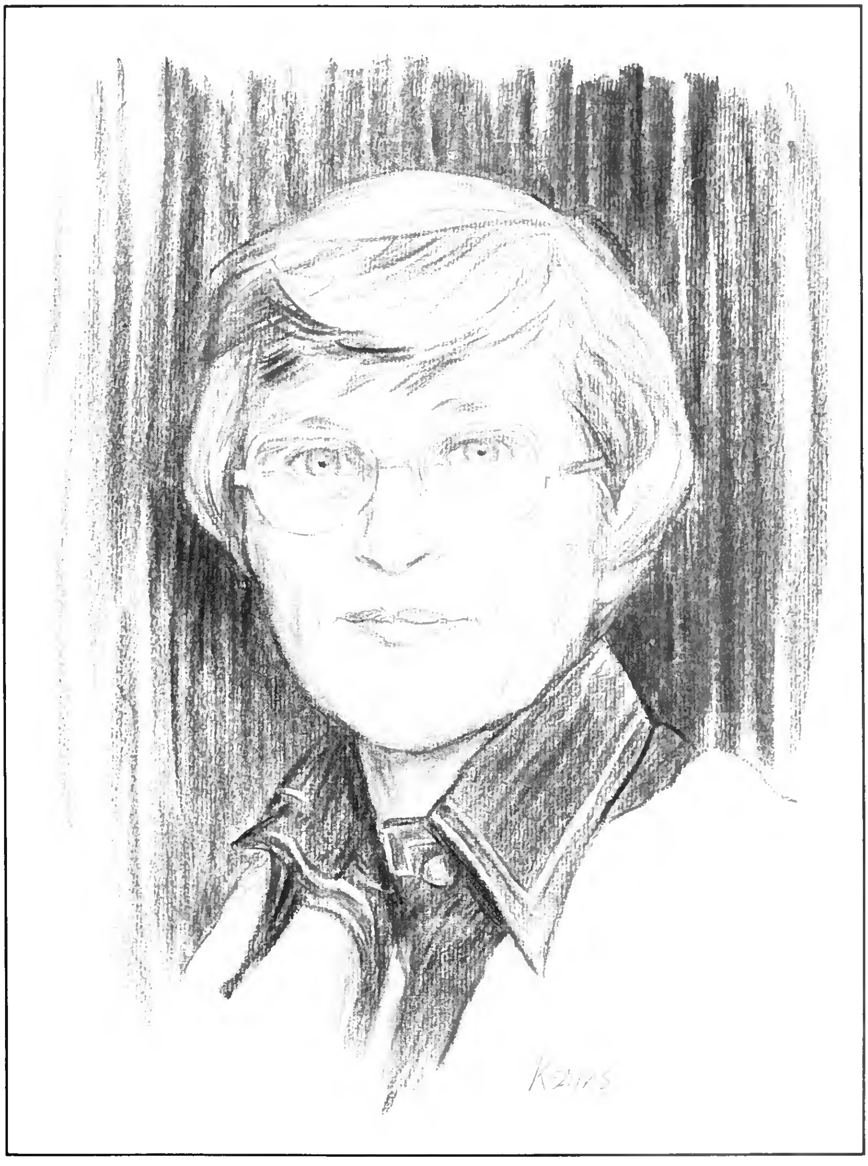
profile Ruth Dixon Turner



Portrait by Charles Kerins

Benthic Biologist

by Michael B. Downing

Topically, she tells you little about her personal life; it is her way. She gamely dodges all enticements to introspection; and yet she gives you her all. Watch her as she closes in on you to repeat a favorite incident or idea: her excitement is contagious.

Her specialty is wood-boring mollusks. "Only now are we beginning to learn something of their physiology. They are difficult to collect and are not attractive animals, so malacologists pay little attention to them — though they are extremely destructive to wooden waterfronts and boats."

Ruth Dixon Turner leans forward, lowers her voice. "But no one asked why. Why did this piece of wood get infested and not that one?" She allows herself a reflective smile as she moves back into her seat. "That's what got me started. That is what I have tried to do ever since."

Spurred by an interest in the systematics — "There were so many names, and the descriptions and figures of the species were so poor" — she soon found herself stumped by the very problem she was hoping to resolve. In her first paper on shipworms, she described a "new" species from the West Indies, only to learn that the species had been described from Sumatra 122 years earlier. "I was horrified that I should have made such a mistake, and I vowed that I would not describe another teredinid until I had made a complete inventory of every name in the family."

A few years later, still at work on the inventory "a great thing happened." Turner was invited to present a paper on teredinid systematics at a Friday Harbor symposium by Dixie Lee Ray. "How she knew who I was I don't know, but I will be forever grateful to her, because it was at that meeting I first 'met the Navy.'" Sid Galler, then head of the Oceanic Biology Branch of the Office for Naval Research (ONR), liked her paper, appreciated her problems, and asked what he could do to help.

Her vow to know her animals defined her needs: access and time. Funded continuously by ONR for more than 20 years, Turner appreciates the Navy's sense of perspective. "One of the great things about ONR is that they believe that good long-range research depends on continued support. Though I've never had really large grants, I have been able to plan long-term projects involving students, colleagues, and personnel in several branches of the Navy."

Her conversation is punctuated with references to these colleagues. She is the quintessential company woman — loyal and anxious for collaborative effort. Recounting a Navy experiment to collect boring and fouling organisms by placing panel arrays 50 feet below the surface to the bottom, at intervals from Fort Lauderdale to the Tongue of the Ocean, she pauses: "No university could support this kind of work, but by cooperating with John DePalma of the Naval Oceanographic Research and Development Agency we were able to prove experimentally that larviparous shipworms (those that brood larvae in their gills) were typically tied to shore and that the oviparous shipworms (with free-swimming larvae) were typically found in panels well offshore."

How could a whole family of obligate deep-sea wood borers — some 40 or more species — evolve, if there was no wood in the deep sea?

But, Turner and her colleagues discovered that the distribution of shipworms contradicted their experimental thesis, which was in line with general ecological theory. This sequence is exemplary: complete the experimental work and take your results to the field. When she straightens her 5′ 3″ frame in mock-military attitude and delivers her favorite command — "Know your animals" — it is clear that this biologist practices what she preaches. In fact, it is the larviparous species that get around the world. Unlike the oviparous species, whose larvae must feed in the plankton for 30 days or more, the larviparous larvae are ready to settle on floating parent wood when they are released. "It is possible that a wooden ship from Europe would be harboring the fourth or fifth generation of a larviparous species by the time it reached Australia."

Backed by ONR funding, Turner herself became something of an expert at getting around the world. She has worked in India with the Forest Research Institute on several occasions; that nation's fishing industry is particularly hard-hit by the damage done by the wood-boring shipworms. As a one-to-one exchange scientist under the U.S./U.S.S.R. Joint Committee on Cooperative Studies of the World Oceans, Turner studied the life history of *Zachsia zeukewitshchi*. It was the first she had seen of these animals in their sea habitat and she hopes someday to return to the marine station at Vostok to continue her research.

And only hours after this interview, she was headed 200 miles due south of Woods Hole to go down 3,600 meters in the Atlantic. "One of our most reliable sites. We're at the base of the shelf and below the edge of the Gulf Stream. We have placed quite a bit of wood there and several settlement trays, which Fred Grassle [Associate Scientist in the Biology Department at the Woods Hole Oceanographic Institute (WHOI)] and I monitor as regularly as possible."

"We" includes the crew and scientists aboard the catamaran *Lulu* and, of course, Turner's 16-ton diving companion *Alvin*, the deep submergence research vehicle operated by WHOI for the Navy. Turner's intended take is a new batch of *Xylophaga*, wood-boring bivalves.* The animals in this family (Pholadidae) are frequently confused with shipworms (Teredinidae). "These obligate deep-sea wood borers utilize the wood as a food and by so doing make this photosynthetic food source — which is recalcitrant enough to reach the deep sea without being eaten — available to the other animals and life systems in the deep."

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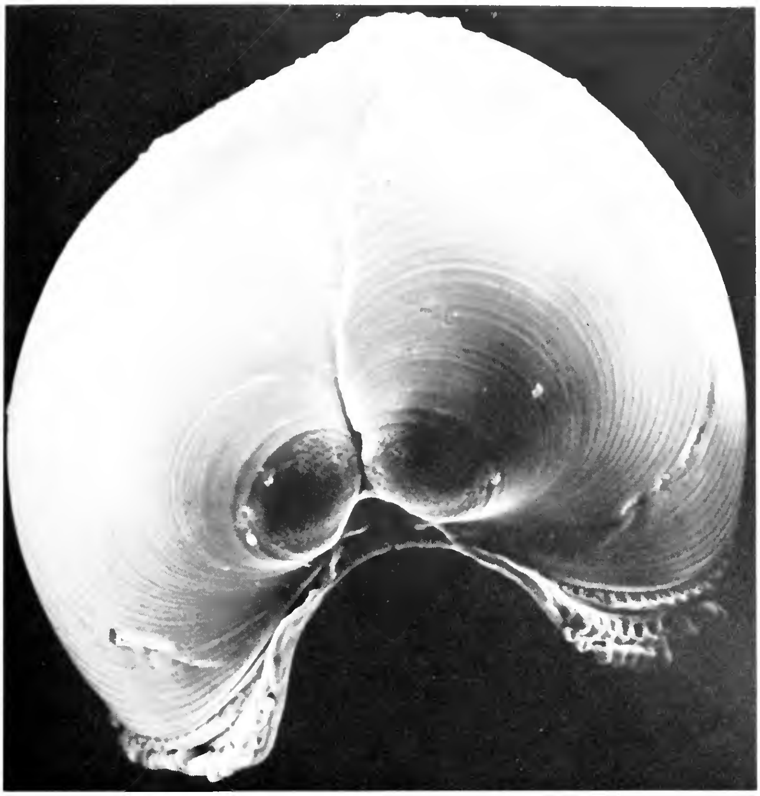
*In fact, Turner got something more. The wood left at the site 3 years earlier was greatly reduced. Many of the older *Xylophaga* were parasitized, indicating build-up of more complicated populations. And, among the animals retrieved, she has "definitely a new species, and possibly a new genus of wood borers."



A deep sea wood-boring bivalve, newly metamorphosed, taken on the scanning electron microscope at 300x. (Photo courtesy of Museum of Comparative Zoology/Harvard University)

These borers were the first known opportunistic species in the deep sea. Author of the definitive monographs on both Teredinidae and Pholadidae, Turner likely did not expect to be thrust into the international limelight by virtue of her pursuit of these species. Her increasing interest in deep-water borers, however, brought attention to her work.

"Whenever we put down wood we found them, yet the benthic biologists said they seldom dredged up wood. How could a whole family of obligate deep-sea wood borers — some 40 or more species — evolve, if there was no wood in the deep sea? This question bugged me for a long time.

"Then came that 'happy accident' when *Alvin* was lost and after 11 months on the bottom the condition of the lunches on board suggested that bacteria were not as active in the deep as had been thought. This led to the first controlled biological experiments in the deep sea and the establishment of the first permanent bottom station."

It was via an offer from Robert D. Ballard, formerly with ONR Boston and at the time associated with the WHOI *Alvin* group, that Turner first dove in *Alvin*. "I left Cambridge that afternoon and the next morning visited *Lulu* and *Alvin* and then boarded the *Gosnold,* because there were no living quarters for women on *Lulu* at that time."

Ferried to *Alvin* on a Boston Whaler for the dive, Turner recalls her descent in the sub as "through an inverted snowstorm of luminescence, an experience I'll never forget. Reaching the bottom, I gazed out the port virtually speechless for better than half an hour. When I finally got ready to make some notes I asked the pilot, Val Wilson, for the date. He said, 'Don't you know it is Friday, August 13th — and we had the courage to take the first female down in this thing?' It was the first I knew that I was making history."

Her career path to the benthos was not a direct one. The eight years after she took her B.S. she spent teaching, and curating the bird collection at the New England Museum of Natural History (forerunner of the Boston Museum of Science). As a biology instructor at Vassar and, in 1944, as a master's candidate at Cornell, the would-be ornithologist accidentally discovered Vassar's uncataloged and improperly stored mollusk collection.

Fascinated, she plunged from air to sea. After a 14-month stint at the William F. Clapp Laboratory in Duxbury, Massachusetts — "I relied on my basic biology to get me through the transition" — she joined the staff of the mollusk department at Harvard's Museum of Comparative Zoology (MCZ). It was there, in 1954, that she took her Ph.D. from Radcliffe and began to establish herself with the great biologists and marine scientists of the period.

Turner also was among the very last students taught by Henry Bigelow. On mention of his name, she leans forward again, lights a cigarette hurriedly. "Uncle Henry? He was great. I had a one-on-one course with him: Bigelow and Turner! He was quite elderly when I worked with him, and he could still figure out more that I didn't know in five minutes than anyone I've known. He was famous, but not petrifying: he scared me enough to let me know I had a long way to go. But, I figure that's what all professors are supposed to do!" As she leans back her voice gives way to an unusual wistfulness. "Though I've all but quit now, I still maintain that some of the very best conversation takes place over a cigarette. Nothing like it. I used to meet with Clench and Bigelow and all the others every day at Harvard for an informal smoking session on the steps of the MCZ. And I learned more there, listening for all I was worth, than in some courses."

By the mid-1950s Turner herself was emerging as one of the eminences she had so eagerly sought out. As a research associate, an Alexander Agassiz Fellow in Zoology and Oceanography, and a lecturer in the Biology Department, she became a fixture at Harvard — when she wasn't at one of her sites.

Science should be fun. There is always something new, something you hadn't planned.

"It has been exciting to put down 'islands of wood' and watch communities develop on and around them. The first to arrive are the larvae of wood borers." Within two years, grazers, filter feeders, scavengers, and predators abound. "How do all these species — we have taken 81 species from a piece of wood 24 x 6 x 1 inches — find the wood? What are their life histories? Their growth rates?"

These questions extend to her celebrated work near the thermal vents off the Galápagos Islands. "The thermal vents are also transient islands of food — based on chemosynthesis. My interest is to compare the feeding types, life histories, and growth rates of the animals around the vents with those around the wood islands." The results of this work suggest that growth and reproduction rates in the deep-sea species can be similar to those of littoral species.

Unlike many purists, Turner is anything but dismayed by the media attention to the exploration of the hot vents. "Anyone who can popularize science is great. They sell us. Literally. More people know about the excitement of the hot-vents research because of one National Geographic show than we could ever have informed. In India, people recognized me from the program. Such contributions are immeasurable. And any scientist knows that the glamor is less than 1 percent of the story. I suppose, though, that youngsters might get the wrong impression occasionally."

Frankly, Ruth Turner seems capable of dealing singlehandedly with student perceptions. "I get young students in the freshman seminars at Harvard; they are alive. It's just a matter of directing and sustaining them. And getting them caught up in the excitement of animal biology before someone else gets hold of them."

Promotion academically came late and quickly for Turner. She is a rarity for having never been in a tenure-track position before she was made a full professor at Harvard in 1976. And, in 1979, WHOI appointed her to the official post of guest investigator. Her collaborative work with Roger Mann, a WHOI biologist, has expanded over these years, embracing investigations in all related fields.

"At last, I am working with a group of people who can tackle all the problems. John Waterbury has cultured bacteria from the Gland of Deshayes found in the gills of shipworms, and shown that it both fixes nitrogen and digests cellulose. Roger Mann and Scott Gallagher are looking at energy budgets in larval and adult shipworms. Brad Calloway, a graduate student, works on histology and brooding biology. I'm an anatomist and systematist."

And something more. Competence and accomplishment constantly give way to a cultivated sense of wonder, and she elicits this sensibility in those around her. "Science should be fun. There is always something new, something you hadn't planned."

Including a surprise celebration of her 65th birthday during a 1979 cruise on *Lulu*, mention of which is answered with a begrudged smile. "I didn't realize it was my birthday — I don't know how old I am. But after the cake and all, Brodie (George Broderson) came up and pulled a silk rose from under his shirt. Where the hell he got it, I don't know. It is the most beautiful silk rose."

Birthdays notwithstanding, she won't stop diving in *Alvin* "until they just won't let me down." For the record, and to save her the "rigamarole" of counting up entries in her field book, a WHOI computer obligingly disclosed that the first woman scientist to dive in *Alvin* was, at the time of this interview, late for a prelaunch meeting for her forty-third dive.

"Cooperative work allows for the most rapid, efficient progress in this type of study. No one person has enough expertise to work alone." She speaks, characteristically, from experience. "Nothing replaces knowing your animals. That takes time — sometimes more time than you thought you had to give. Nine to five just isn't the way science goes, at least my kind of science doesn't. You can't control your time, schedule everything in advance. Science has its own ways."

Exacting, enduring, and cooperating — though she might not admit as much, Ruth Dixon Turner was talking about herself.

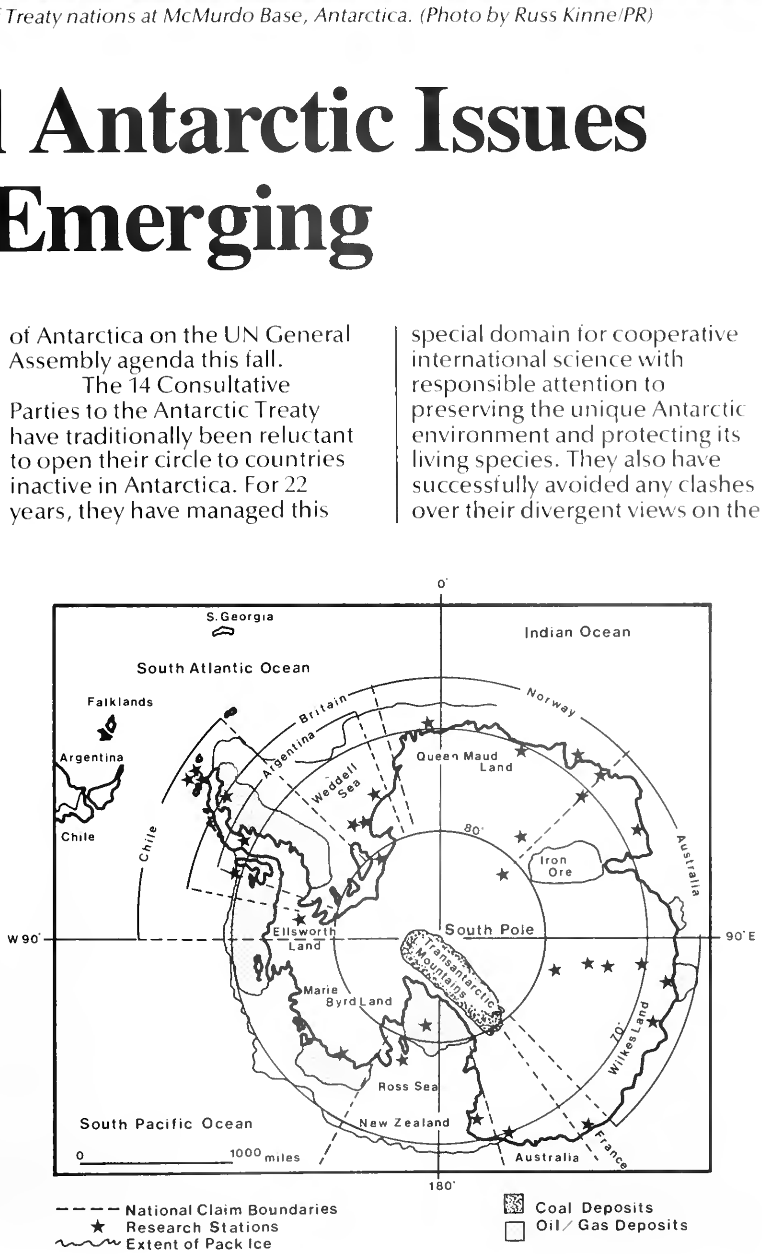
Bust of Admiral Byrd in front of the flags of Treaty nations at McMurdo Base, Antarctica. (Photo by Russ Kinne/PR)

Critical Antarctic Issues Emerging

After decades as a peaceful, scientific backwater, Antarctica and the Southern polar regions have emerged in 1983 to capture international and public attention. Special negotiations held this year to conclude a legal framework to govern minerals activities in Antarctica have sparked interest in the area as a source of potential mineral wealth. They also have aroused concerns among environmentalists and polar scientists worldwide about potential damage to the fragile Antarctic environment.

Increasing interest in Antarctic science among nations not party to the 1959 Antarctic Treaty, combined with the gleam of mineral wealth and the application of the common heritage of mankind principle to seabed minerals beyond national jurisdiction in the 1982 Law of the Sea Treaty, have brought a call to "widen international cooperation in Antarctica." For too long, in the eyes of many of the world's nations, Antarctica has remained the province of an exclusive "club," with vestiges of colonialism attached. Their heightened level of interest in Antarctica today seems guaranteed to place the question of Antarctica on the UN General Assembly agenda this fall.

The 14 Consultative Parties to the Antarctic Treaty have traditionally been reluctant to open their circle to countries inactive in Antarctica. For 22 years, they have managed this special domain for cooperative international science with responsible attention to preserving the unique Antarctic environment and protecting its living species. They also have successfully avoided any clashes over their divergent views on the



area's territorial status.* In effect, the 1959 Antarctic Treaty "froze" the territorial status of Antarctica in order to reach agreement on demilitarizing the continent and furthering the scientific cooperation engendered during the 1957-58 International Geophysical Year.

In 1959, however, the nations that became party to the Antarctic Treaty did not have to address resource-development issues and attendant questions of ownership. Even the upsurge in fishing activities off Antarctica in the mid-1970s did not pose insoluble difficulties. As coastal states' claims to 200-mile zones of fishery jurisdiction drove the distant-water fishing states south to new fishing grounds, the treaty members concluded a Convention on the Conservation of Antarctic Marine Living Resources in 1980, which sidestepped the issue of claims and fisheries jurisdiction off Antarctica. The Convention entered into force in April, 1982. Claims issues are not likely to arise until there are significant and competing fishing efforts in the Southern Ocean.

But minerals activities pose more difficult questions. Title to mineral resources must be secure and exclusive in order to obtain investments in the minerals operation. This requires a widely recognized mechanism to convey title. In Antarctica, the divergent views on territorial status mean that there is no simple answer to "Whose is it?"

In 1982, the 14 treaty members commenced negotiations to design a minerals regime for Antarctica. No doubt they will come to an accord on how to convey title to minerals, for they value the preservation of the Antarctic Treaty system.

*Seven treaty members claim sectors of Antarctica (Argentina, Australia, Chile, France, New Zealand, Norway, and Britain). The claims of Argentina, Chile, and Britain overlap. The other seven treaty members do not recognize any claims (Belgium, West Germany, Japan, Poland, South Africa, the Soviet Union, and the United States), although the United States and the Soviet Union maintain the right to make claim.

Nevertheless, they must now respond to the awakened interest of the international community.

The impending debate in the UN General Assembly this fall presents opportunities and challenges. It will be intricately intertwined with the initiatives of treaty members in minerals negotiations and in their regular biannual meeting, held this September in Australia. In April, 1983, the treaty members took the unprecedented step of inviting the 13 states with consultative status* that have become party to the Antarctic Treaty to attend the meeting as observers.

*China acceded in June 1983: other acceding states are Brazil, Bulgaria, Czechoslovakia, Denmark, East Germany, Italy, Netherlands, Peru, Papua-New Guinea, Spain, Rumania, and Uruguay.

The International Challenge

Activities by countries not party to the Antarctic Treaty raise additional questions about the treaty system. For the last two Antarctic summers, the Indian Government has sent expeditions to Antarctica, but as of July, 1983, had not decided whether or not it will ultimately adhere to the treaty, which may be subject to formal review beginning in June, 1991. There have been recent indications, however, that India will seek consultative status.

Any state is entitled to conduct peaceful, scientific activities under the Antarctic Treaty. The treaty members obviously prefer that these activities be conducted in accordance with the obligations and principles of the treaty. Activities conducted by nonparties are seen to undermine the application of the treaty. They also raise the possibility that these countries

Argentine Antarctic Institute. (Photo by George Holton/PR) may challenge the self-appointed and exclusive rights of the treaty members to determine the future of Antarctica.

The subject of Antarctica is not new to the international agenda. Over the years, several international community spokesmen have questioned the exclusivity and secrecy of Antarctic Treaty meetings and raised the possibility that Antarctica and its resources could be considered part of mankind's common heritage.*

The question of Antarctica was deliberately excluded from the Law of the Sea negotiations, which applied the common heritage of mankind principle to seabed minerals beyond national jurisdiction. Yet the recent conclusion of the Law of the Sea negotiations, combined with the Antarctic Treaty members' rush to complete a minerals regime, has fueled the belief that the treaty members may be about to appropriate exclusive decision-making responsibilities over, and benefits from, any minerals development which takes place in Antarctica.

There are two difficulties with transposing the common heritage concept as applied in the Law of the Sea Convention to Antarctica: first, seven of the parties to the Antarctic Treaty claim sectors of Antarctica. Only a renunciation of the claims could place Antarctica and its resources indisputably in the "commons" domain. This is unlikely in the near term.

*In September, 1982, the Prime Minister of Malaysia raised the question of Antarctica in the General Assembly, noting that: "It is now time that the United Nations focus its attention on [land areas which have neither natives nor settlers], the largest of which is the continent of Antarctica . . . . The fact remains that these uninhabited lands do not legally belong to the colonial powers. Like the seas and the seabeds, these uninhabited lands belong to the international community. The countries presently claiming them must give them up so that either the United Nations administer these lands or the present occupants act as trustees for the nations of the world."

Second, even though the seven other treaty members do not recognize the claims, they value the Antarctic Treaty regime and its accomplishments. They would be extremely reluctant to accept any precipitous change in procedures governing the area, and they would inevitably side with the claimants in trying to preserve the Antarctic Treaty and its guarantees of peace and stability in the Southern polar regions.

Antarctic Minerals Development

The third meeting in the negotiations for an Antarctic minerals regime took place in Bonn, West Germany, from July 11 to 22, 1983. Earlier meetings took place in Wellington, New Zealand, in June, 1982, and January, 1983. Three primary questions were addressed: 1) the "external accommodation," that is, how to not prejudice the interests of all mankind in Antarctica; 2) the "internal accommodation," relating to an agreement which both claimants and nonclaimants can accept in light of their differing views on the territorial status of Antarctica; and 3) how to protect the Antarctic environment and its dependent ecosystems.

There are no immediate prospects for commercial development of Antarctic minerals. Offshore oil and gas interests represent the most likely candidates for initial development activities, but these interests must first identify the potential. According to John Garrett, senior consultant to Gulf Oil Exploration and Production Company, "given the overhang of surplus capacity, I don't think oil prices will support anybody going to Antarctica in this century."

F. G. Larminie, General Manager of British Petroleum's environmental control center in London, told the Pacific Science Congress meeting in New Zealand in February of this year that he estimated it would take 25 years to extract marketable quantities of oil from the Antarctic if work started today, given the present state of knowledge of oil exploration technologies in ice-covered regions. And "that's without taking any account of economic considerations."

In the June, 1983, issue of *Offshore*, the magazine asked 22 of U.S. industry's top geologists if they were granted an unlimited exploration budget and the authority to go anywhere, where would they go and why. Michel T. Halbouty, former Chairman of President Reagan's Energy Policy Advisory Task Force, said, "Antarctica. [It] is the last truly frontier resource area on the earth . . . . The continental margins of Antarctica occupy an area roughly similar to the continental margins of North America and are comprised of sediment wedges many kilometers thick . . . .

"A portion of the offshore Antarctica margins that are conjugate to the Bass-Gippsland Basins of the Bass (Tasman) Strait in a Gondwanaland reconstruction may prove to contain large quantities of hydrocarbons. About 2.5 billion barrels of proven reserves are associated with the Cretaceous

Adélie penguins on an iceberg in Hope Bay, Antarctica. (Photo by Jan and Des Bartlett/PR)

and Tertiary sediments of the rift basins in the Gippsland Basin of Australia, which was apparently formed during or just prior to the breakup of Australia and New Zealand from Antarctica. The Ross Shelf-Balleny Islands area of Antarctica, conjugate to the Tasman Rise, has been surveyed using the seismic reflection method. This reconnaissance geophysical data, as well as drill hole information from several Deep Sea Drilling Project drill holes in the area, indicate a very thick sediment cover and thick concentrations of ethane and higher molecular-weight gases in the interstitial waters of the sediments."

The Antarctic Environment

How to protect the unique Antarctic environment and its dependent ecosystems is an issue of heightened concern among: 1) environmental constituents worldwide; 2) the treaty members, and in particular those most nearly adjacent to the Antarctic continent; 3) the world scientific community, whose activities in this pristine laboratory have made significant contributions to the store of scientific knowledge; and 4) international organizations with responsibility for the world environment.

Concern for the environment, however, coexists in tenuous harmony in the Antarctic sphere with 1) the sense of urgency in completing a minerals regime that must be accepted by consensus; 2) varying degrees of emphasis among the treaty members on development versus conservation goals, and on how to establish a decision-making process that can accommodate these biases; and 3) the political imperative of devising a structure for decision-making on minerals resources development that does not prejudice either the claimant or the nonclaimant position.

Since an Antarctic minerals regime will not emerge full-blown from these negotiations, but will rather provide a framework for the dynamic growth of institutions and rules as such activities become feasible, what is most important, from an environmental protection point of view, is that the principles and standards upon which decisions will be based, and the procedures for making these decisions, ensure maximum consideration of protecting the environment.

Under the minerals regime contemplated, the first determination will be the basic issue of the circumstances under which proposed mineral activities will be acceptable, if at all. All subsequent decisions will flow therefrom. The standards and criteria applied to this determination and how it is taken will be critical to protecting the Antarctic environment.

Lee A. Kimball,
Consultant to the International Institute for Environment and Development

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concerns

Reagan Stand on LOS Treaty Could Prove Costly

As has been noted elsewhere, including in the pages of *Oceanus*, the United States has decided not to sign the recently completed United Nations Convention on the Law of the Sea. While for the most part the provisions of that treaty are in concert with the United States' interests, those defining the regulation of deep seabed mining in the international area were deemed not to be.

Over the objections of many marine analysts, the Reagan Administration has decided on a strategy of embracing those treaty provisions it finds acceptable and moving independently in those areas where it finds the treaty lacking: a strategy of "pick and choose," if you will.

On March 10, 1983, President Reagan proclaimed an extension of the sovereign rights and jurisdiction of the United States to a distance of 200 nautical miles from shore (see *Oceanus*, Vol. 26, No. 2, p. 67). The establishment of a U.S. Exclusive Economic Zone (EEZ) was expected by most in the marine community and can be seen, at least in part, as an initial effort on the part of the Administration to begin to effectualize those aspects of the new United Nations Treaty on the Law of the Sea that it finds to be most in its national interest.

At face value this may seem a wholly reasonable if not enlightened approach. However, as with most decisions in the political arena, along with the benefits accrued from a given decision there are also attendant costs. In this case, the decision to stay outside the treaty and to act independently of it, could, under certain circumstances, incur substantial costs.

It should be remembered that the treaty whose ratification is being debated in more than 120 world capitals is the product of more than a decade of intensive negotiation. Its various provisions result from numerous trade-offs that have been skillfully molded into a tenuous package that pleases virtually no one and fully meets the interests of few, if any, countries.

When the United States attempts to selectively accept individual provisions from the treaty, it must realize it is doing so at some risk. Many international legal scholars have come to view the treaty as a contract fully applicable only to parties that have ratified or acceded to it. If this rather widespread opinion were to be accepted by a majority of the maritime states, the costs to the United States could be quite high. Two examples serve to illustrate this point.

The first concerns the status of strait transit. With the extension of the territorial sea from 3 to 12 miles, a number of international straits fall completely within the territorial seas of the adjacent countries. One of the earliest important compromises struck at UNCLOS III was that such straits could be freely transited under a new concept termed "strait transit," which allows for the unimpeded transit of ships through international straits and, importantly, for the submerged transit of submarines. Many legal scholars would suggest that strait transit is not currently customary international law and that the degree to which strait transit is now honored is because compromise on the concept was completed quite early in the bargaining to develop a comprehensive treaty. Strait transit does not exist in the international agreement currently in force; that is, the 1958 Convention on the Territorial Sea and the Contiguous Zone (in fact, Article 14: 6 of that treaty states that "[S]ubmarines are required to navigate on the surface and to show their flag").

If the United States were to remain outside the treaty, three different scenarios concerning this question could emerge. First, the United States could be successful in its arguments that transit passage is already part and parcel of customary international law and activities in such areas would proceed accordingly. Second, the United States could make the same claim but not convince certain key nations (such as Indonesia and Malaysia) and could face the protests and conflict that would emerge from those disagreements. Third, the United States could successfully negotiate a series of bilateral agreements with critical strait nations.

It is unlikely, given the United States' current relations with many developing countries, that it will be possible to gain universal agreement for either of the first two options. The likelihood of conflict over the issue is high. Even if the United States were to take its case to the International Court of Justice and win, the amount of time such a case would take to prepare, argue, and resolve would be long (even if the U.S. Department of Defense were to make available its transit records as evidence) and the costs of delay would be high. The third option also has several potential costs. The process of independently negotiating the numerous necessary treaties would also result in delays and larger expenses. Further, such bilateral or multilateral treaties, negotiated both serially and in parallel, should be consistent with one another, which could prove difficult given the differences in interests among coastal nations. If they are not consistent or uniform then the potential exists for confusion for both naval and general maritime navigation.

A second example is that of marine science. The Exclusive Economic Zone as defined in the convention, grants coastal nations limited jurisdiction over the regulation of marine scientific research within the zone. A coastal nation's consent is required to conduct research, but, according to the treaty, such consent shall be granted under "normal circumstances." While the concept of a 200-mile EEZ does exist independent of the treaty in international law (as ruled recently by the International Court of Justice in the Lybian/Tunisian case) the specifics of jurisdiction with regard to access for research within the zone do not. It is possible that a coastal nation, in retaliation for the United States acting outside of the treaty (and, in its eyes, outside the law), would refuse access to U.S. scientists. If such a practice were to become widespread, it could create substantial problems for the U.S. marine scientific community.

There are several reasons that favor coastal nations responding in this way. First, marine science is an ongoing activity that can be dealt with by developing nations in a politically timely fashion. Second, decisions on access are often made by government officials who do not appreciate the value of the scientific work being proposed (the value of the science is thereby inappropriately discounted). And third, it is easier to deny scientific access (essentially a passive act) than it is to force a transiting submarine to the surface. These reasons serve to highlight the present vulnerability of marine science to politically motivated actions driven by a U.S. decision to act independently of the Law of the Sea Convention. In fact, there is evidence that such problems are already emerging.

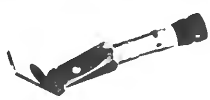
Systematic Evaluation Needed

The status of the convention and its individual provisions in international law figure prominently in the way the rest of the world will deal with the United States. An important consideration is the degree to which the treaty will drive the practice of coastal nations which is, in turn, largely a function of the number of countries either ratifying or acceding to the convention. If nonratification is widespread, the United States will be less open to the kinds of retaliation described here. If, however, the United States stands alone in its disapproval, the costs could be substantial.

What is needed, before much further action, is a more systematic evaluation of the specific benefits and likely costs that will derive from the unilateral approach currently favored by the United States. This nation's approach must be cautiously based on the actions of those nations that abstained in the final vote on the convention. Of those nations, Japan has already signed the treaty, and the Soviet bloc countries have said they will do so shortly. That leaves a rather small group of nations (which at this point includes several West European countries) still supporting the U.S. position.

This is not a situation in which the United States can afford to be too stoic. If Great Britain, West Germany, and Belgium decide to sign the treaty, the United States could incur costs that would well outweigh any potential benefits derived from rejecting the treaty. This is a time for the United States to tread lightly and to avoid precipitous activity, and to await an indication that "like-minded" nations will follow its lead.

Robert E. Bowen,
Research Fellow,
Marine Policy and
Ocean Management Program,
Woods Hole
Oceanograpic Institution



letters

To the Editor:

We were somewhat perturbed to read the article entitled "Ocean Dumping" by Farrington, *et al* (*Oceanus*, Vol. 25, No. 4, pp. 39-50, Winter 1982/3) and discover that, according to its Figure 1, one of the world's "major dumping locations" is situated off the west coast of New Zealand's North Island — the only such site in Australasia.

New Zealand is a small, sparsely populated, largely agricultural country with a small (by world standards) amount of heavy industry which produces what are commonly referred to as toxic or hazardous wastes. These wastes are either disposed of onshore, recycled, or discharged as minor components in the few major marine sewage outfalls around the coast. The little black square purportedly depicting New Zealand's sole ocean dump site is far removed from any such outfall, is alongside one of this country's most rural provinces, and is in fact the exact location of the Maui A natural gas production platform. This platform forms half the base of New Zealand's gas processing industry, and is operated for the government by Shell-BP-Todd Oil Services Limited. The only wastes discharged to the sea at this site are process wastes and sewage effluent and the company has never dumped any toxic or solid wastes in the area — it in fact has spent some considerable effort in removing material accidentally dropped from the platform from the seabed. Hardly a major dump site!!

The Taranaki Catchment Commission is the regional agency responsible for licensing all uses of natural water in this area, out to the 12 mile limit offshore, and it has no record of any dumping in the area.

Discussions with officers of the Ministry of Transport, the government department responsible for marine activities, have revealed that no ocean dumping of any kind of waste has occurred in this area, or anywhere in New Zealand to a degree which would rank the site alongside those in North America or Europe.

We would be most interested therefore to learn of any ocean dumping at this or any other site in New Zealand, and would request you to check with either the authors of the article, or the acknowledged source of the information (I. W. Duedall, *et al*) and either confirm or refute our contention that, in fact, New Zealand has no major ocean dumping site as defined in this particular article.

Mike Patrick,
Senior Water Conservator,
Taranaki Catchment Commission
Stratford, New Zealand

Janet Roborgh,
Co-Leader,
New Zealand Values Party

(Authors' Reply: Dr. Patrick and Ms. Roborgh have raised an interesting point. Figures 1 and 2 in the Oceanus *article of concern were taken, with permission, from Duedall, et al (1983) as cited. We have further checked the reference source for the data compiled in those figures. The data for ocean dumping off New Zealand were obtained from reports published by the Intergovernmental Maritime Consultative Organization, which is the Secretariat for the London Dumping Convention and of which New Zealand is a Contracting Party and reports annually specific information regarding ocean dumping permits.*

These reports are:

LDC 2/Circ. 31 (19 March 1979) for ocean dumping in 1976.

LDC 2/Circ. 33 (10 April 1979) for ocean dumping in 1977.

LDC 2/Circ. 47 (12 February 1980) for ocean dumping in 1978.

LDC 2/Circ. 64 (30 April 1981) for ocean dumping in 1979.

From these records New Zealand has reported ocean dumping the following:

1976 — *Industrial Wastes (fish processing wastes) sewage sludge, misc. solids (handcuffs, firearms, ammunition, wire rope), radioactive substances and dredged material at five dumpsites.*

1977 — *Sixteen permits were reported — 1 industrial waste permit, 14 dredged material permits, and 1 firearms permit.*

1978 — Twenty permits were reported — 2 for handcuffs and firearms, 1 for parts of aircraft engines, and 17 for dredged materials.

1979 — Sixteen permits were reported — 1 for liquid industrial wastes (the dumpsite we used in Figure 1, at which 10,000 m^3 of industrial wastes were ocean dumped), and 15 permits for dredged materials.

Thus, on a global scale, New Zealand dumps only a relatively small volume of waste compared to several Northern Hemisphere countries. However, we cannot refute absolutely the contention of Patrick and Roborgh "that, in fact, New Zealand has no major ocean dumping site as defined in this particular article" because the term "major" may have a different meaning in terms of global scale or regional scale.

Our intention was not to directly or indirectly chastise those nations involved in ocean dumping of any type of waste but to "advocate a flexible policy which explicitly recognizes that today's decisions [about ocean dumping] can be re-evaluated, modified, or even abandoned as new knowledge is acquired." ***Michael Champ, Professor, American University, and John W. Farrington, Senior Scientist, Department of Chemistry, and Director, Coastal Research Center, Woods Hole Oceanographic Institution***)

To the Editor:

Roger Revelle concludes his article "The Oceans and the Carbon Dioxide Problem" (*Oceanus*, Vol. 26, No. 2, pp. 3-9, Summer 1983) with, "Unless other forces intervene, mankind can look forward to a warm climate for a long time to come." Whenever I read, or teach, about how CO_2 will warm up the earth, I think:

— If CO_2 creates a "greenhouse" effect, which
— warms up the oceans and lakes, and
— this increases the rate of evaporation from the hydrosphere,
— which results in increased cloud cover and ice,
— which raises the earth's albedo so that
— less solar energy reaches the earth's surface,
— thus cooling this old planet, it won't get warmer.

Will the temperature of the earth go up or down? The answer is probably "yes." Dr. Revelle need not sweat it.

Cyrus A. Adler,
Director,
Shore Walkers of New York

To the Editor:

Greenpeace USA has initiated a research campaign to determine the status and ecological impacts of proposed activities on the Outer Continental Shelf. We are concerned that the Department of the Interior, in its frantic haste to develop our OCS resources, will overlook the possibilities of irreparable ecological damage. Of particular interest to this office has been the DOI's plan to begin selling leases for deep seabed mining.

In your article "Cobalt-Rich Areas Reported Within EEZ" (*Oceanus*, Vol. 26, No. 2, pp. 72-74, Summer, 1983), you postulated that "given the present low price of cobalt, manganese, and nickel on the international metals market, it is unlikely that ocean mining for manganese nodules and cobalt rich crusts will take place before the end of the century." The Minerals Management Service (DOI) has begun the process of offering the Gorda Ridge for deep seabed mining development, that will culminate with a lease sale *next year.* Would you care to comment on this?

In the same article, you also mentioned that "the interest of many commercial firms is now centered on the proposed Minerals Management Service lease program in the Gorda Ridge area." Which firms are those?

Evidence would seem to indicate that the DOI is willing to offer leases at the first sign of interest, before substantive geological information (or competition) arrives. Would you be inclined to agree with this observation?

Mark Easton,
OCS Research Team,
Greenpeace New England,
Boston, Massachusetts

(Editor's reply: It is my understanding that the Minerals Management Service (MMS) only initiates a leasing program if a company or companies express interest in exploring and developing a particular area. As in the leasing of rights to potential oil-bearing property on land, these offshore leases do not necessarily imply immediate (within the next 10 years) development. In any event, an Environmental Impact Statement is required before the lease sale can take place. S.P.C. (System Planning Corporation) Ventures is one concern that has expressed interest in the MMS leasing program; two consortia [unidentified] also have indicated interest.)

books & films

The Future of Gas and Oil From the Sea **by Gerard J. Mangone, ed. 1983. Van Nostrand Reinhold Company, Inc., New York, N.Y., 215 pp. $35.00.**

Environmental Planning Guidelines for Offshore Oil and Gas Development **by John T. E. Gilbert, ed. 1982. Published for the East-West Center by The University Press of Hawaii, Honolulu. 64 pp. $6.00.**

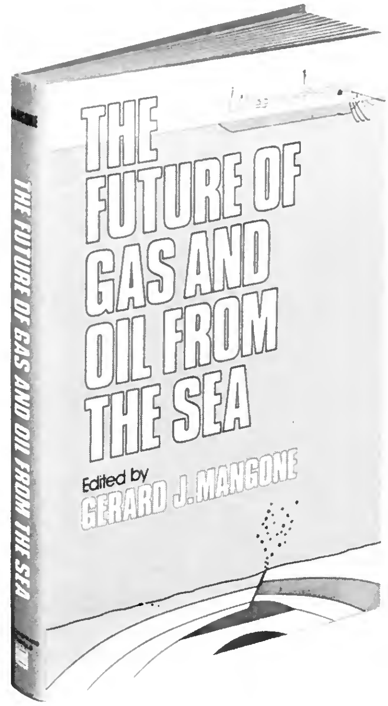
The Future of Gas and Oil From the Sea is a valuable source of information on many aspects of offshore energy resources. The book discusses past experience and future developments in the recovery of oil from submerged areas. It also suggests options for public-policy decisions that will assure a reliable energy source.

This book will be of interest to energy planners, geologists, and mechanical, industrial, and environmental engineers, as well as to oceanographers in general. It is based on a national conference held by the Center for the Study of Marine Policy at the University of Delaware.

The authors contend that as much gas and oil remains to be found under the oceans as has already been found under land. Sections on drilling and recovering oil and gas from frontier areas, from under deep water affected by high winds, and from polar regions, point up some of the technical problems related to exploiting undersea reserves.

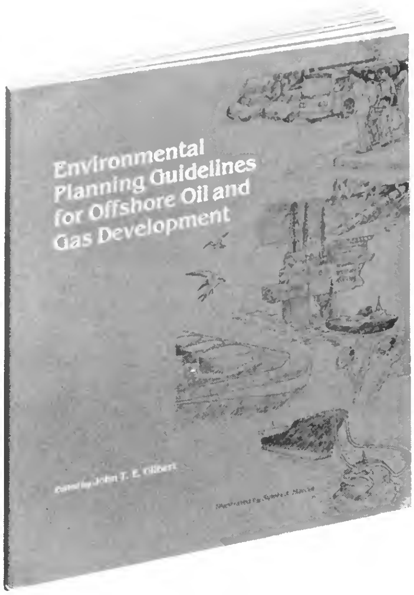
Numerous illustrations accompany information on the latest advances in drilling rigs and their equipment, new types of tankers and vessel transfers, and improvements in pipeline transmission of gas and oil. Also discussed are the effects of government regulation on the offshore industry. Special attention is given to the Outer Continental Shelf Act and its administration.

In the foreword to the book, Pierre S. duPont, Governor of Delaware, states: "Securing additional energy resources is a critical part of solving American economic problems. The United States must reduce its dependence on foreign oil for national security reasons, of course, but also because the cost of



purchasing that oil requires tens of billions of dollars each year — money that the United States desperately needs for investment at home. The development of adequate domestic coal, nuclear, and oil resources thus becomes one of the two or three priorities of the nation. The time has come to begin that development with a new spirit, with the belief of the American people that it is time to change ineffective policies of the past, especially in energy resource production."

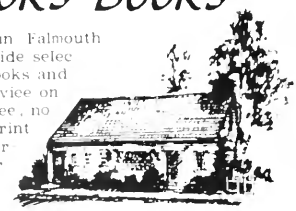
Environmental Planning Guidelines for Offshore Oil and Gas Development is a slim volume prepared by a Working Group of the East-West Environment and Policy Institute of the East-West Center at the University of Hawaii. It is aimed at providing policy makers and concerned citizens with a broad overview of the environmental aspects requiring attention in the planning for offshore exploration, development drilling, and production.



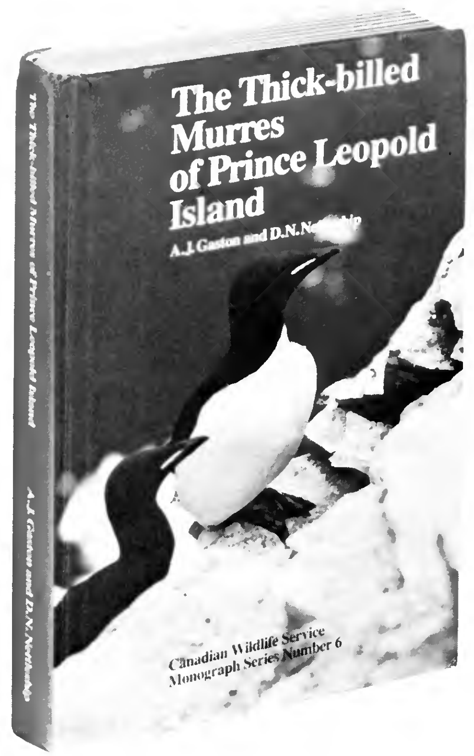
The guidelines are intended for use by technical advisors and regulatory officials at central and regional government levels, and to provide a basis for oil company and government negotiations in the setting of environment-related conditions in exploration/development contracts. The book is edited by John T. E. Gilbert, senior investigating officer of the New Zealand Commission for the Environment.

There are a considerable number of illustrations throughout this volume. Unfortunately, for this reviewer, they appear oversimplified and detract somewhat from the text, giving the book a "primer" quality. The captions, too, seem oversimplified. The text, on the other hand, is very readable, stressing throughout that "early planning is the key to recovering offshore oil and gas without the occurrence of unacceptable changes in the natural environment."

Paul R. Ryan



The Thick-billed Murres of Prince Leopold Island **by A. J. Gaston and D. N. Nettleship. 1981. Canadian Wildlife Service, Ottawa, Ontario, Canada. 350 pp. + xxvii. $32.00 (Canada); $37.50 (elsewhere).**



Surely among the great natural spectacles of the marine world are the enormous breeding colonies of seabirds found massed along the high cliffs of certain remote Arctic islands. The thick-billed murre (*Uria lomvia*), a pelagic fish-eating bird, is a major component of these high-Arctic seabird colonies and the marine ecosystem that supports them. Formerly one of the most abundant seabirds in the world, its western Atlantic population alone numbered around 10 million in the 1950s. Today this population has dwindled to around 2.3 million because of heavy adult mortality from oil fouling, shooting, and (especially) drowning in commercial fishing nets.

It was this population decline, along with increasing oil-exploration efforts in the Canadian Arctic, that prompted a 3-year study of reproduction among thick-billed murres, the results of which we see here. Canadian Wildlife Service biologists Tony Gaston and David Nettleship have done a superb job assembling and synthesizing a massive amount of data on the breeding ecology of the murres of Prince Leopold Island, one of the eight or ten significant nesting colonies (approximately 100,000 pairs) where these birds concentrate during summer in the western North Atlantic.

This is a clearly written and well organized book, with six chapters, each of which can be read without extensive cross referencing. In addition to the introduction and conclusion, there are chapters on: attendance and behavior at the colony; timing and success of reproduction; development of young; and adult weight, food, and feeding areas. Each of these four central chapters has a distinctly scientific format, with separate sections for methods, results, discussion, and summary. However, the book's emphasis falls on the presentation of results and how they were acquired, rather than on their interpretation. Most readers will find the listing and evaluation of the methods overly detailed, since they were written with an eye toward future field studies. But such attention to detail seems entirely appropriate for a monograph like this; Gaston and Nettleship have defined research topics and methods that should be of great interest to anyone working with colonial seabirds.

With 87 tables, 127 figures, and 350 pages, this book is hardly light reading. Yet for those with a strong interest in the ecology of nesting seabirds, and how they are studied, this book is a must. Likewise those interested in the structure and function of marine ecosystems, particularly in the Arctic, will find much food for thought here. And, its price makes this hardcover book (these days) a good bargain.

We need more published studies on colonial seabirds that are this thorough, for such work has tremendous practical (management) value and theoretical interest. This study, for example, defines (among other things) where the Prince Leopold Island murres feed and what their main prey species are, how the numbers of birds in the colony shift by day and by season, and what factors influence nesting success. Such information is critical if intelligent decisions are to be made about increasing human activity in Arctic seas.

Of less immediate management value, but important for understanding thick-billed murres and their conservation, are answers to theoretical questions, including the factors controlling the size of murre colonies, how the birds find their patchily distributed food sources, why they fledge their young precocially, and why extensive polymorphism of eggs and chicks occurs. Gaston and Nettleship provide fascinating discussions of such evolutionary issues in their concluding chapter; if their conclusions are preliminary, they only point out how much remains to be learned about this species and its supporting ecosystem. Nevertheless, the authors learned a lot about thick-billed murres, in only three years, and they present their findings well. We now know more about the reproductive ecology of this species than of most other colonial seabirds, and the murres should benefit.

Alan Poole,
Boston University Marine Program,
Marine Biological Laboratory,
Woods Hole, Mass.

Wanderer On My Native Shore **by George Reiger. 1983. Simon & Schuster, New York, N.Y. 286 pp. $14.95.**

It takes guts to write another book about the East Coast. It has been done many times before and the results have often been classics. The distinguishing feature of many of these books is an elegant blend of scientific fact and poetic observation. Rachel Carson, John Hay, and John and Mildred Teal immediately come to mind. *Wanderer On My Native Shore,* though touted on the cover as joining the ranks of these classics, falls just short.

The book is precisely what its title implies, a series of first-hand anecdotes by an avid fisherman, naturalist, and environmentalist. As conservation editor of *Field and Stream* and field editor of *Audubon* magazine, George Reiger has had ample opportunity to wander the length of the East Coast, meeting people, fishing, and monitoring the environmental health of the shoreline.

These first-hand experiences are backed up by the author's extensive familiarity with the many popular journals that deal with marine and coastal research. In this regard, the book is an excellent overview of what has been learned about environmental problems along the East Coast during the last few decades. However, there are two drawbacks that make it difficult for environmental books such as *Wanderer On My Native Shore* to become classics. First, the genre is dated. Voluminous, dismal facts and figures about coastal degradation were the vogue of the late 1960s. Second, environmental information itself quickly becomes dated — DDT is banned, PCBs are found to be more lethal.

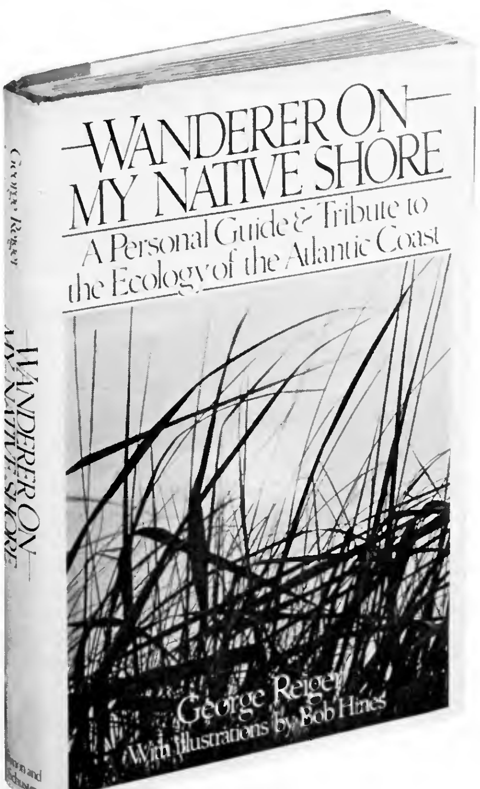
Too often, Reiger evokes the feeling of canoeing along the fog-bound Maine coast, or starts to explain the scientific reasons for the spread of red tide, only to move suddenly to a fishing story. Was he afraid to embarrass his audience with too much emotion or bore them with too much science? I found myself tiring of fishing stories.

Fishing stories are like romance novels; they have tried-and-true plots complete with good guys, bad guys, and struggles between the two. At their best, they generate great tales — *Moby Dick, Old Man and the Sea;* at their worst, they are trite.

Yet this book is also a journey into the past. As the author travels south, he returns to the memories of his youth. It is in childhood when our powers of observation are most acute. We are as impressed by the intricacies of a sand flea as the number of scup caught by the end of a day. The best writers, like the best scientists, retain this childhood fascination with the fundamental beauty and intricacy of the natural world.

In Reiger's reminiscences about his childhood, his writing comes alive. When he describes his experiences collecting animals for the Tabor summer camp, or diving along the Florida coast, the author writes with an elegant combination of scientific fact and poetic observation.

In the chapter on Florida, Reiger describes diving on fleeting schools of fish and discusses their strategems. He explains how the wrasse blenny



mimics the color of the blueheaded wrasse to fool larger fish. At this point, the writing rivals the prose of Stephen Jay Gould, or Konrad Lorenz, masters at taking natural curiosities and spinning out endless essays of philosophical biology.

Reiger is at his best when describing the schemes of people who despoiled his childhood Florida. Some of his descriptions of the Flaglers, Merricks, and Fishers — self-styled first families of Florida's Gold Coast — make these people sound as if Florida would have been better served had they been incarcerated in the quiet seclusion of a Florida asylum.

Perhaps it is the nature of such a book that the author has to move quickly over subjects about which entire treatises have been written. *Wanderer On My Native Shore* offers a readable overview of many of the environmental problems that have plagued our eastern coast during the last few decades. In so doing, it gives us a slice of life, a piece of history that tells us what it was like along the East Coast for a brief moment in time.

Bill Sargent,
science writer,
National Marine Fisheries Service,
Woods Hole, Mass.

Gulfstream: Spin and Flow. **A film produced by the National Film Board of Canada and distributed by Bullfrog Films, Oley, Penn. Sale: $450.00 (16mm); $100.00 (video). Rental: $50.00. 28 minutes.**

Gulfstream is beautiful to the eye and full of interesting bits of information. Its hero is a small trimaran, which journeys from the Gulf Stream's beginnings, near the Equator, all the way to the Grand Banks of Newfoundland. Pushed along by the Stream's power, this zippy vessel requires only 15 days to make the 2,000-mile trip, during which various physical and biological phenomena are introduced. The film is intended for viewers with seventh-grade education or better; as an educational tool, it is suitable for high school students and others who are unfamiliar with the Gulf Stream. The photography is excellent, and would be pleasing to even a trained oceanographer.

The narrator — the trimaran's skipper — explains the physical forces that cause currents to flow at the Gulf Stream's origins. Animated drawings and satellite photographs help clarify and substantiate concepts the narrator discusses. The little boat sails along, first poking through the doldrums, then nearly flying while speeded by the trade winds. She passes the Sargasso Sea, weathers a fierce storm, and finally reaches the Labrador current at journey's end. Underwater footage is used liberally. Especially eye-catching is an iridescent ctenophore, delicately lit with rainbow colors. A sargassum fish, camouflaged in orange, "walks" around in its weedy home on fins modified for grasping. Blue-fin tuna prey on smaller fish with casual, machine-like disinterest.

Just as spectacular is the footage of weather systems. Thanks to time-lapse photography, we can see giant white clouds billowing and storms brewing and fizzling over the Atlantic. A thin tornado-finger reaches down from a great black cloud, striking a whirlpool into the sea.

Gulfstream successfully stimulates curiosity about many things oceanographic, and the trimaran theme adds a note of human interest. But the film seems to ramble from one subject to the next, rather than being organized, and there is very little explanation of the logical continuity between the physical and biological phenomena in the Gulf Stream. Often it jumps alarmingly from a discussion of some global weather force to underwater pictures of a minute sea creature. Of course, connections exist between physical oceanography and the biological and ecological aspects of the oceans, but for the newcomer to oceanography such connections need to be explained.

Gulfstream would be a good jumping-off point for high-school science teachers hoping to rouse students' interest in the fascinations of the Gulf Stream.

Elizabeth Miller

Books Received

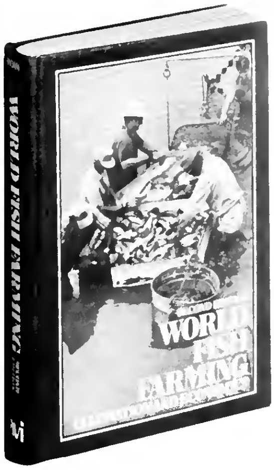
Aquaculture

Histology of the Striped Bass **by David B. Groman. 1982. American Fisheries Society Monograph Number 3, American Fisheries Society, Bethesda, Md. 120 pp. $12.00.**

The striped bass has been an important food source and sport fish in the United States for more than two centuries. Its life history is well understood, but only a few papers have been published on its histology. More than 21 states now stock or culture this species, while anadromous stocks are suffering diminishing spawning success. This book is meant as a reference for aquaculturists concerned with health maintenance of striped bass; it includes discussions and photographs of all major organ systems from normal fish.

World Fish Farming: Cultivation and Economics **by E. Evan Brown. 2nd edition. 1983. AVI Publishing Company, Westport, Conn. 516 pp + xviii. $35.00 (U.S.), $40 (elsewhere).**

This updated version covers more countries than did the first edition, including the People's Republic of China, the Soviet Union, and countries on all continents but Africa and South America. Beginning with



the United States and Canada, the author discusses more than 100 species of fish and invertebrates cultured around the world.

Biology

***Biology and Conservation of Sea Turtles*, Karen A. Bjorndal, ed. 1982. Smithsonian Institution Press, Washington, D.C. 583 pp. $25.00.**

The papers in this volume were presented at the World Conference on Sea Turtle Conservation, held in Washington, D.C., November, 1979. There were more than 300 participants from 40 nations. The book presents the summary of sea turtle biology from the conference, and a conservation strategy. The papers are grouped into sections on biology; status of populations; and conservation theory, techniques, and law.

***Modeling Fluctuating Populations* by R. M. Nisbet and W. S. C. Gurney. 1982. John Wiley & Sons, New York, N.Y. 379 pp. $57.95.**

The purpose of this book is to present, in a do-it-yourself fashion, mathematical techniques useful in analyzing models of fluctuating populations. The authors hope to help reverse the growing split between population biologists who are mathematically confident and those who are not. According to the authors, modern abilities in population dynamics allow quantitative, testable models only of laboratory systems; therefore, the three major case studies used as examples are of laboratory populations. The techniques employed are applicable elsewhere, including applications with deterministic (single-species, age structure, interacting species) and stochastic (birth and death in a static environment, variable environments) models.

***Acmaeidae (Gastropoda, Mollusca)* by David R. Lindberg. 1981. The Boxwood Press, Pacific Grove, Calif. 122 pp. $12.50.**

This is one in a series of identification manuals on invertebrates of the San Francisco Bay estuary system. All known California limpets in the family Acmaeidae are described, illustrated, and discussed, in a manner designed to help the amateur or professional malacologist identify species in this common group. The limpets are difficult to differentiate, but reliable identifications can be made using radular (mouth) characteristics. Under each group, descriptive and tabular keys are included. Extensive field work went into this book's preparation; there are chapters on morphology, anatomy, systematics, and distribution and ecology.

***The Sharks of North American Waters* by Jose I. Castro; drawings by D. Bryan Stone III. 1983. Texas A&M University Press, College Station, Texas. 180 pp. + xii. $19.50.**

Designed for anyone interested in identifying sharks, this is a guide to all species found within 500 nautical miles of the shores of Canada and the United States, and a few deep-water species. A general account of sharks — their evolution, anatomy, reproduction, and utilization — makes up the first part of the book. The second portion includes an illustrated key to the families of sharks, family and species descriptions, and an appendix of monotypic families.

***The Water Naturalist* by Heather Angel and Pat Wolseley; photographs by Heather Angel. 1982. Facts on File, Inc., New York, N.Y. 192 pp. $19.95.**

Extensively illustrated with color and black-and-white photographs and drawings, this book approaches the study of natural history through investigations of watery habitats.

Progressing from still through running waters, to estuaries and the open ocean, the authors describe and explain the processes that enable life to exist, myriads of life forms, and the problems of changing environments. Many projects, designed for household and make-it-yourself equipment, encourage readers to actively take part in their studies.

Mammals in the Seas. Volume III: General Papers and Large Cetaceans. **1983. FAO Advisory Committee on Marine Resources Research, Working Party on Marine Mammals. Rome, Italy. 504 pp. + x. $80.50.**

Third in a series documenting the proceedings of the United Nations' Scientific Consultation on the Conservation and Management of Marine Mammals, this book is a collection of papers on the problems encountered in studying marine mammals and ongoing developments in research. The 38 articles, written in English and abstracted in English, French, and Spanish, vary in length and scope; focusing on individual species, they cover such topics as anatomical details, conservation, population dynamics and assessment, and the status of the whaling industry.

Education

Celestial Navigation by Sun Lines **by Hewitt Schlereth. 1983. Seven Seas Press, Inc. Newport, R.I. 341 pp. + x. $25.00.**

This is the second volume of *The Cruising Navigator*. The sun is the most useful heavenly body for practical navigation; to use the information in this book, one also needs a sextant and an accurate time piece. Part 1 is a guide to the basics, with quizzes and answers; parts 2 and 3 cover theory and practice; part 4 provides work sheets; and part 5, tables of figures necessary for sun navigation. The book is an "on-board" edition — styled like a notebook, for easy use at sea.

Ocean Science **by Keith Stowe. 2nd edition. 1983. John Wiley & Sons, New York, N.Y. 673 pp. + xiii. $57.95.**

Keith Stowe's book is designed as an introductory college text for students with little background in the sciences, and this is an extensively updated and expanded edition. Basic information on marine geology, physical oceanography, and marine biology and ecology is subdivided into 22 chapters, each followed by questions reviewing the material discussed. The author's purpose is to convince students that the world around them is a rational place, easily understood by studying examples and applying common sense. Material is broken down into small, manageable units; numerous charts, graphs, and photographs accompany the text.

Systems Ecology: An Introduction **by Howard T. Odum. 1983. John Wiley & Sons, New York, N.Y. 644 pp. + xv. $49.95.**

Systems ecology is the study of whole ecosystems, including measurements of overall performance and study of system design. This textbook, written for college seniors and graduate students, has four parts: Energy, Systems and Simulation; Design Elements; Organization and Pattern; and Systems of Nature and Humanity. Energy-language diagrams are used, which combine kinetics, energetics, and economics. Each chapter is followed by study questions and suggested readings.

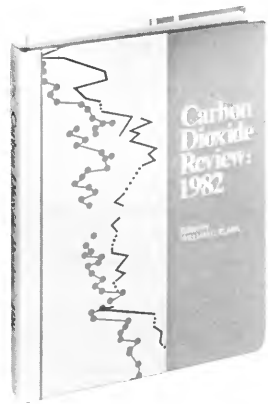
At the Sea's Edge: An Introduction to Coastal Oceanography for the Amateur Naturalist **by William T. Fox; illustrated by Clare Walker Leslie. 1983. Prentice-Hall, Inc., Englewood Cliffs, N.J. 317 pp. $12.95.**

This book is meant as a field companion for those who enjoy walking along the shore, and as a text for high-school students and beginning college students. Field sketches and photographs illustrate the three main topics: physical processes, coastal landforms, and marine ecology; also included are some simple field techniques to aid observation. Chapters on geology, weather and climate, waves, and tides are followed by discussions of beaches, and barrier islands and spits, and the ecology of coastal areas. Coral reefs ecology is covered in the last chapter.

Environment

Cayman Islands Seashore Vegetation: A Study in Comparative Biogeography **by Jonathan D. Sauer. 1982. University of California Press, Berkeley, Calif. 161 pp. + xiv. $14.25.**

To produce a regional comparison of the ecologically diverse Caribbean, the author documented and studied more than 100 species of seashore vegetation on the Cayman Islands. Brief synopses of natural history and human intervention on the islands open the book. Variations in species distribution are discussed, according to physical characteristics of a zone (beach thickets, mangroves, supratidal areas) and substrate (rock, sand, shingle, limestone). Following the discussions are an appendix (species list), profiles of the seashore, photographs, and tables.



Carbon Dioxide Review: 1982, **William C. Clark, ed. 1982. Institute for Energy Analysis, Oak Ridge, Tenn. 469 pp. + xix. $35.00.**

This review contains essays and commentaries on eight major issues of today's carbon dioxide debate. There also are notes on recent developments, a selection of reference data, and a bibliographic guide to literature in the field. A full-color wall map depicting carbon levels in vegetation throughout the world is included.

Environmental Oceanography: An Introduction to the Behavior of Coastal Waters **by Tom Beer. 1983. Pergamon Press, Elmsford, N.Y. 262 pp. $30.00 (hardcover); $13.00 (paperback).**

This book explains the physical processes that act on beaches, reefs, estuaries, the coastal atmosphere, and the continental shelf. The chapters are graded in mathematical and conceptual difficulty. In each case, an introductory chapter is followed by one tackling the subject in more depth; for instance, the descriptive chapter on shore processes is followed by detailed accounts of waves and tides. This book is designed for environmental planners, administrators, and students, and does not assume a formal background in the physical sciences.

Coastal Research in the Gulf of Bothnia, **Karl Muller, ed. 1982. Kluwer Boston, Inc., Hingham, Mass. 462 pp. + xvi. $87.00.**

The Gulf of Bothnia is that long finger of water between Sweden and Finland, part of the Baltic Sea. Besides being very far north, it is unique in that it has no tides, low salinity, and is covered with ice for five to seven months each year. Worldwide interest in the health of coastal ecosystems inspired this study, performed chiefly by the Department of Ecological Zoology at the University of Umea. There are six sections. The first describes the study area, and is followed by sections on river and coastal interactions, phyto- and zooplankton, insects, fisheries, and heavy metal problems in the Gulf of Bothnia.

Geology

CRC Handbook of Geophysical Exploration at Sea, **Richard A. Geyer, ed. 1983. CRC Press, Boca Raton, Fla. 445 pp. $83.50.**

Academicians, government scientists, and industrialists, from Canada, England, Egypt, and the United States, contributed to this book. It surveys geophysical methods used to obtain and interpret information; discusses instrument systems and the special needs of instrumentation at sea; and includes case histories of the use of integrated analyses in solving geophysical problems. The purpose is to help improve understanding of the earth beneath the sea, so that its hidden resources might be found.

Marine Policy

The Politics of Mineral Resource Development in Antarctica **by William E. Westermeyer. 1983. Westview Press, Boulder, Co. 200 pp. $19.00.**

Antarctica is the subject of much discussion and international legal debate regarding the regulation of future mineral resource exploration. The present Antarctica Treaty, in effect for 21 years, has recently proven inadequate in areas of mineral exploration and mining. This book begins with an analysis of the present treaty, followed by an evaluation of possible alternatives for a new treaty. The several proposals are considered both in terms of the costs and benefits to individual nations and the collective impact on the Antarctic region.

Maritime Boundary Delimitation: An Annotated Bibliography **by Ted L. McDorman, Kenneth P. Beauchamp, and Douglas M. Johnston. 1983. Lexington Books, D.C. Heath and Co., Lexington, Mass. 207 pp. $24.95.**

In most areas of the world, offshore boundary conflicts are a problem: more than 100 boundary-delimitation issues currently await resolution. This book's purpose is to help researchers deal with the proliferation of published material on the subject. The entries, most of which are legal works published since 1960, are divided into seven chapters, such as Theory: Zones and Boundaries and Areas of Dispute. The annotations are short (two to four sentences), and there are cross-references. An appendix contains all the existing bilateral ocean-boundary agreements the authors could locate.

Stochastic Modeling of Ocean Fisheries Resource Management **by Tracy R. Lewis. 1983. University of Washington Press, Seattle, Wash. 118 pp. $25.00.**

Many models used for natural-resource management assume such "knowns" as current and future demands for the resource, prices, and costs of production. In reality, uncertainty is a common condition; this study introduces and analyzes a general model of resource management that incorporates various aspects of uncertainty. The model, developed with help from findings in decision science, fisheries biology, and other fields, is applied in the Eastern Pacific yellowfin tuna fishery. The author has designed his discussion for general readers, with unfamiliar concepts defined in the text.

***Resource Management and Environmental Uncertainty: Lessons from Coastal Upwelling Fisheries,* Michael H. Glantz and J. Dana Thompson, eds. 1981. John Wiley & Sons, New York, N.Y. 491 pp. + xvii. $66.50.**

This book brings together research from closely related, but not often interacting, fields on the topic of fisheries management in conditions of environmental uncertainty. In addition to the physical and biological aspects of oceanography, the book analyzes economic, political, and social factors involved in the interactions between science and society. There are four parts: background, scientific aspects of El Niño, societal aspects, and considerations for the future. The authors demonstrate how scientific information is used in different societies, and show that many decisions are based not on sound science, but on political and economic considerations.

***Law of the Sea: U.S. Policy Dilemma,* Bernard H. Oxman, David D. Caron, and Charles L. O. Buderi, eds. 1983. Institute for Contemporary Studies, San Francisco, Cal. 184 pp. $7.95.**

This book tries to illuminate the controversy created by the Reagan Administration's decision to keep the U.S. out of the Law of the Sea treaty and to rely instead on customary law and "mini-treaties." Many of the contributing authors participated in the treaty negotiations. Following the introduction, the nine essays are divided into four sections: rights, interests, and national equity; practical differences (seabed mining); Law of the Sea and the future of international order; and an appendix summarizing the Law of the Sea Convention.

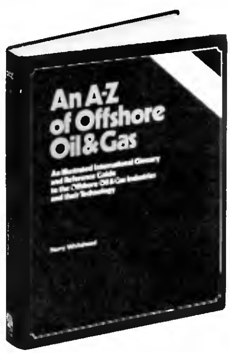
Books Policy

Oceanus welcomes books from publishers in the marine field. All those received will be listed and a few will be selected for review. Please address correspondence to Elizabeth Miller, editor of the book section.

Oil and Gas

***An A-Z of Offshore Oil and Gas: An Illustrated International Glossary and Reference Guide to the Offshore Oil and Gas Industries and their Technology* by Harry Whitehead. 1983. Second Edition. Gulf Publishing Company, Book Division, Houston, Texas. 438 pp. $39.95.**

This book defines more than 4,000 terms used by the offshore oil and gas industries, including 900 new entries. Augmenting the glossary, 30 appendices contain information presented in tabular and diagrammatic form, such as statistics and maps. There is information on rig construction, components, new terminology, new discoveries, sonics, surveying and safety, and official and private organizations important in the various fields.



Physical Oceanography

***The Applied Dynamics of Ocean Surface Waves* by Chiang C. Mei. 1983. John Wiley & Sons, Inc. New York, N.Y. 740 pp. $75.00.**

This book, a reference and guide for engineers, came from the author's experience teaching a two-semester course on the subject at the Massachusetts Institute of Technology. In the last 20 years, our knowledge of ocean surface waves has grown as a result of scientific curiosity and attempts to resolve major ocean engineering problems. The theory and basic physics of ocean surface waves are presented, along with their major applications to ocean engineering. The 13 chapters include highlights such as a comprehensive treatment of linear diffraction theory.

General Reading

***1983 World Record Game Fishes,* M. B. McCracken, ed. 1983. The International Game Fish Association, Fort Lauderdale, Fla. 328 pp. $7.95.**

Ever think that bluefish you caught last weekend was so big that it must have broken all the records? With this book you can verify world-record catches, and learn the rules and requirements necessary to qualify for those records. As well as documenting record-setting catches, the 1983 edition includes information on the status and organization of the International Game Fish Association for members and prospective members. Another section is devoted to subjects of interest to the angler, from developments in fisheries science to helpful hints and expert advice. A "guide to fishes" aids in identifying more than 150 freshwater and saltwater fishes with illustrations, charts, and text.

***Evolution Without Evidence: Charles Darwin and the Origin of Species* by Barry G. Gale. 1982. University of New Mexico Press, Albuquerque, N.M. 238 pp. $21.95.**

In this study, Gale examines the period 1838 to 1859 in Darwin's life, at the beginning of which the great naturalist read Malthus's *Essay on the Principle of Population,* and at the end of which he produced *Origin of Species.* Scholars have long debated Malthus's influence on Darwin; Gale looks at Darwin's lengthy incubation of his theory, closely examining Darwin's correspondence and autobiography. The resulting portrait is of a man ill-equipped, in the 1830s, to present his theory to the public.

***Dogwatch and Liberty Days: Seafaring Life in the Nineteenth Century* by Margaret S. Creighton. 1982. Peabody Museum of Salem, Salem, Mass. 88 pp. + vii. $14.95.**

During the 19th century, every sailing vessel carried a logkeeper, who maintained an official account of weather, sail changes, and ship's position. In addition, some sailors kept personal diaries, in which they reported shipboard life with introspection and emotion. The text of *Dogwatch and Liberty Days* is drawn from the diaries of 104 seafaring men, and is illustrated with journal sketches, paintings, and photographs of objects used or manufactured on shipboard. All the diarists quoted were deepwater sailors, leaving American ports on voyages lasting one to four years. Creighton reports their thoughts with the idiosyncrasies of syntax intact.

***California Coastal Access Guide*, by the California Coastal Access Commission. 1983. University of California Press, Berkeley, Cal. 288 pp. $7.95.**

This handbook tells where to go on the coast of California, how to get there, and what each location is like. The introduction covers people's rights, boating, geology, and history; the remainder, or guide section, is organized by county and interspersed with articles on tsunami, surfing, and many other subjects. The book is extensively illustrated with maps, photographs, drawings, and charts enumerating the parks, their facilities, and environs.

***Reaching Port: A Montana Couple Sails Around the World* by Keith Jones. 1983. St. Martin's Press, New York, N.Y. 260 pp. $13.95.**

At their home in Billings, Montana, the author and his wife spent 10 years building a seagoing ketch that would take them on a five-year trip around the world. Jones' experience was limited to five years in the construction business and three in the Seabees. Other than that, all he had was the determination to make his dream come true. In this book, the process of building the boat and all the fun and hardship the couple had on their voyage are described in a crisp, fast-moving style full of good humor and love of life.

***Boca Grande: A Series of Historical Essays* by Charles Dana Gibson. 1982. Published by the author, P.O. Box 840, Boca Grande, Fla. 216 pp. $12.95 + $1.00 postage.**

The author examines in detail the history of the islands of Charlotte Harbor, on Florida's southwest coast. Before the Spanish got there, this region was inhabited by the little-known Calusa Indians; in the 18th and 19th centuries, it was an important fish-producing area, providing protein to the slave populations of the Spanish West Indies. Other industries boomed and then failed there, and now the region is best known for its tarpon sports-fishery.

***Seacoast Maine: People and Places* by Marin Dibner; photographs by George A. Tice. 1982 Down East Books, Camden, Me. 208 pp. $9.95.**

An unusual look at the coast of Maine, created by two artists—a writer and and a photographer. Dibner calls the book "a year's portfolio of humanity at times intriguing, tragic, funny, confusing, tied together with love and nostalgia." The black-and-white photos, very captivating, strike an excellent balance with the prose.

***The Story of the Mary Rose* by Ernle Bradford. 1982. Hamish Hamilton, London, England. 207 pp. £9.95 (U.K. only).**

The pride of the Tudor Navy, the *Mary Rose* sank off the Isle of Wight in 1545, before she even fired a shot. The silt of the Solent preserved her these last 437 years, and in 1982 she was raised with the help of modern underwater archaeological techniques. This book tells the warship's story: how she sank with her full complement of sailors and archers drowning; attempts made to raise her at the time and in the 19th century; and the work done in our time to bring up the *Mary Rose*. Illustrated with photographs of underwater retrieval operations and items brought up from the *Mary Rose's* watery bed; maps, paintings and drawings from the 16th century; and pictures of the many people involved in the modern excavation.

General

***Sea Kayaking: A Manual for Long-Distance Touring* by John Dowd. 1983. University of Washington Press, Seattle, Wash., and Douglas & McIntyre, Vancouver, British Columbia, Canada. 240 pp. $8.95.**

The kayak is commonly thought of as a river-going vessel; yet, originally, it was designed for sea travel. Since the late 1970s, sea-kayaking expeditions have become increasingly popular. In this guide, equipment, navigation, tides and currents, hazards and emergency procedures, and many other topics of interest to novice and experienced sea-kayak adventurers are discussed. The author began kayaking as a schoolboy in New Zealand 20 years ago; since then he has made several long voyages, including a trip of more than 2,000 miles across the Caribbean from Venezuela to Florida.

Books for Children

***Shells of the World Coloring Book* by Lucia de Leiris. 1983. Dover Publications, Inc., New York, N.Y. 46 pp. $2.50.**

This is one of the best coloring books we have seen. Each page is a line drawing of a mollusk in its typical habitat. Actual sizes and scientific names are provided, and some species are shown eating their favorite foods. High-quality printing on the fold-out back cover reproduces every scene in its natural colors.

***Nature with Children of All Ages: Activities and Adventures for Exploring, Learning, and Enjoying the World Around Us* by Edith A. Sisson. 1982. Phalarope Books, Prentice-Hall, Inc., Englewood Cliffs, N.J. 195 pp. + xii. $10.95.**

Sharing nature with children — learning about it together — can be easy, and this book sets out to help. Children are naturally curious, and by encouraging them to examine the world around them, we foster appreciation for all forms of life. This book is full of projects, divided into chapters on things that go together. Each chapter is followed by a bibliography. Materials called for are simple and inexpensive. A sample project: "catching" an orb spider web — without hurting the spider — with paper and spray paint.

***Zachary Goes Groundfishing on the Trawler Lucille B.* by Alice True Larkin; illustrations by Abbey Williams. 1983. Down East Books, Camden, Me. 60 pp. $5.95.**

Here we join Zachary as he takes his first cruise on a Maine fishing trawler. With clear, straightforward text and drawings, the author and illustrator use the day-trip to explain the Maine groundfishing industry: the men and their boats, the huge nets and other equipment, and the fish they catch.

***Storm Treasure* by Robert M. Packie; illustrated by Sherry Streeter. 1982. Down East Books, Camden, Me. 154 pp. $8.95.**

Karen Tibbers is a young girl growing up on a saltwater farm in Down East Maine. The year is 1919. One cool autumn day Karen goes beachcombing, only to stumble on ancient treasure uncovered by a recent storm. She even finds a skull! Who left the treasure? Karen, her friends, and her family unravel the mystery, at the same time introducing readers to life on a Maine farm in the early 20th century.

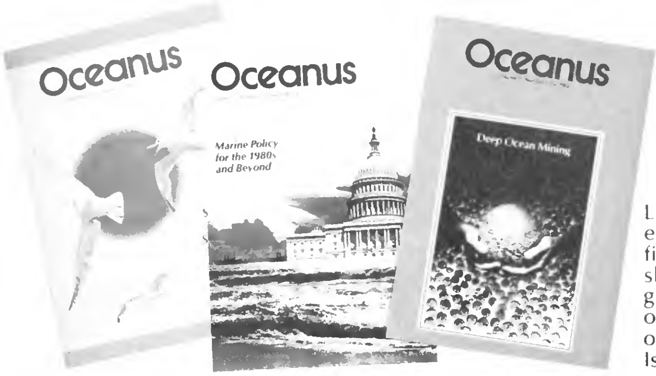
Advertiser Index

as well as for plate tectonics data.

- **Oceans and Climate,** Vol. 21:4, Fall 1978 — *Limited Supply only.*
- **General Issue,** Vol. 21:3, Summer 1978 — The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.
- **Marine Mammals,** Vol. 21:2, Spring 1978 — Attitudes toward marine mammals are changing worldwide.
- **The Deep Sea,** Vol. 21:1, Winter 1978 — Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.
- **General Issue,** Vol. 20:3, Summer 1977 — The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.
- **Sound in the Sea,** Vol. 20:2, Spring 1977 — The use of acoustics in navigation and oceanography.

was designed for sea travel. Since the late 1970s, sea-kayaking expeditions have become increasingly popular. In this guide, equipment, navigation, tides and currents, hazards and emergency procedures, and many other topics of interest to novice and experienced sea-kayak adventurers are discussed. The author began kayaking as a schoolboy in New Zealand 20 years ago; since then he has made several long voyages, including a trip of more than 2,000 miles across the Caribbean from Venezuela to Florida.

A Valuable Addition to Your Library



Oceanus

back issues

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Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

- **General Issue,** Vol. 26:2, Summer 1983 — Articles cover the effects of carbon dioxide buildup on the oceans, the use of mussels in assessments of chemical pollution, a study of warm-core rings, neurobiological research that relies on marine models, the marginal ice zone experiment, and career opportunities in oceanography. A number of "concerns" pieces on the U.S. Exclusive Economic Zone round out the issue.
- **Seabirds and Shorebirds,** Vol. 26:1, Spring 1983 — Many bird species play important roles in marine ecosystems. This issue contains articles on the feeding methods, breeding habits, migration, and conservation of marine birds. Other features include articles on the National Marine Sanctuaries Program and the 2-year ban on radwaste dumping by foreign nations.
- **Marine Policy for the 1980s and Beyond,** Vol. 25:4, Winter 1982/83 — This issue examines the role of government in human activities affecting the sea. Each author makes recommendations for the future. The articles focus on the problems of managing fisheries, the controversy over dumping wastes in the oceans, the lack of coordination in United States Arctic research and development, military-sponsored oceanographic research, the Law of the Sea, and the potential for more international cooperation in oceanographic research.
- **Deep Ocean Mining,** Vol. 25:3, Fall 1982 — Eight articles discuss the science and politics involved in plans to mine the deep ocean floor.
- **General Issue,** Vol. 25:2, Summer 1982 — Contains articles on how Reagan Administration policies will affect coastal resource management, a promising new acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.
- **Oceanography from Space,** Vol. 24:3, Fall 1981 — Satellites can make important contributions toward our understanding of the sea.
- **General Issue,** Vol. 24:2, Summer 1981 — A wide variety of subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.
- **The Coast,** Vol. 23:4, Winter 1980/81 — The science and politics of America's 80,000-mile shoreline.
- **Senses of the Sea,** Vol. 23:3, Fall 1980 — A look at the complex sensory systems of marine animals.
- **A Decade of Big Ocean Science,** Vol. 23:1, Spring 1980 — As it has in other major branches of research, the team approach has become a powerful force in oceanography.
- **Ocean Energy,** Vol. 22:4, Winter 1979/80 — How much new energy can the oceans supply as conventional resources diminish?
- **Ocean/Continent Boundaries,** Vol. 22:3, Fall 1979 — Continental margins are being studied for oil and gas prospects as well as for plate tectonics data.
- **Oceans and Climate,** Vol. 21:4, Fall 1978 — *Limited Supply only.*
- **General Issue,** Vol. 21:3, Summer 1978 — The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.
- **Marine Mammals,** Vol. 21:2, Spring 1978 — Attitudes toward marine mammals are changing worldwide.
- **The Deep Sea,** Vol. 21:1, Winter 1978 — Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.
- **General Issue,** Vol. 20:3, Summer 1977 — The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.
- **Sound in the Sea,** Vol. 20:2, Spring 1977 — The use of acoustics in navigation and oceanography.