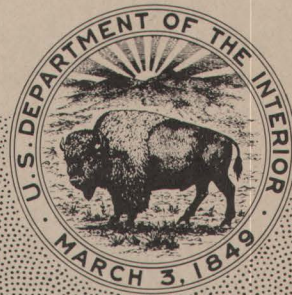


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The Worldwide Search
for Petroleum Offshore—
A Status Report for the
Quarter Century, 1947-72

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By Henry L. Berryhill, Jr.

G E O L O G I C A L S U R V E Y C I R C U L A R 6 9 4

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ABSTRACT

At the end of 1972, offshore petroleum exploration was in progress on the submerged continental margins of 80 countries. Some 780 oil and gas fields had been discovered. Estimated worldwide volume of oil discovered offshore as of January 1, 1973, is 172.8 billion barrels of oil, or about 26 percent of the world total, and 168.4 trillion ft³ of natural gas. Present reserves of oil are 135.5 billion barrels, of which 70 percent is in the Persian Gulf. Some 90 percent of the oil discovered offshore has been found in 60 giant fields having reserves of 500 million or more barrels each.

INTRODUCTION

During the past decade the search for petroleum on the submerged continental margins of the world has accelerated at a rate surpassing earlier forecasts. The floors of the world's oceans and seas adjacent to the continents are the major exploration focus of a large segment of the petroleum industry, and the offshore search in progress has been referred to as the beginning of one of the most massive oil-hunting eras in history (McCaslin, 1972, p. 106)

Awareness of the presence of oil and gas in the rocks beneath the oceans is neither a recent insight nor the result of a single dramatic new development in exploration techniques. Development of the capability to find and produce large quantities of petroleum from beneath the sea floor has been a growth process that is but the latest chapter in the history of the petroleum industry.

The first interest in the production of petroleum from the offshore came with the discoveries of sizable fields onshore immediately adjacent to the shoreline of such places as California and Lake Maracaibo. As early as 1896, petroleum was produced offshore from a sea-

ward extension of the Summerland field, California (Yerkes and others, 1969). Drilling was done from wooden piers built outward from shore. In 1923, the Venezuelan Gulf Oil Company acquired concessions extending 1 km off the shores of Lake Maracaibo. In 1926, the initial discovery was made in the Lagunillas field in the shallow waters of Lake Maracaibo (Oil and Gas Journal, 1959). Lagunillas proved to be a giant field, and its discovery indicated that additional oil and gas deposits lay farther out in deeper water. Methods developed for offshore operation at Lagunillas became world famous and helped pave the way for future operations (Critz, 1947). Discovery of oil on Bahrain Island in 1932 brought the realization that substantial amounts of petroleum might lie beneath the waters of the Persian Gulf. The occurrence of large and productive salt domes along the coast of the Gulf of Mexico in Texas and Louisiana suggested that the oil-bearing province extended offshore, and in 1938 oil was discovered off Louisiana in 8 m of water a mile (1.6 km) from shore. Through 1946, nine wells were drilled in the Gulf of Mexico, five off Louisiana and four off Texas. All were in shallow water close to shore, and all were drilled from rigid platforms (Critz, 1947).

The developments in offshore petroleum exploration summarized herein had their beginning in the Gulf of Mexico during the summer and fall of 1947. The first subsea well completed from a mobile platform was in the Gulf of Mexico, and drilling thereafter was no longer limited to the water-depth restrictions of the rigid platform that had to be built in place. Using two World War II surplus Navy barges

and a surplus Navy LCT converted to form a drilling platform, Kerr-McGee Oil Industries, Inc. discovered oil in Ship Shoal Block 32 on October 4, 1947, 12 miles (19.2 km) from the Louisiana shore (Seale, 1948). The ability to drill successfully from a mobile platform was demonstrated, and the era of large-scale exploration and production from the offshore was launched.

The prelude to the Kerr-McGee discovery had been the events and activities in the United States during the few years prior to 1947 that indicated the mounting interest of both industry and the Federal Government in the petroleum possibilities of the offshore. During the late 1930's, industry had become increasingly active in geophysical exploration in shallow waters close to shore. In 1943, as a result of war demands and petitions for leases in the tidelands of California, the Department of the Interior investigated the possibilities of exploring and producing petroleum from the offshore areas. In 1945, the Congress, seeking additional petroleum resources, held a series of hearings on possible new sources. During these investigations the Director of the U.S. Geological Survey, W. E. Wrather, pointed out that the continental shelves of the United States, as well as those around the world, are potential oil-bearing areas (U.S. Senate, 1945). The Senate investigations resulted in an action that was to have a significant impact on future development of petroleum resources offshore. On September 28, 1945, President Truman issued a proclamation asserting "that the exercise of jurisdiction over the natural resources of the sub-soil and seabed on the continental shelf by the contiguous nation is reasonable and just . . . the continental shelf may be regarded as an extension of the land mass of the coastal nation and thus naturally appurtenant to it." In November 1946, Everett DeGolyer, in a speech before a meeting of the Independent Natural Gas Association, announced that geophysical studies in the Gulf of Mexico within the 10-m water depth between the Sabine River and the Mississippi River indicated at least 30 salt-dome structures of both piercement and nonpiercement types that were similar to those already producing petroleum along the Gulf coast (Critz, 1947). Thus the pattern was established

that would guide offshore exploration in the years ahead: (1) Explore first those areas immediately adjacent to established onshore production, (2) search for similar easily discovered structures, and (3) explore for the harder-to-find structures. By the end of 1946, Louisiana, then claiming seaward proprietorship of the sea floor to 27 miles (43 km) from shore, had leased 675,385 acres on the offshore and a number of companies were actively exploring (Critz, 1947).

In the few years after 1947 came the controversy between the maritime States and the Federal Government over jurisdiction of the seabed of the continental shelf. The legal disputes and court proceedings involved in the controversy delayed development of offshore petroleum resources for some 6 years. On August 7, 1953, President Eisenhower signed the Outer Continental Shelf Lands Act, which provided the immediate leasing of Federal offshore areas by the Department of the Interior and the validation of leases previously issued by the states. In decisions in 1954, the Supreme Court settled the jurisdictional boundary disputes by giving proprietorship of the inner 3 miles (5.8 km) of the shelf to the maritime states. In separate decisions, Texas was given jurisdiction 3 leagues seaward (10.3 miles, 16.5 km) and Florida was likewise granted a 3-league jurisdiction over that part of its offshore in the Gulf of Mexico. Federal jurisdiction was established for that part of the shelf seaward from the State boundaries, and the first Federal lease sale was held in 1954.

The petroleum industry moved to the offshore in response to increasing consumer demands which no longer could be met adequately by onshore sources. The year 1947 is significant not only as the beginning of the "modern era" of offshore exploration but also as the last year in which the United States was a net exporter of petroleum. The year 1948 was the first full year in which the United States reversed its historical position as a net exporter and became a net importer of oil (World Oil, 1948). The trend has not been reversed, and the United States now imports nearly 40 percent of its total petroleum consumption. The worldwide demand for petroleum and its products is now doubling about every 10 years. Over the next

15 years, man is expected to consume as much or more petroleum than in the entire previous 116-year history of the industry.

Though land areas will continue to attract exploration for years to come, current emphasis is on the offshore areas for substantial new sources of petroleum. The purpose of this report is to review the scope of the offshore petroleum search now in progress around the world, to present the geographic distribution and magnitude of the petroleum found to date, to review the time factors involved in the exploration and development of offshore fields, and to summarize the geologic characteristics of the major offshore producing areas. No attempt is made to provide a descriptive step-by-step history of development nor to present a detailed geologic and technologic analysis, but rather to examine the factors that have influenced development to date and that might affect future predictions and expectations.

SCOPE OF THE SEARCH

Exploration for petroleum beneath the world's oceans and seas is in progress on parts of the submerged margins of every continent except Antarctica. Investigations are being carried out as far south as the Straits of Magellan near the southern tip of South America, at approximately 53° S. lat, and as far north as the arctic islands of North America, at approximately 80° N. lat. Efforts to date have been carried out primarily on that part of the continental margin known as the continental shelf, but in some areas exploration is now being extended into the deeper waters over the continental slope and in a few places onto the even deeper continental rise. Figure 1 is a map showing the various oceans and seas and the position of the 2,500-m isobath that approximates the base of the continental slope; figure 2 is a diagrammatic profile of the continental margin, showing average dimensions and the terminology applied to the physiographic provinces of the submerged margin.

The relatively flat-lying continental shelf and the more steeply dipping continental slope, which together form the continental terrace, have a combined area of 55.4 million km². Of this, about half, or 27.1 million km², is occupied by the continental shelf. The continental

rise, which extends as a gently sloping apron from the base of the continental slope to the abyssal plain, covers 19.2 million km². The combined area of the continental margin is 74.6 million km², or about 20.6 percent of the world's sea floor, an area about half as large as the total land area of the globe. The world's continental margins have not been mapped in the detail necessary to give precise areal dimensions; thus the areas given, taken from McKelvey, Stoertz, and Vedder, 1969, are best approximations.

Offshore exploration during 1972 was in progress on the continental shelves and slopes of 80 countries and involved 134 companies (Wagner, 1972). Some 400 drilling units were operating on the continental shelves of 70 countries (McCaslin, 1972, p. 106) and, at the end of 1972, commercial production was reported from 26 countries. Discoveries have been made, but development has not as yet progressed to production, off the shores of 15 additional countries.

The extent of licensing, concessions granted, and areas under exploration for the various parts of the world are shown in figure 3. The figures on the map indicate the number of petroleum companies involved in specific concession areas. Where no numbers are shown, that information was not available. Some 40 countries have issued licenses for exploration in water depths greater than 200 m, several to depths greater than 2,000 m. Most of the licenses for exploration in water depth in excess of 200 m have been granted within the past 2 years.

The total number of offshore exploratory holes and wells drilled to date around the world could not be obtained, although in the United States alone the total number of offshore holes drilled is approximately 16,000. The approximate number of wells that have produced from offshore areas around the world as of December 31, 1972, is 17,400 (Weber, 1972). The largest percentage of offshore producing wells is in the northern Gulf of Mexico and in Lake Maracaibo, Venezuela. Most offshore wells are in water depths less than 70 m, but recent trends are carrying exploration into deeper water, and successful oil wells have been drilled in water more than 400 m deep.

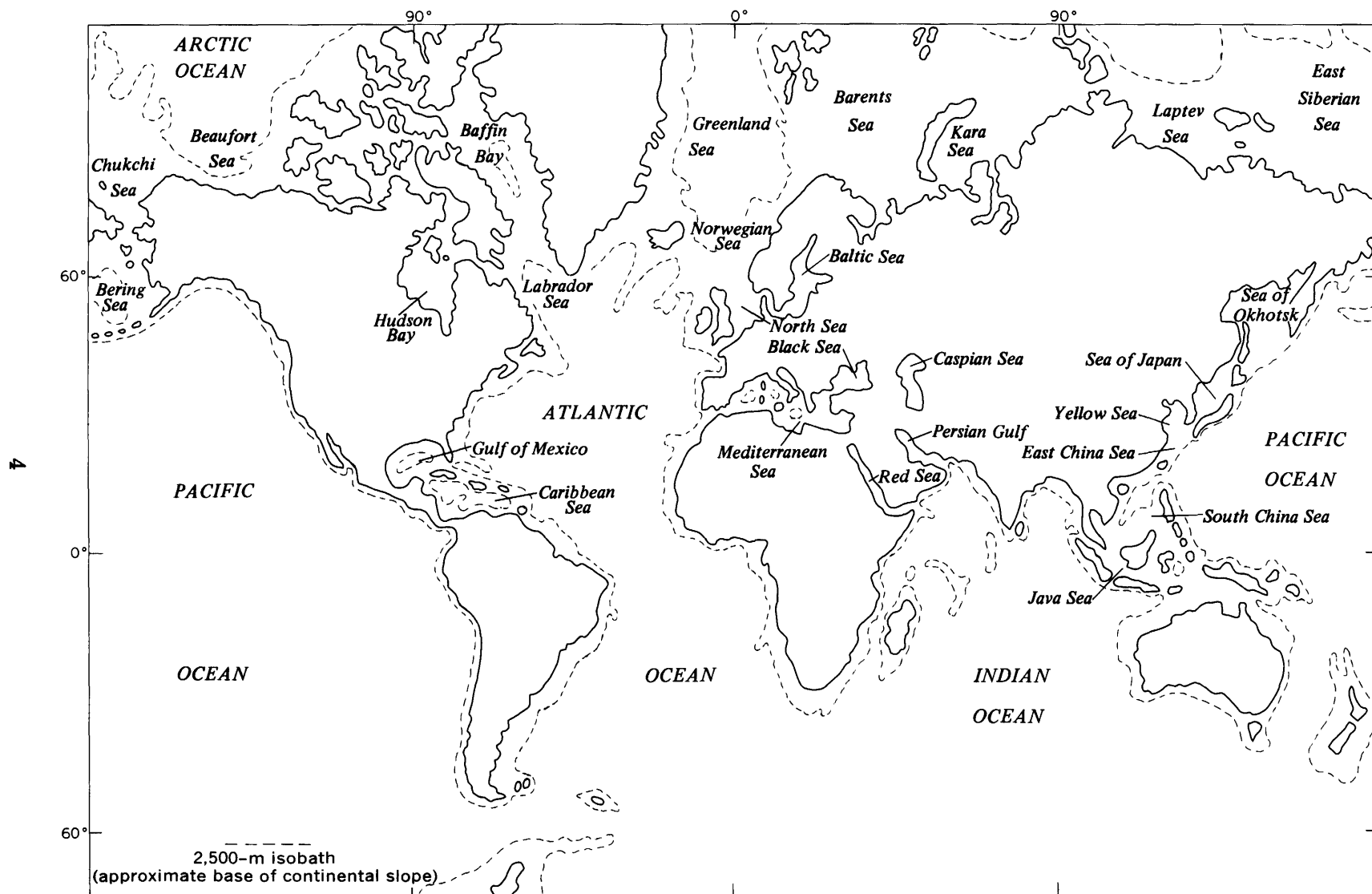


FIGURE 1.—World map (Mercator projection) showing oceans and seas and generalized position of the 2,500-m isobath (dashed line).

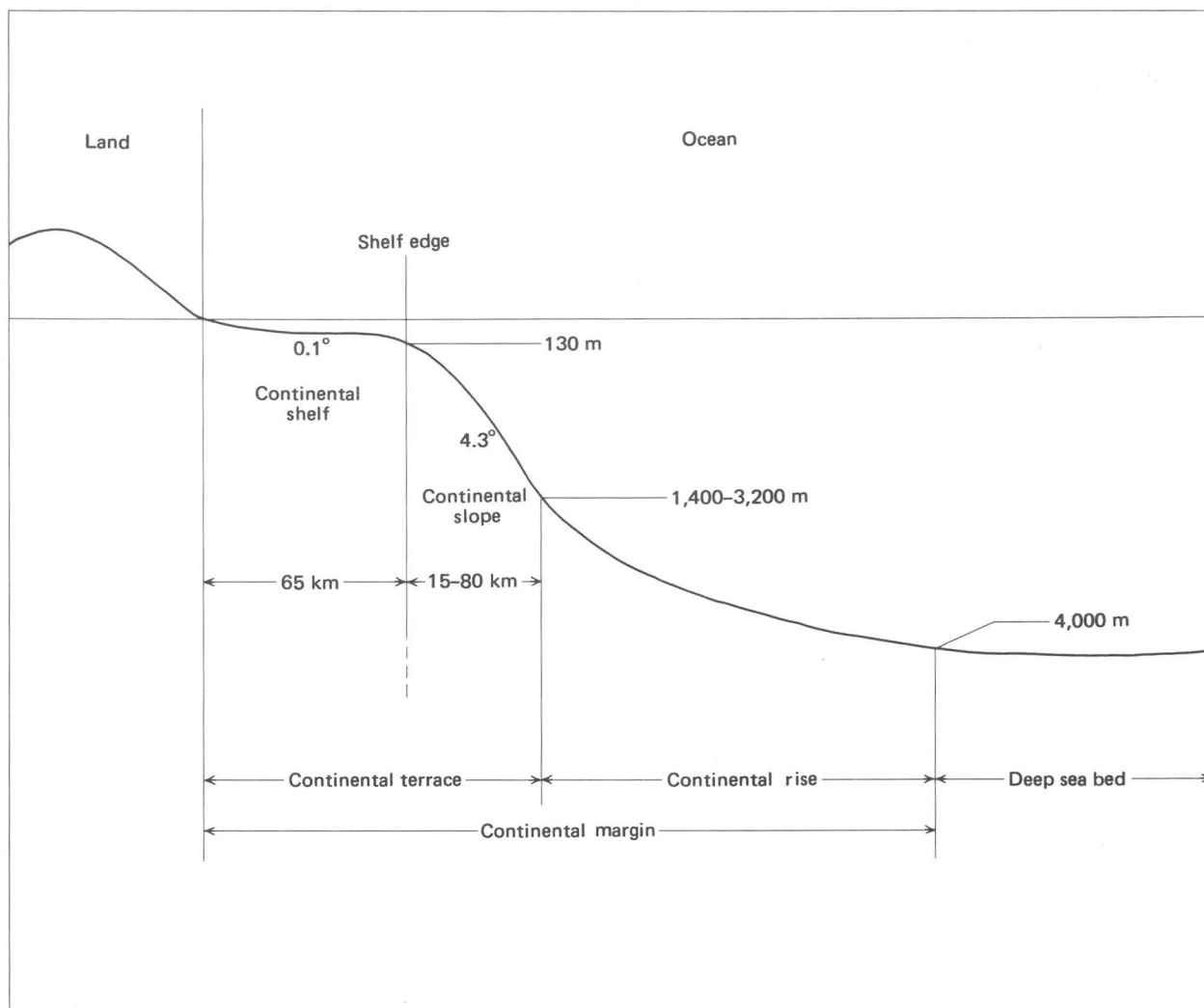


FIGURE 2.—Profile of the continental margin. Numbers shown are worldwide averages. From McKelvey, Stoertz, and Vedder (1969).

Drilling companies of the United States are involved on a worldwide scale. The current disposition of mobile drilling rigs owned by companies of the United States is shown on figure 4; of the total, 68 are operating in waters off the United States and 122 are working off the coasts of other countries.

RESULTS OF EXPLORATION

NUMBER AND GEOGRAPHIC DISTRIBUTION OF FIELDS DISCOVERED

Some 780 oil and gas fields had been discovered on the submerged continental margins of the world by early 1973. Of that total, 493 fields are listed as oil and 287 as gas. These

figures must be qualified as provisional and incomplete because most reporting media have only recently begun to separate offshore data from total petroleum statistics. Consequently, for the several categories of information—wells drilled, reserves, and production—the data now available for some offshore areas are still somewhat ambiguous; for others they are incomplete; and for a few, no data are available. An accurate compilation of the number of gas fields is almost impossible to derive because many fields produce both oil and gas. In some areas, such as the Persian Gulf, gas is flared and is neither reported as a reserve nor as production. For oil fields in general, accurate counts are difficult to establish because in early stages

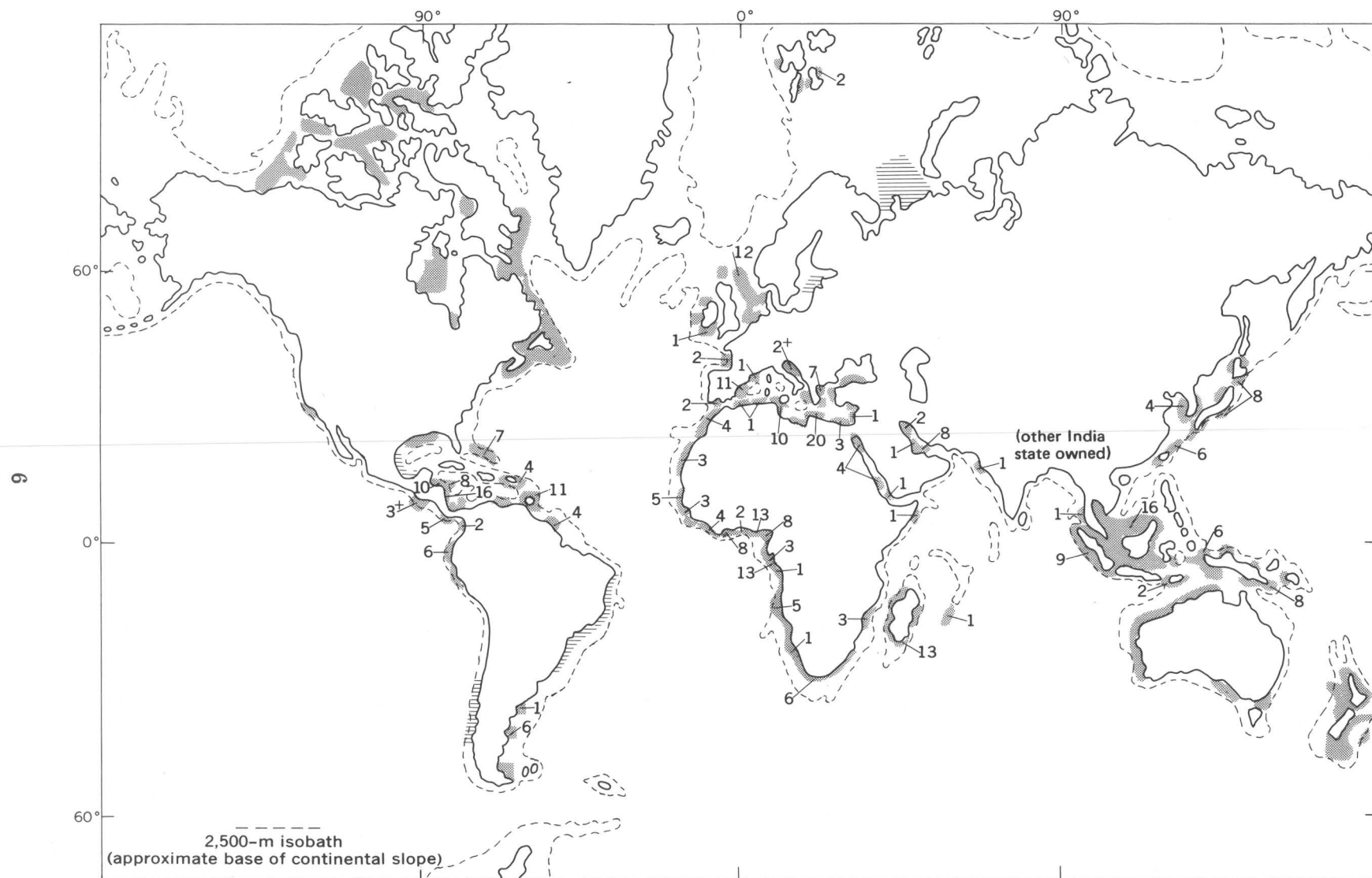


FIGURE 3.—Generalized offshore areas under concession for exploration worldwide (shaded). Ruled pattern indicates areas under exploration by nationally owned companies. Figures indicate number of companies holding licenses within the specified segment of the offshore—not known for some areas. The concessions, licensed areas, and other areas of exploration have been compiled largely from Wagner (1972).

of discovery, pools and fields may be reported indiscriminately.

Of the oil and gas fields discovered in the offshore areas, 70 are classified as giants. Sixty of these giants are classified as oil and ten as gas fields, although eight of them produce both oil and gas. Some of these produce from onshore as well as offshore. The geographic location of the giant fields is shown on figure 5. As used in this report, a giant oil field is one containing more than 500 million barrels of estimated recoverable oil; a giant gas field is one containing more than 3,500 billion ft³ of estimated recoverable gas. (This definition of "giant" coincides with that used by Halbouty, 1970, p. 5).

In this report, the data on the offshore oil and gas fields comes primarily from Halbouty (1970), Weber (1972), and Albers and others (1973). Use of the term "field" in referring to petroleum-producing units and of the names applied to them is based on the published identification of others. (See Halbouty, 1970, p. 5, 504.)

The distribution of the world's offshore oil and gas fields as well as a listing of other discoveries made but not yet developed to production are shown on table 1.

TABLE 1.—Numbers of offshore oil and gas fields listed by continent and country

[*, indicates discovery but no field development as yet]

Location	Numbers of offshore fields			
	Giant fields		Other fields	
	Oil	Gas	Oil	Gas
<i>Africa</i>				
Angola-Cabinda	1	--	1	--
* Cameroun	--	--	--	--
Congo (Brazzaville)	1	--	--	--
* Dahomey	--	--	--	--
Egypt	3	--	4	1
Gabon	--	--	13	6
* Ghana	--	--	--	--
* Libya (gas)	--	--	--	--
Nigeria ¹	2	--	31	--
* South Africa (gas)	--	--	--	--
* Tunisia (oil)	--	--	--	--
* Zaire (oil)	--	--	--	--
Total	7	--	49	7
<i>Asia</i>				
Middle East: ²				
Abu Dhabi	3	--	--	--
Dubai	2	--	5	--
Iran	7	--	5	--
Iran-Saudi Arabia	1	--	--	--
Qatar	2	--	2	--
* Ras al Khaimah (oil)	--	--	--	--
Saudi Arabia	5	1	3	--
Saudi Arabia-Kuwait	--	--	--	--
Neutral Zone	2	--	1	1

TABLE 1.—Numbers of offshore oil and gas fields listed by continent and country—Continued

Location	Numbers of offshore fields			
	Giant fields		Other fields	
	Oil	Gas	Oil	Gas
<i>Far East:</i>				
Indonesia	--	--	19	--
Japan	--	--	³ 3	--
Malaysia-Brunei	1	--	6	--
Malaysia-Sarawak	--	--	2	--
* Papua-New Guinea (gas)	--	--	--	--
Total	23	1	46	1
<i>Europe</i>				
Denmark	--	--	6	2
Italy	--	--	1	20
* Ireland	--	--	--	--
Netherlands	--	--	1	11
Norway	⁴ 2	1	4	1
* Spain	--	--	1	--
United Kingdom	4	4	9	19
U.S.S.R.	2	--	11	--
* West Germany	--	--	--	--
Total	8	5	33	53
<i>North America</i>				
* Canada (Atlantic Shelf)	--	--	--	--
Mexico	2	--	14	--
United States	7	--	⁵ 276	⁵ 202
Total	9	--	290	202
<i>Oceania</i>				
Australia	4	3	5	8
New Zealand	--	1	1	--
Total	4	4	6	8
<i>South America</i>				
Caribbean:				
Trinidad-Tobago	--	--	2	6
Venezuela	⁶ 9	--	--	--
Other South America:				
* Argentina ⁷	--	--	1	--
Brazil	--	--	3	--
* Ecuador	--	--	--	--
Peru	--	--	5	--
Total	9	--	11	6
Total (Worldwide)	60	10	435	277

- ¹ Sizable gas reserves but not reported by field.
² Sizable gas reserves associated with oil but unreported separately by field.
³ Three others are onshore-offshore.
⁴ Sizable gas reserves associated with Ekofisk Field.
⁵ Approximate because tabulation not available by field for Gulf of Mexico, where most of the fields are located.
⁶ Five are offshore extensions of onshore fields.
⁷ Offshore extensions of Golfo de San Jorge reported but no information available.

For an additional 22 countries, exploratory drilling offshore until January 1, 1972, had failed to yield discoveries of petroleum. These are shown in the list below by continent and region. Included in the list are five countries where noncommercial petroleum has been found. Sources of the drilling data used in compiling the list are the annual summaries of foreign developments in the "Bulletin of the American Association of Petroleum Geologists," 1960 through 1972.

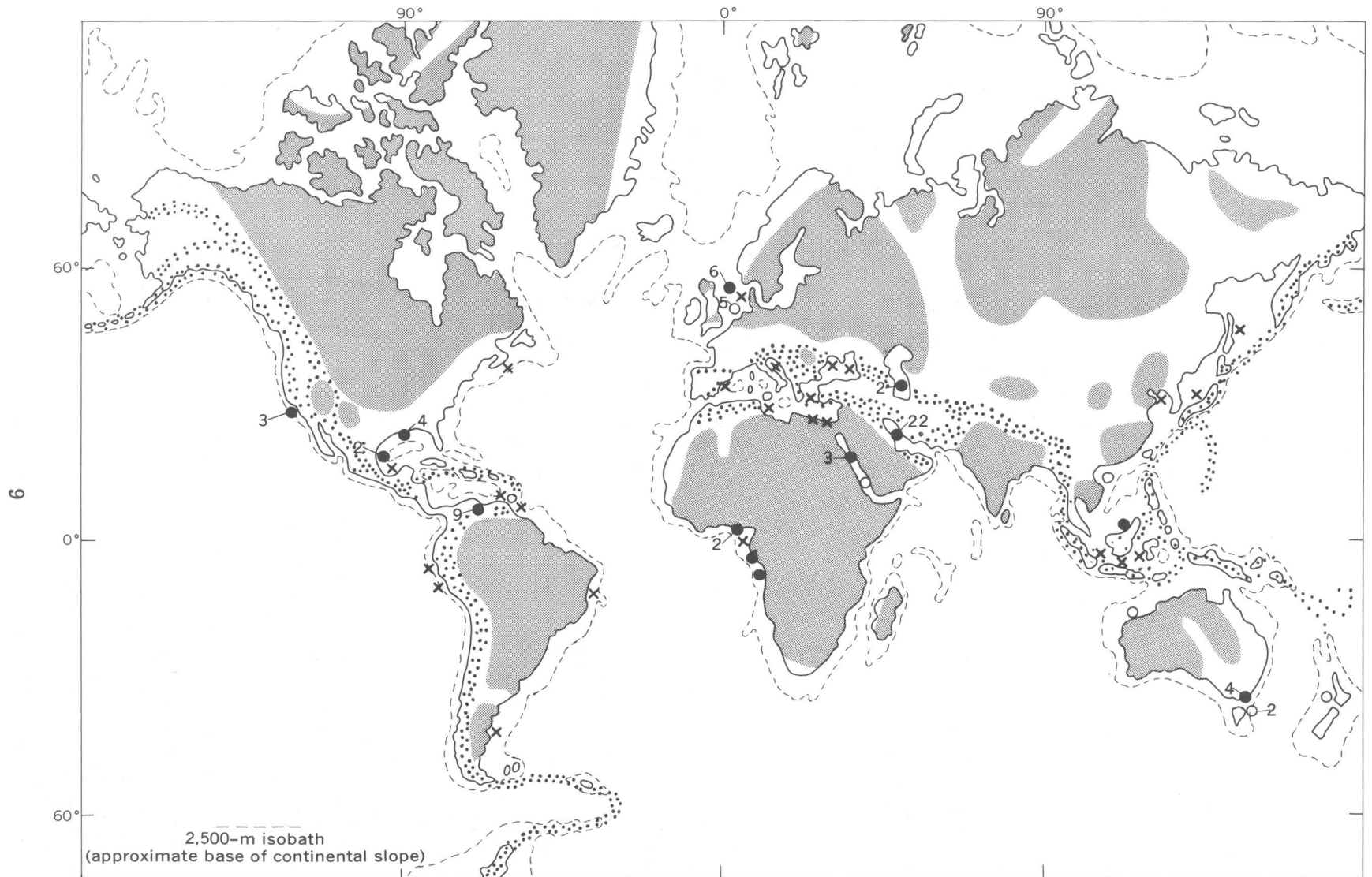


FIGURE 5.—World's giant oil and gas fields relative to generalized orogenic belts. Active belts (stippled); belts inactive since Paleozoic and Mesozoic times (unpatterned); regions not subjected to orogenic movements since Precambrian time (shaded). Solid circles are giant oil fields; open circles are giant gas fields; X indicates general areas of discovery either of less than giant size or areas under field development. Figures indicate the number of fields in a specified area. Adapted from Drake (1972).

<i>Location</i>	<i>Year of Initial Drilling</i>
Africa:	
West Africa:	
Congo, Republic of -----	1966
Equatorial Guinea -----	1968
Liberia -----	1971
Mauritania -----	1969
Morocco ¹ -----	1969
Portuguese Guinea -----	1968
Senegal -----	1966
Spanish Sahara -----	1966
East Africa:	
Ethiopia -----	1965
Malagasy -----	1970
Mozambique -----	1969
Sudan -----	Prior to 1964
Asia:	
Middle East:	
Turkey -----	1970
Israel -----	1970
Far East:	
India ¹ -----	1971
Philippines (two wells) -----	1971
Thailand (one well) -----	1971
West Malaysia, including central part of South China Sea. -----	1970
Central America and Caribbean:	
Columbia -----	1971
Honduras -----	1971
Nicaragua -----	1966
Europe:	
France -----	1972
Greece ² -----	1971
Malta -----	1971
Yugoslavia ² -----	1971
South America:	
Guyana ³ -----	1967
Surinam -----	1965

¹ Show of oil.

² Show of oil and gas.

³ Show of hydrocarbon.

The countries without significant offshore discoveries to date share a common characteristic. With the exception of Colombia, none has had previous significant petroleum production on land and, without exception, there has been little or no production from their onshore coastal areas near the continental shelves. The most recent licenses issued by some countries in this group have been for exploration farther out on their continental margins in water depths greater than 200 m, indicating that industry interests are shifting farther seaward with the hope of finding oil and gas beneath the outer part of the continental margin.

CHRONOLOGY OF OFFSHORE DISCOVERIES

Considering the exponential growth rate in the worldwide demand for petroleum and the belief that the offshore must be looked to as a large potential future source of petroleum, it is important in establishing expectations for the future to know what the overall success has been in finding new fields and how much

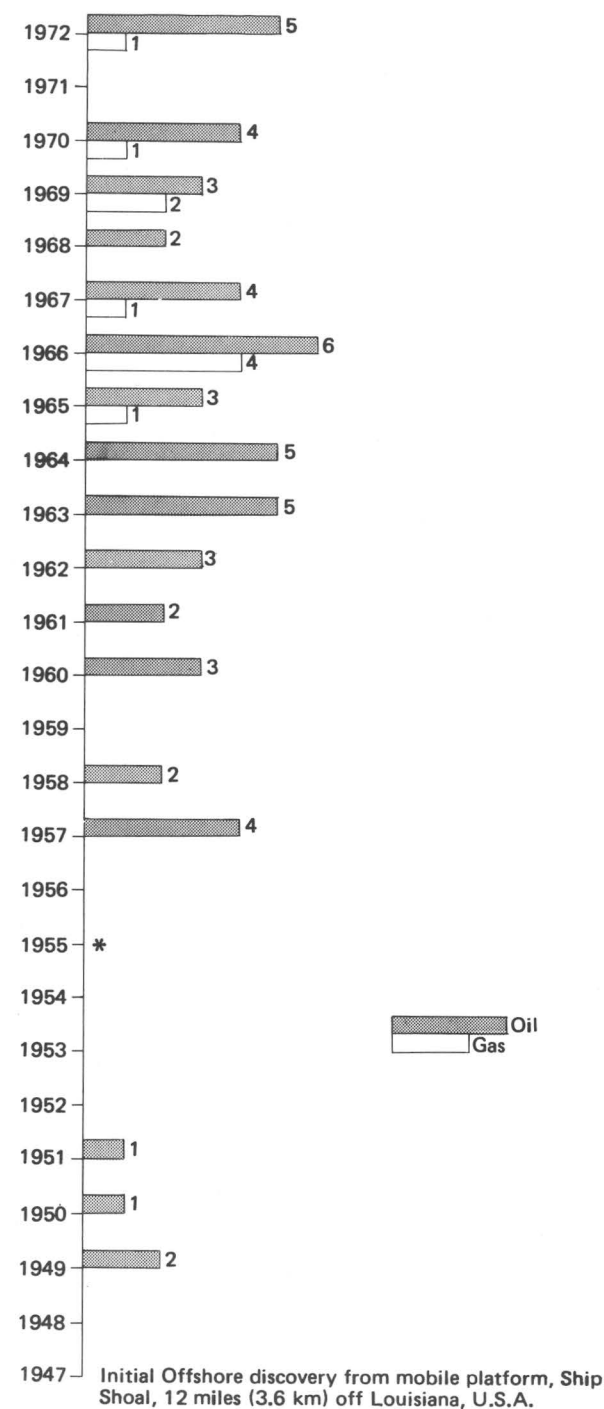
time is involved in locating a field in a new area and subsequently bringing it to production.

Several factors have strongly influenced the rates of discovery and development of petroleum offshore during the period beginning in 1947. These factors are (1) technical capability, including exploration techniques and engineering methods for drilling, producing, and transporting the petroleum from offshore, (2) onshore oil production adjacent to the offshore area, (3) local physical environmental conditions which include sea-floor topography, water depth, sea state, and climate, (4) political and legal circumstances, including boundaries of proprietorship, regulations, and attitudes for granting licenses, concessions, and leases, attitudes toward environmental effects, and attitudes about the petroleum company ownership, and (5) capital available for investment.

Obviously, geologic conditions and, to a degree, long-term patterns of environmental conditions do not vary with time, although they vary considerably from place to place. The finding of petroleum as a function of geologic conditions and the production of petroleum found in a given environmental situation, whether offshore or on land, are directly dependent upon man's scientific and technical ability and upon economic circumstances at the time. The extent to which exploration and production are allowed depends on political attitudes that are both national and international in scope and not predictable on either a short- or long-term basis. Long-term demands may override political considerations, but even this is not a completely valid assumption.

Available data are not sufficient to permit the tabulation of the chronology for the discovery of all 780 fields. However, the discovery record for the 70 fields now reported as giants is reasonably well known, and figure 6 has been prepared showing the distribution of 65 of these fields on a time basis during the past 25 years. As the giants contain most of the known offshore petroleum, the rate of their discovery provides a good gauge of the success in offshore exploration to date.

The pattern shown by the chart reveals a low discovery rate for the years prior to 1957 and an increased rate of discovery after 1962. The low rate of discovery prior to 1957 re-



* Year of first offshore wildcat in Eastern Hemisphere, Matbakh No. 1 off Qatar in the Persian Gulf (Heater, 1956, p. 1647).

FIGURE 6.—Chronology of discovery of offshore giant oil and gas fields. Figures indicate number of fields discovered during the specified year. Excluded are the onshore-offshore fields of the Venezuela Bolivar coastal group for which the offshore discovery dates could not be obtained.

flects the limited geophysical and drilling capability for work offshore. Offshore geophysical exploration techniques and drilling and production ability have been improved considerably since the late 1950's. Though not indicated by the chart, geologic knowledge gained in petroleum-producing areas locally adjacent to the continental shelves has profoundly affected the rate and pattern of discovery offshore. The search for offshore petroleum began in areas having established production along the adjacent shoreline, where geologic conditions governing the petroleum occurrences were known, and those regions have the largest number of offshore fields. According to Klemm (1971a) nearly one-third of all producing basins involve some offshore production, and 60 percent represent extension of established onshore production. The offshore giants may be categorized on the basis of available data as follows: 22 percent are direct offshore extensions of fields that were first discovered onshore, 56 percent have geologic conditions that relate closely to the producing areas onshore, and 22 percent are in geologic settings either not related closely to a petroleum-producing area onshore or not predictable on the basis of onshore geology. Thus, of the 70 major finds in the offshore to date, some 78 percent are in geologic settings that are related closely to known onshore conditions. All the offshore extensions were discovered before 1965, and all those not related closely geologically to the onshore have been discovered since 1964.

In the face of the rapidly rising demand for petroleum, the amount of time involved in the discovery and development of a commercial field offshore has a direct bearing on predicting both the short-term and long-range impact of offshore petroleum on future energy supplies.

The offshore giants have been examined in this report in terms of time elapsed between the beginning of geophysical explorations and eventual discovery and in subsequent development to an initial stage of significant production, defined for the purpose of this analysis as at least 1 million barrels per year. The discovery and development time frame for the giants has been averaged and is shown in table 2 in three categories based on extent of prior geologic knowledge. For excellent summaries of trends in basin development and of the rela-

TABLE 2.—*Discovery and development time, in years, for the giant offshore petroleum fields*

[Discovery time, from initial geophysical exploration. Development time, from discovery to production rate of 1 million barrels per year. Figures in parentheses indicate range of data. Data not complete for all fields]

Extent of previous geologic knowledge	Average time lapse		
	Discovery	Development	Discovery plus development
Offshore extension of producing onshore field, excluding Lake Maracaibo (7 fields).	4.4 (2-8)	3.0 (1-6)	7.4
Offshore geology related to that of onshore producing area (25 fields).	6.4 (1-12)	2.6 (1-4)	9.0
Offshore geology not closely related to onshore producing area (7 fields).	6.4 (4-10)	4.1 (3-6)	10.5

tion of giant fields to basin types, reference to Klemme (1971a-d) is suggested.

As dates for the beginning of exploration could not be obtained in many cases, only 56 percent of the giant fields could be included in the summary shown in table 2. Furthermore, as information on the time expended in exploration and discovery of most of the many fields of less than giant size is not available, the averages indicated are meaningful only as a general résumé. Also, in considering the time required for offshore development, it must be remembered that technical capability has grown with increasing experience in offshore exploration and development. This probably will continue in the future and could, to some degree, shorten the overall time required to find and develop. Factors that cannot be accounted for in any extrapolations of a future discovery-production time frame for the offshore are the geologic subtleties that must be accurately interpreted, the political constraints that might be imposed on development and production, and the extent of technical problems that might be encountered when exploration and development reach into the deeper waters beyond the continental shelves.

The ranges of time shown in table 2, even though they represent incomplete information, have been influenced by local circumstances which have affected the rate of development. The factors that have influenced development can best be recognized by a brief description of several specific areas.

In the Persian Gulf area, reserves of petroleum on land are so large that there has not been great urgency to proceed with haste in

developing the offshore. Furthermore, in the Persian Gulf, where the overall petroleum potential has been so great and individual fields are so large, development and production have proceeded rather systematically in response to market demands.

In Nigeria, where a large petroleum potential was not identified until the 1960's, exploration and development of producing capacity have proceeded rapidly both on land and offshore, and drilling activity has been intense. The impetus for rapid development has been twofold: the market demand for Nigeria's low-sulfur oil, and a desire on the part of the government of Nigeria to expand and develop its production capacity as rapidly as possible. Consequently, fields discovered offshore generally have been brought to production in periods of 2 to 4 years. The very rapid development off Nigeria adds another factor that will have a long-range effect on discovery and production rates, not only for Nigeria, but for any area that undergoes initial rapid exploration and development. This factor is the increasing difficulty of finding petroleum after the most obvious and accessible structures have been tested. The discovery rate on the shelf off Nigeria has fallen rapidly in the past several years from 85 percent in 1967 to 14 percent in 1971. Exploitation of the Nigerian Continental Shelf has been rapid because physical constraints have been minimal, production to date has come from fields in relatively shallow water, and demand for its low-sulfur oil is high.

In the North Sea, other circumstances have prevailed, and the time required for development has been longer. Recognition of the North Sea as a potential new source of petroleum came with the onshore discoveries of gas at Groningen in the late 1950's. Geophysical exploration of the offshore followed soon thereafter, but drilling was delayed until 1964 when jurisdictions of the various countries bordering the North Sea were established and boundaries of proprietorship drawn. The time expended in the development of the North Sea as a petroleum province has been influenced principally by two factors: geological interpretations that guided initial selection of sites for detailed investigation and drilling, and the rigorous physical conditions at sea. Though the Groningen dis-

coveries suggested an offshore potential, the North Sea presented a frontier in terms of geologic knowledge. In the early stages of exploration, effort was directed to the southern periphery of the basin nearest areas of known geologic conditions. Not until the late 1960's was exploration directed to the central part of the basin where the large oil discoveries have been made. Thus, initial geologic interpretations prior to exploratory drilling within a prospective offshore province can affect the time between exploration and discovery. The stormy North Sea has given the oil industry its greatest test in grappling with severe physical conditions. Rigs and platforms must be built to withstand possible wave heights of 100 feet (30 m). Consequently, platforms must be built that can withstand an overturning force exerted by waves and currents that is 10 times greater than that exerted on platforms in the Gulf of Mexico. A comparison of sea-state conditions in the northern North Sea with those of other offshore areas and the effect of sea state on downtime in both drilling and supply operations is shown in figure 7, taken from

Taylor (1973, p. 62). Exploration and development drilling under rigorous North Sea conditions is both long and costly and has put a drain on investment capital. The time from initial discovery to anticipated production in 1974 from the Forties field in the south-central part of the North Sea will have been 10 years. The Forties field was one of the first two giants discovered in the North Sea. Table 3, gives an industry summary of the time required and cost for finding and developing a large oil field in the North Sea.

The United States Continental Shelf in the Gulf of Mexico has had the greatest concentration of exploration and drilling and by far the largest number of producing fields of any offshore area in the world. Even there, precise data on the time required to discover and produce from a given field is difficult to obtain. Consensus from a variety of sources seems to be that the average time required to bring a field to significant production after initial discovery has been 1-3 years. When account is taken of the time devoted to exploratory drilling, the elapsed time from granting of leases

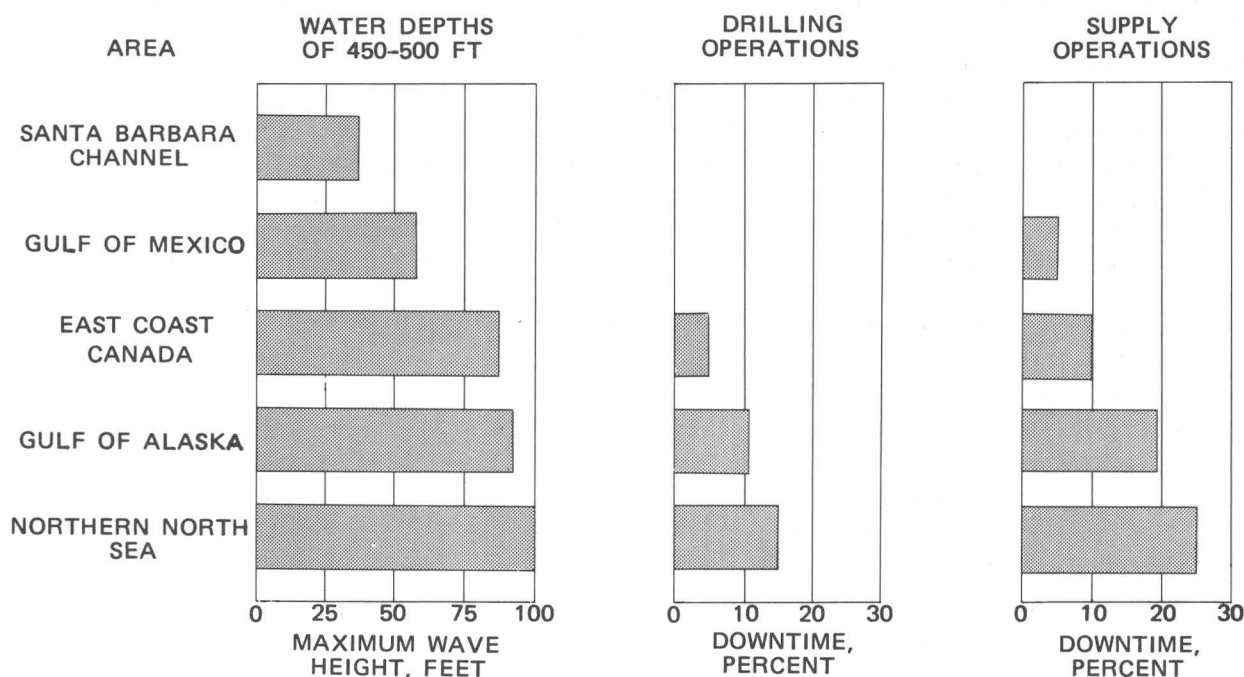


FIGURE 7.—Comparison of sea-state conditions in selected offshore areas and the effect on drilling and supply operations. From Taylor (1973).

TABLE 3.—*Time span and costs for finding and developing an oil field in the North Sea*

[Field size, 1 billion barrels recoverable reserves and 250,000 barrels per day capacity. Adapted from Petroleum Press Service, 1972, p. 410]

	Time (years)	Direct employ- ment (men)	Capital invest- ment (millions)	Operating expendi- ture (millions)
Exploration: 2,000–4,000 km of geo-physical surveys, 5–30 exploration-appraisal wells.	¹ 2–6	200–400	\$24–147	-----
Construction: plan-ning design, pro-duction well drill-ing, production and transport facilities.	¹ 5–6	1,000–2,000	\$612	-----
Production -----	² 16–20	300–400	³ \$122–245	\$612–735

¹ Overall range for exploration and construction, 7–12 years.

² Includes buildup, 3–5 years; plateau, 5 years; and decline, 8–10 years.

³ Dependent on type of secondary recovery scheme or other operation necessary.

to production of petroleum has generally been 3–4 years. After the December 1972 lease sale in the Gulf of Mexico, which included blocks on the outer part of the continental shelf in water depths ranging from 250 to 425 feet (76–129 m), industry sources forecast that significant production from these leases could be expected in 4–5 years (Ocean Industry, 1973).

The principal determining factor in the time required to find and produce from a new concession is how soon the initial significant discovery will be made, a factor that relates in part to how the geology of the prospect has been interpreted. The time span for finding new fields on the continental shelf in the Gulf of Mexico would be expected to be relatively short because the northern continental shelf of the gulf is a salt-dome province, and the nature of the targets is reasonably well understood. As the search moves away from the area of such obvious targets to other areas of the gulf, such as the carbonate banks of the Florida shelf, more subtle geologic conditions may be found that could change the time required for discovery and development.

Obviously, the time involved in finding and producing petroleum offshore results from a composite of circumstances, each of which may vary in degree of influence from one area to another. Consequently, it is not possible to correlate directly from area to area the time required to find and produce petroleum purely on the basis of past experience. Nevertheless, one can make the generalization that in areas

such as the Gulf of Mexico salt-dome province, offshore Nigeria, and the Persian Gulf where the potential is large and the nature of the geological targets is reasonably well understood, new discoveries can be made and brought to production within a time span of 3–4 years. For areas such as the North Sea, where the potential is large but physical conditions of the environment are a limiting factor, a reasonable expected time span from granting of a concession to significant production is 7–12 years.

Assuming that the next few years will bring a concerted effort to find new sources of petroleum offshore, how soon can the United States expect to have substantially increased production to help meet its large and growing domestic demand? Outside the Gulf of Mexico, the obvious prospects for large future offshore efforts are the Atlantic continental margin, southern California, Alaskan waters including the Gulf of Alaska, the Bering Sea, the Chukchi Sea, and the Beaufort Sea shelf off northern Alaska, and Prudhoe Bay.

Because of its proximity to the large population and industrial centers of the eastern part of the country, the Atlantic continental margin of the Eastern United States is receiving increased attention as a possible new source of petroleum. Offshore geophysical exploration on the Atlantic Continental Shelf began some 10 years ago, and over the past 8 years considerable geophysical work has been done on that part of the shelf north of Cape Hatteras. How soon could we expect production from the northeastern United States Atlantic Continental Shelf if the decision to drill is made in the reasonably near future? The Atlantic Continental Shelf has not been drilled for oil and gas, and its onshore extension, the Atlantic Coastal Plain from southern Florida to New Jersey, has yielded no significant shows of petroleum from the scattered drilling that has been done all along the coast over the past several decades. Because it falls in the category of those offshore areas around the world with no history of adjacent onland petroleum production, its petroleum potential cannot be judged accurately from geologic conditions that exist along the coast. However, sedimentary rocks along the shoreline are known to thicken seaward beneath the shelf and reach thicknesses of more

than 5,000 m along parts of the outer edge of the continental shelf and farther out beneath parts of the continental slope and rise (Maher, 1971, p. 4). If petroleum is present in commercial quantities, the time lapse from granting of leases to discovery will depend upon the accuracy of initial geological interpretations in picking targets for initial exploratory drilling. Assuming reasonably early discovery after exploration drilling begins, development and production will encounter physical conditions at sea that will range regionally from somewhat more rigorous than those in the Gulf of Mexico to those that will at times approach conditions typical of the North Sea on the northern part of Georges Bank. A reasonable time lapse from discovery to significant production probably would be in the range of 6–10 years, the actual time required to produce depending on where and beneath what depths of water petroleum might be found. As for the Gulf of Alaska, where sea states are virtually analogous to those of the North Sea and where climatic conditions are harsh, significant production could be estimated somewhere within the range of 8–12 years depending on early discovery after initial drilling starts.

Speaking from a high-level industry viewpoint, the Chairman of the Board of the Exxon Company, U.S.A., remarked recently in the August 1973 issue of the Exxon publication "The Lamp" that the United States could not expect significant production from either the Atlantic Continental Shelf or the Gulf of Alaska in this decade.

Several of the factors that influence the time required to find and produce new sources of petroleum from the offshore in areas not previously tested by drilling can be expected to change, and these changes will affect the time required to produce. The ability to complete and maintain wells from units placed directly on the sea floor will reduce the time required to carry out development drilling not only in areas of heavy sea states, such as the North Sea, but in other areas as well. Planning and development of sea-floor completion systems has been underway for some years, and four known subsea tests are also underway (Bleakley, 1973). One of these has been in successful operation since October 1972, in 375 feet (114 m)

of water in the Gulf of Mexico (Taylor, 1973; Bleakley, 1973). Testing of a sea-floor system in the North Sea is planned for the near future.

However, some of the time that will be saved by use of sea-floor completion systems may well be offset as exploration moves further into new areas of the offshore where the geologic conditions are less well known. The current trend into areas less well known is, as has been mentioned, taking the search into deeper water where exploration times will be longer and engineering costs much higher, placing a heavier burden on capital available for investment. Weighing both the multiple factors involved and their varying interplays from place to place, the time required to produce after initial discovery in frontier areas will likely remain 2–5 years for those areas that are in water depths of less than 300 feet (91 m) and will be in the range of 7–14 years for those that are in water more than 400 feet (121 m) deep.

No attempt has been made to summarize the costs and economics of offshore development because data are not readily available and thus are too incomplete to permit a definitive discussion. However, the estimated development cost for the Ekofisk field complex in the North Sea is \$1.5 billion (Oil and Gas Jour., 1972, p. 33). This estimate is based on a water depth of less than 85 m. The estimate does not include higher costs of development that will be encountered for those parts of the Ekofisk field complex that are farther out in depths of 200 m and more. The cost of laying a crude-oil and condensate pipeline from the Ekofisk field to the United Kingdom, a distance of some 320 km, is estimated to be \$200 million (Oil and Gas Jour., 1972, p. 45). Although the costs just discussed are for a specific situation that may not apply generally, they reflect the high costs involved in developing new large fields in frontier areas of exploration where physical conditions are rigorous.

In summarizing the economics of offshore production, the comments of Weeks (1973a) are pertinent to the general trend that might be expected in the future. He stated, p. 17, "studies show that costs of exploitation increase at an exceedingly rapid rate with increasing water depth; for example at 330 m

the cost will be at least four times higher than at 33 m, where the cost is already twice that of an on-shore field of similar characteristics. Operations under 330 m or more of water may be so costly that only giant fields will perhaps be profitably exploited . . . Distance from shore will also influence the economic possibilities of developing offshore fields, particularly in the case of natural gas, as there are no viable alternatives for transporting to shore installations other than by pipeline."

OFFSHORE PETROLEUM RESERVES AND PRODUCTION

The current status of the worldwide search for petroleum offshore and its success are revealed best by examination of the production and reserves figures for those areas where exploration and development have progressed to the point that production has become substantial and reserves can be estimated with reasonable accuracy. The geographic distribution and the magnitude of offshore oil production and reserves by continent and country to January 1, 1973, are shown in table 4; production and reserves of natural gas to January 1, 1972, are shown in table 5. The giant fields are listed by name. The reserves and production figures for the tables have been taken largely from Weber (1972) and from Albers and others (1973). The production figures for 1972 that have been included in the cumulative production figures in table 4 were taken from McCaslin (1973a).

The tables are provisional for several reasons. Only in the past 2 years have offshore statistics begun to be reported separately from total production in some of the reporting media. Consequently, ambiguities and inconsistencies exist in both production and reserves statistics reported for some of the fields in the Gulf of Mexico and for some of the fields that straddle the shoreline and produce from both onshore and offshore. Furthermore, some of the estimates of reserves are not available for some fields of less than giant size, as indicated in the tables. Nevertheless, in all cases, the reserve estimates tabulated are based on some drilling, not broad favorability factors, and, therefore, are essentially measured reserves.

The reserve and production figures listed in tables 4 and 5 are somewhat less than the

TABLE 4.—Provisional estimated recoverable reserves, in millions of barrels, and cumulative production offshore

[Giant fields indicated by name. Parentheses indicate figure estimated from initial drilling. NA, not available. SI, shut in, not producing. X, field partly onshore]

Location, field, and year discovered	Estimated recoverable reserves	Cumulative production to 1/1/73	Estimated remaining reserves
<i>Africa</i>			
Angola-Cabinda:			
Cabinda "B," 1966 -----	1,230	127	1,103
Other (1 field) -----	NA	NA	NA
Congo (Brazzaville), Emeraude			
Marine, 1969 -----	500	1	499
Egypt:			
Amal, 1968 -----	2,500	0	2,500
El Morgan, 1965 -----	780	381	399
Belayim Marine, X, 1961 -----	1,400	225	1,175
Other (4 fields) -----	NA	NA	NA
Gabon (13 fields) -----	1,100	68	1,032
Nigeria:			
Meren, 1965 -----	628	113	515
Okan, 1964 -----	588	166	422
Other (31) -----	1,295	236	1,059
Total -----	10,021	1,317	8,704
<i>Asia</i>			
Middle East:			
Abu Dhabi:			
Mubarras, 1969 -----	2,000	0	2,000
Umm Shaif, 1958 -----	2,223	328	1,895
Zakum, 1964 -----	1,257	339	918
Other (6 fields) -----	NA	0	NA
Dubai:			
Fateh, 1966 -----	1,581	128	1,453
Fateh, SW, 1970 -----	¹ (500)	0	¹ (500)
Iran:			
Bahrgansar, 1960 -----	1,039	85	954
Cyrus, 1962 -----	814	30	784
Darius, X, 1961 -----	1,334	250	1,084
Henijan ² , 1968 -----	454	17	437
Nowrouz, 1966 -----	969	24	945
Sassan, 1966 -----	1,467	204	1,263
Rostam, 1967 -----	1,000	56	944
Other (5 fields) -----	NA	NA	NA
Iran-Saudi Arabia, Fereidoon-			
Marjan, 1966 -----	10,000	0	10,000
Qatar:			
Idd-el-Shargi, 1960 -----	2,115	123	1,992
Maydan-Mahzam, 1963 -----	10,249	303	9,946
Saudi Arabia:			
Berri 4, X, 1964 -----	5,926	223	5,703
Safaniya X, ³ 1951 -----	25,377	2,307	23,070
Manifa X, 1957 -----	11,010	98	10,912
Qatif X, ³ 1964 -----	9,039	375	8,664
Abu Sa'fah, 1963 -----	6,529	166	6,363
Other (3 fields) -----	NA	NA	NA
Saudi Arabia-Kuwait Neutral Zone:			
Kahfi, ⁴ 1960 -----	1,734	952	782
Hout, 1969 -----	993	70	923
Other (1 field) -----	NA	NA	NA
Middle East subtotal -----	97,615	6,078	91,537
Far East:			
Malaysia-Brunei:			
Ampa, SW, 1963 -----	2,341	178	2,163
Other (6 fields) -----	689	82	607
Malaysia-Sarawak (2 fields) ---	⁵ 200	NA	⁵ 200
Indonesia (10 fields) -----	⁶ 400	27	⁶ 373
Japan -----	24	9	15
Far East subtotal -----	3,654	296	3,358
Total -----	101,269	6,374	94,895
<i>Europe</i>			
Norway:			
Ekofisk, 1970 -----	3,010	13	2,997
Edda, 1972 -----	(500)	0	(500)
Other (4 fields) -----	NA	NA	NA
United Kingdom:			
Brent, 1972 -----	(1,000)	0	(1,000)
Forties, 1970 -----	4,400	0	4,400
Comorant, 1972 -----	(1,000)	0	(1,000)
Halibut, 1972 -----	NA	(Industry places in giant class)	NA
Other (9 fields) -----	NA	NA	NA
Denmark (6 fields) -----	NA	SI	NA
Netherlands (1 field) -----	NA	NA	NA
Italy (1 field) -----	152	66	86
Spain (1 field) -----	150	0	150

See footnotes at end of table.

TABLE 4.—Provisional estimated recoverable reserves, in million of barrels, and cumulative production offshore—Continued

Location, field, and year discovered	Estimated recoverable reserves	Cumulative production to 1/1/73	Estimated remaining reserves
U.S.S.R.:			
Sangachaly-Duvannyi-Bulla, 1963	1,036	100	936
Neftyanne—Kamni, 1949	1,260	760	500
Other (11 fields)	NA	NA	NA
Total	12,508	939	11,569
North America			
Mexico:			
Arenque, 1967	1,000	4	996
Atun, 1966	924	25	899
Other (14 fields)	200	53	147
United States:			
Louisiana:			
West Delta Blk. 73, 1962	720	111	609
Bay Marchand Blk. 2, X, 1949	780	364	416
South Pass Blk. 24, 1950	1,072	340	732
Timbalier Bay, X, (1955-63)	651	361	290
Other (9 fields) ⁶	2,599	1,207	1,392
Other (248 fields) ⁷	6,000	3,868	2,132
California:			
Huntington Beach, X, 1962	501	415	86
Wilmingon, X, 1964	1,279	713	566
Santa Ynez, ⁸ 1970	3,000	0	3,000
Other (11 fields)	580	243	337
Texas (2 fields)	98	8	90
Alaska, Cook inlet (4 fields)	746	328	418
Total	20,150	8,040	12,110
Oceania			
Australia:			
Barracouta, 1965	502	6	496
Halibut, 1967	645	152	493
Kingfish, 1967	1,010	79	931
Marlin, 1966	500	NA	NA
Other (1 field) ⁹	208	68	140
Other (4 fields)	NA	NA	NA
New Zealand (1 field)	11	1	10
Total	2,876	¹⁰306	¹⁰2,070
Caribbean			
Trinidad-Tobago (1 field)	420	236	184
Other (1 field)	NA	NA	NA
Venezuela:			
Centro, 1957	743	282	461
Ceuta, 1957	623	195	428
Lama, 1957	2,675	1,675	1,000
Lamar, 1958	1,841	593	1,248
Bolivar Coastal:			
Bachaquero, X	¹¹ 15,000	13,591	1,409
Cabimas, X			
Lagunillas, X			
Tia Juana, X			
Mene Grande, X	3,962	2,672	1,290
	601	573	28
Total	25,865	19,817	6,048
South America (other than Venezuela)			
Argentina	NA	NA	NA
Brazil	NA	NA	NA
Peru	141	51	90
Total (Other than Venezuela)	141	51	90
Total, (Worldwide)	172,830	¹⁰36,844	¹⁰135,486

¹ Fateh, SW reported as giant but reserves not available; figure listed is estimated minimum.

² Included as giant through reserves slightly less than 500 million barrels.

³ Dates of initial onland discovery.

⁴ Extension of Safaniya Field.

⁵ Estimated.

⁶ Fields with estimated reserves of >100 million barrels at time of discovery.

⁷ For 34 wells of this group, cumulative production is half of reserves; this ratio was applied to the reported production for 215 of the wells (Weber, 1972) to obtain estimate of 6,000 million barrels.

⁸ Estimate based on single well.

⁹ Barrow Island Field.

¹⁰ Minus figures for Marlin Field, Australia.

¹¹ Total reserve listed for Bolivar Coastal onshore and offshore is 30,000; offshore part is estimated to be half of total.

TABLE 5.—Provisional worldwide estimated recoverable offshore gas reserves and cumulative production, in billions of cubic feet

[NA, not available. INC, incomplete]

Location	Estimated recoverable reserves	Cumulative production to 1/1/72, except at noted
Africa:		
Egypt	¹ 1,000	NA
Gabon	7,000	NA
Nigeria	10,000	NA
Total	18,000	NA
Asia, Middle East:		
Saudia Arabia	14,600	NA
Kuwait-Neutral Zone	875	37
Union of Arab Emirates:		
Abu Dhabi, Dubai, Ras al-Khaimah, Umm al-Qaiwan, Sharjah, Ajman	2,165	NA
Total	17,640	37 (INC)
Europe:		
North Sea ²	60,000	1,130
Italy	3,530	³ 300
Total	63,530	1,430
North America, United States	39,500	20,600
Total	39,500	20,600
Oceania:		
Australia	20,300	48
New Zealand	6,000	0
Total	26,300	48
Caribbean, Trinidad-Tobago	3,500	39
Total	3,500	39
Total, (worldwide)	168,470	22,154 (INC)

¹ Gas is also produced from the El Morgan Field but the amount is not available.

² Discovery rate in the North Sea has been high during the past year and an accurate breakdown of reserves by country is not available.

³ To 1/1/71.

actual values because of the lack of statistics for a number of fields of less than giant size. Nevertheless, it is unlikely that inclusion of data not currently available for the smaller fields would substantially change the order of magnitude of either the worldwide or regional totals as shown in the tables, because the amounts of reserves for fields of less than giant size are small relative to the reserves in the giant fields.

The geographic distribution and magnitude of petroleum reserves and production offshore relative to onshore reserves and production are shown graphically by figure 8. Of the offshore oil discovered so far, 56 percent has been found in the Persian Gulf, and an additional 14

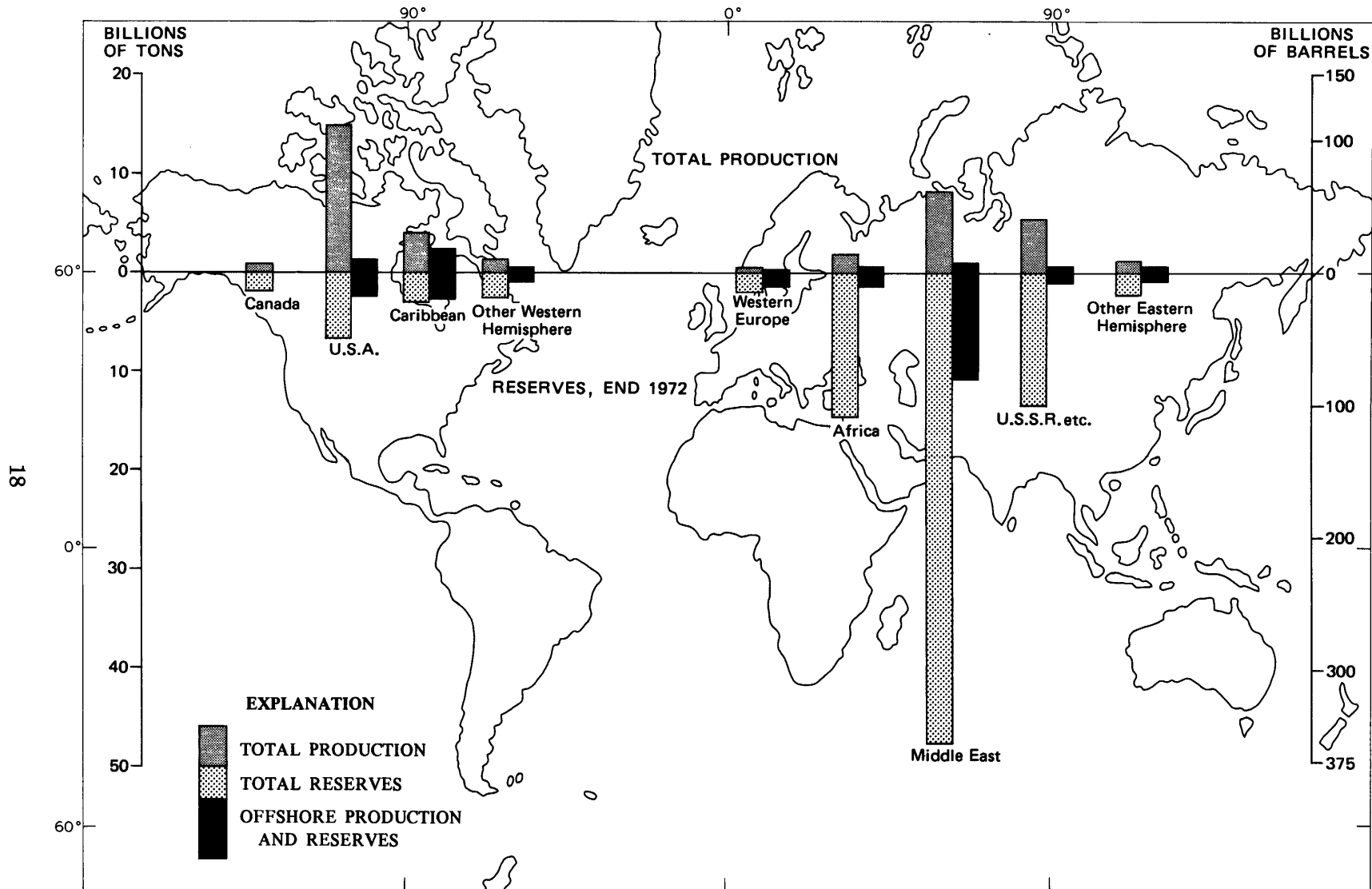


FIGURE 8.—Relation of offshore oil reserves and production to total world oil reserves and production. Adapted from the British Petroleum Co., Ltd. (1973).

percent is reported for Lake Maracaibo, giving the two areas 70 percent of the world offshore total. The offshore estimated oil reserves, as reported in table 4, represent approximately 26 percent of the world's estimated recoverable reserves at this time.

The giant offshore oil fields contain some 157,-817 million barrels or about 90 percent of the oil reported recoverable for the offshore. In

terms of estimated recoverable reserves, seven of the offshore giants rank among the 20 largest oil fields in the world; six are in the Persian Gulf. The Safaniya Field, Saudi Arabia, is the world's largest offshore field, and it ranks second among all oil fields, both onshore and offshore. Table 6 shows the ranking of the offshore oil giants among the world's 20 largest oil fields.

TABLE 6.—*World's largest oil fields, in billions of barrels*

[*, offshore giants. Principal source, Weber, 1972]

Rank	Production		Estimated recoverable reserves	
	Field	Amount	Field	Amount
1	Kuwait (5+ fields)	13.3	Saudi Arabia (Ghawar)	75.4
2	*Venezuela (Lagunillas)	7.7	*Saudi Arabia (Safaniya)	25.3
3	Saudi Arabia (Ghawar)	6.6	U.S.S.R. (Samotlorskoye)	15.1
4	Iraq (Kirkuk)	5.6	U.S.S.R. (Romashkino)	14.3
5	Iran (Agha Jari)	4.8	Iraq (Rumaila)	12.3
6	Venezuela (Bachaguerro)	4.2	*Saudi Arabia (Manifa)	11.0
7	U.S.A. (East Texas)	4.0	*Venezuela (Lagunillas)	10.5
8	Saudi Arabia (Abqaiq)	3.7	Iraq (Kirkuk)	10.2
9	*Venezuela (Tia Juana)	2.6	*Iran-Saudi Arabia (Fereidoon-Marjan)	10.0
10	Iran (Gach Saran)	2.5	Iran (Marun)	9.7
11	*Saudi Arabia (Safaniya)	2.3	U.S.A. (Prudhoe Bay)	¹ 9.6
12	Algeria (H. Messaoud)	1.66	*Saudi Arabia (Qatif)	9.0
13	Iran (Haft Kel)	1.63	Iran (Gach Saran)	8.8
14	U.S.S.R. (B.S.R.)	1.6	Saudi Arabia (Abqaiq)	8.6
15	*Venezuela (Lama)	1.6	Iran (Ahwaz)	8.5
16	Libya (Zelten)	1.5	Libya (Sarir)	7.7
17	*U.S.A. (California-Wilmington)	1.48	Iran (Bibi Hakimeh)	7.5
18	Iraq (Rumaila)	1.4	*Saudi Arabia (Abu Sz'Fah)	6.5
19	Indonesia (Minas)	1.38	U.S.A. (East Texas)	6.0
20	U.S.S.R. (Aliyurt)	1.35	*Saudi Arabia (Berri)	5.9

¹ Some sources estimate as high as 20 billion.

In overall production from the offshore, Venezuela, the United States, and the countries of the northwest Persian Gulf have accounted for some 92 percent of the world total. Production rates have been considerably higher in Venezuela and the United States than in the Persian Gulf, and, consequently, a considerably larger percentage of the discovered oil in each of these countries has been depleted. Of the estimated offshore reserves, some 91,537 million barrels, or approximately 70 percent, are in the Persian Gulf.

Total offshore oil output in 1972 increased 3.8 percent over 1971 (McCaslin, 1973a, p. 126). Worldwide production from the offshore increased from 2.6 billion barrels in 1970 to 3.3 billion barrels in 1972 (McCaslin, 1973a, p. 126) and now accounts for about 17 percent of total world production.

Data are still not sufficient for making either a complete estimate of potential subsea petroleum resources or for making a meaningful

revision of Week's 1969 estimate of 700 billion barrels, a figure that is based on mass volumes of sedimentary rocks and broad geologic favorability factors. In fact, Weeks (1973a) has revised his 1969 estimate to 2,272 billion barrels of ultimate potentially recoverable oil plus oil equivalent of the gas. However, with regard to the validity of his new estimate, Weeks (p. 13) stated, "It should be pointed out that in making this estimate it was assumed that all of this petroleum will be economically recoverable. This may not be found possible particularly with respect to deeper water areas of lower average productivity. It must be emphasized that such estimates are, at best, speculative and are based on industry experience in more mature areas having similar geological characteristics. The fact that the figures employed are relatively specific should not be interpreted as altering their speculative nature." He stated further (p. 16-17), "Of the total estimated resources of 2,272 billion barrels, perhaps less than 25 per-

cent are in potentially highly productive areas . . . 372 billion barrels of potential petroleum resources will be found in highly productive areas."

The world subsea petroleum resource potential is unquestionably large, but the magnitude obviously cannot as yet be accurately defined. Offshore exploration for petroleum, now of worldwide scope, is becoming increasingly intense in many areas of the world. Results, disappointing to date in some areas, have been spectacular in others. Over the next few years, the worldwide reserves of petroleum will be substantially increased, and by the end of the next decade, offshore data should be sufficient to make significantly improved estimates of world subsea petroleum potential.

For the United States, estimates of offshore petroleum potential have ranged from conservative to highly optimistic. For the Gulf of Mexico, McCaslin (1972, p. 108), reporting the opinion of others, gave a "reasonable potential" of 21 billion barrels of oil and 169 trillion ft³ of natural gas. The State of California estimates its offshore potential to be 30 billion barrels. The outer continental shelf waters off California almost certainly have an even larger potential. In a report on the energy resources of the United States, Theobald, Schweinfurth, and Duncan (1972, p. 8-10) estimated that the undiscovered petroleum resources of the offshore to the 2,500-m water depth that might be found and recovered under approximate 1972 economic conditions and using existing techniques are 200 billion barrels of oil and natural gas liquids and 850 trillion ft³ of natural gas. Their estimate was derived by considering first the geological favorability of the offshore areas and then extrapolating the results of past exploration drilling to the remaining unexplored but favorable rocks, following a method developed by A. D. Zapp and T. A. Hendricks (Hendricks, 1965).

The future petroleum potential worldwide, including offshore areas, recently has been summarized in a series of four articles by Weeks (1973b-e). Though petroleum resource potential for offshore areas is not listed separately from total potential, the four articles are an excellent global coverage. His discussions summarize the interplay of reserves, production,

and mounting demands and what these portend for the future of petroleum as an energy source.

GEOLOGIC SUMMARY OF THE WORLD'S OFFSHORE PRODUCING AREAS

Areas of the world's oceans and seas having geologic conditions generally favorable for the occurrence of petroleum are portrayed on sheet three of the McKelvey and Wang report of 1970. However, as pointed out in their report and as indicated in the foregoing summaries of this report, conditions considered most favorable for petroleum are highly localized, and exploration efforts, though geographically extensive, have become more concentrated in those areas where initial exploration and ensuing discoveries have indicated a high potential. No attempt is made here to describe in detail the geologic conditions in the specific producing areas but rather to summarize the geologic characteristics of the areas containing giant petroleum fields.

The most favorable habitat of petroleum offshore, as onshore, is the sedimentary basin and in particular those basins where sediments have accumulated to a thickness of more than 1,000 m. Such basins are scattered over all the continents but, at the present stage of geologic time, tend to be concentrated along the continental margins—the shelf, slope, and rise. Large amounts of detritus are eroded from the landmasses and carried to the oceans and seas by rivers and deposited in the oceans peripheral to the continents. However, the sizes of these basins, their internal geologic structure, their tectonic history, and the thickness of sedimentary rocks in them vary considerably. The general distribution by thickness of sedimentary rocks peripheral to the continents is shown by figure 9. The shaded areas on the map indicate those areas where the thicknesses are more than 3,300 m. Within these areas are basins containing sedimentary rocks more than 7,000 m thick, but because of scale limitations no attempt has been made to show these areas or to outline specific basins. The formation of the basins that through geologic time eventually become habitats for oil is a part of the wide scope of tectonic processes that have molded the face of the earth as we see it today. The general tectonic belts of earth, separated on the basis of the geologic age, in which various

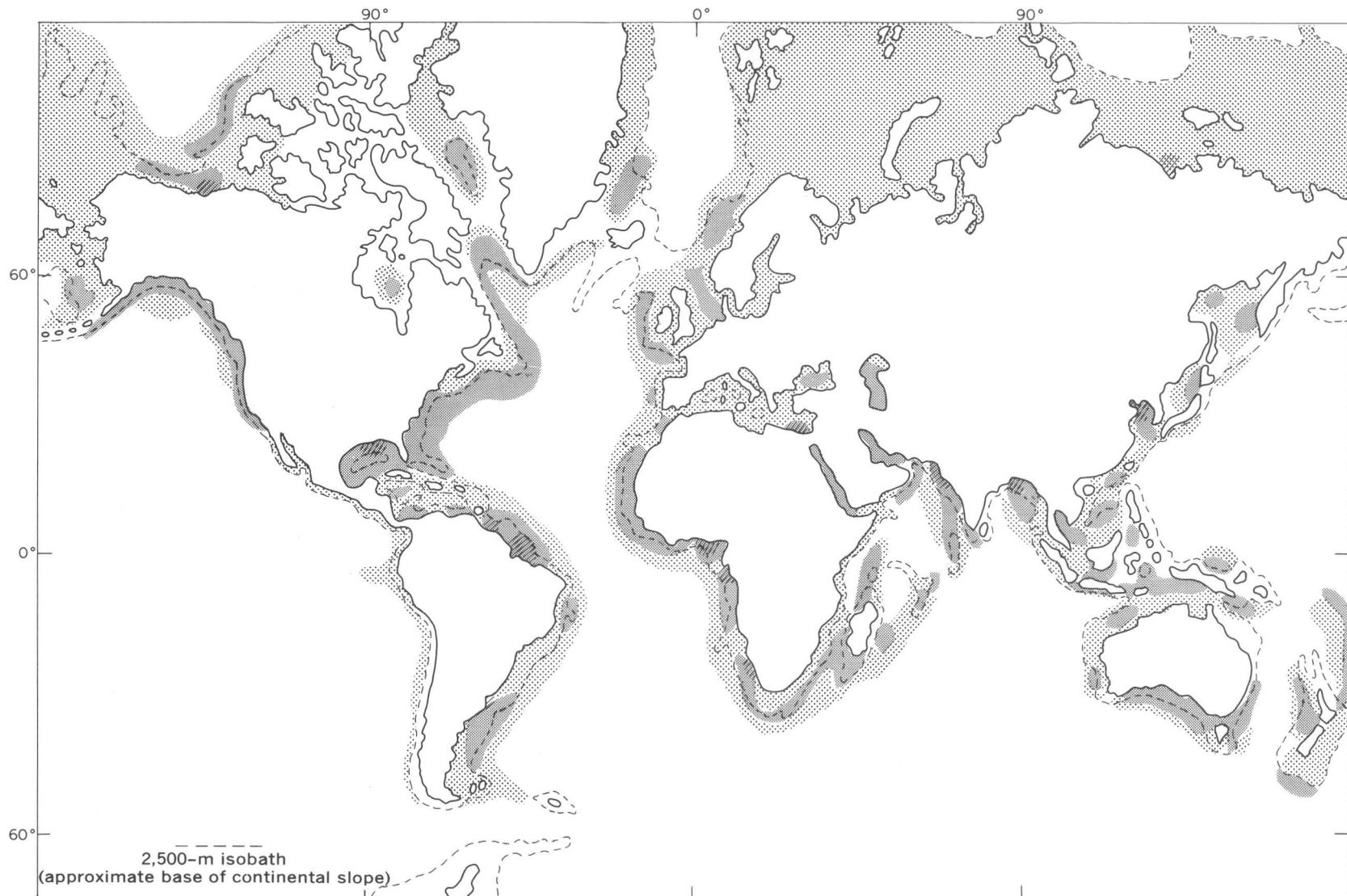


FIGURE 9.—Thickness of sedimentary deposits in the submerged continental margins. Stippled areas contain deposits 1,000 to 3,300 m thick; shaded areas contain deposits more than 3,300 m thick. Ruled pattern areas represent major deltaic deposits in the submerged continental margin. Adapted from booklet, "Deepwater Capabilities" produced by staff of Esso Production Research Company (1972).

parts of the crust have been mobile in the past, as well as those that are currently in a mobile state, are shown in figure 5.

For a description of the geology of the submerged continental margins of the world, summaries of broad scope by Hedberg (1970), Emery (1969), and Klemme (1971a), are recommended for the readers wishing a somewhat more detailed overview. Hedberg discusses the continental margins from the viewpoint of the petroleum geologist, Emery presents a sixfold classification of the continental shelves based on origin, and Klemme relates the world's basin areas to the continental masses and their margins. Both the Hedberg and Emery reports point out the limited extent of our knowledge about the geology of the submerged margins. Emery (p. 108-109) classified the present state of knowledge of the continental shelves of the world on a map which shows approximately 65 percent of the total shelf area to be poorly known and an additional 20 percent or so as moderately known. Hedberg concluded his report with the following observations:

1. We still have essentially no direct observational information on the nature of the sediments making up the continental rise—the most impressive accumulation of sediment on the earth's surface....
2. In spite of all our stress on the importance of the contact of oceanic crust and continental crust, and our dependence on refraction seismography information for its identification, we have extremely few adequately detailed continuous refraction surveys across the critical part of the continental margin.
3. Finally, in spite of all our studies of the sediments of the past and the sediments of the margins of today, we are still largely unable to identify and differentiate with assurance in the strata of the past the counterpart deposits of slope, rise, marginal, sea, outer shelf, and the other realms of the continental margins of today.

More intensive research is needed urgently if we are to understand the nature of the continental margins, the crustal processes active there, and their bearing on the geology of the past. This information is of importance to all earth science, but is particularly vital in the search for petroleum.

Some years ago, Weeks (1952, p. 2096), in a discussion of factors that control oil occurrence, proposed a classification of sedimentary basins relative to the earth's crustal framework, degree of mobility, and source and type of sediments. His classification recognizes two

major groups: Basins of mobile belts and those of relatively stable regions. More recently, Klemme (1971a) has elaborated on trends in petroleum basin development using the same general basic classification as Weeks, but building into his presentation more recent development in knowledge about earth's tectonic processes and in particular new ideas concerning basin development and the new concepts of global plate tectonics.

A summary of the geologic characteristics of the giant offshore oil fields relative to their position within the earth's mobile and stable belts, using the basic concepts of Weeks and Klemme, is shown in table 7.

In summary, the overall characteristics of the world's offshore giant petroleum fields as shown by the table are as follows:

<i>Age of producing horizons</i>	<i>No. of fields</i>	<i>Percentage of total fields</i>
Tertiary -----	25	37
Mesozoic -----	32	47
Paleozoic -----	4	6
Not available -----	8	11

<i>Reservoir type</i>	<i>No. of fields</i>	<i>Percentage of total fields</i>
General carbonates -----	24	35
Sandstone -----	35	52
Not available -----	10	14

In terms of petroleum occurrence the three basin subclasses have the following individual characteristics:

1. The intracratonic basins, which are within the continents, contain a total of 19 giant fields and 61 fields of other than giant size: oil and gas seem to occur in very nearly equal proportions, although the oil giants outnumber the gas giants.
2. The intermontane basins, which are within those parts of earth's crust that have been tectonically mobile in both Tertiary and recent times, contain 14 giant oil fields, 19 oil fields of other than giant size, and only one known gas field; they have no known carbonate reservoirs and no evaporites that have played a role in petroleum entrapment.
3. The extracontinental basins, along the periphery of the continents, have a rather wide range of geologic settings that make the class somewhat arbitrary.

TABLE 7.—*Characteristics of giant offshore petroleum fields relative to geologic setting*
[Fields other than giants shown in parentheses; not all fields shown. Ss, Sandstone. Ls, Limestone. NA, Not available]

Basin class and sub-types	Geographic location	Number of fields		Pro- ducing depth ranges (feet)	Geologic age of producing reservoirs	Type of reser- voir	Evaporites significant factor in petroleum concen- tration	Averages of crude oil analyses	
		Oil	Gas					Gravity (degrees Baumé)	Sulfur (per- cent)
Stable regions									
Intracraton:									
Subtype A, intracontinental downwarp.	North Sea -----	6 (20)	4 (33)	4,500- 10,900	Permian- Cretaceous.	Ss. and Ls. ¹	Yes	36.0	0.16
Subtype B, graben -----	Gulf of Suez, Red Sea -	3 (4)	1	5,500- 9,000	Miocene	Ss.	Yes	30.5- 32.0	1.67- 1.80
Subtype C, half-graben ----	Gippsland basin, Australia.	4 (2)	2 (2)	4,500- 8,450	Eocene- Paleocene.	Ss.	No	41.7- 45.4	0.12- 0.16
Total -----		13 (26)	7 (35)						
Mobile regions									
Intermontane:									
Subtype A, Unstable border- land.	California -----	3	-----	2,500- 5,850	Miocene- Pliocene.	Ss.	No	22.1- 22.6	1.44- 1.57
Caucasus foredeep -----	U.S.S.R., Caspian Sea -	2 (13)	-----	600- 16,608	Pliocene	Ss.	No	NA	NA
Large open intermontane basin.	Lake Maracaibo -----	9	-----	2,200- 11,000	Miocene- Cretaceous.	Ss.	No	14.7- 27.0	1.47- 2.68
Subtype B, intermediate be- tween extracontinental and intermontane.	Malaysia, Brunei; New Zealand.	1 (6)	1	7,068- 10,000	Tertiary	Ss.	No	NA	NA
Total -----		15 (19)	1						
Extracontinental:									
Subtype A, Hinge belt and trough and fold basin.	Persian Gulf -----	22	NA	4,000- 11,050	Cretaceous- Jurassic	Ls.	Yes	35.4	2.30
Subtype B, Cratonic margin downwarp and embayment.	Congo (Brazzaville) --	1	-----	1,900	Tertiary- U. Cretaceous.	Ss.	Yes	NA	NA
	Angola-Cabinda -----	1 (1)	-----	1,350- 8,600	Miocene- Cretaceous.	Ss.	Yes	NA	NA
	Gabon -----	(12)	-----	4,265- 9,384	Cretaceous	Ss.	Yes	Wide range.	Wide range.
	Northwest Australia --	(6)	1 (14)	2,200- 14,000	Jurassic	NA	No	37.2	0.02
Subtype C, Major deltaic deposits in cratonic mar- gin downwarp.	Nigeria -----	2 (31)	(1)	4,500- 12,000	Miocene	Ss.	No	39.4	0.09
Subtype D, Major deltaic deposits in subsiding trough along margin of small ocean basin.	U.S., Gulf of Mexico -	4 (281)	(202)	2,472- 16,900	Quaternary- Miocene.	Ss.	Yes	20.2- 34.4	0.33- 0.66
Subtype E, Cratonic down- warp and embayment with buried basement highs.	Mexico, Gulf of Mexico.	2 (13)	-----	9,040- 11,362	Jurassic	Ls.	No	NA	NA
Total -----		32 (344)	1 (217)						

¹ Includes 5 sandstone and 1 limestone reservoirs.

The Persian Gulf area predominates in this third group. Indeed the great magnitude of petroleum in the Persian Gulf makes it unique among the world's offshore oil fields. The areas of major deltaic deposits within the extracontinental basin such as those of the Mississippi and Niger Rivers, are typified both by a large number of fields and relatively large amounts of gas.

Evaporites are involved as an entrapment factor in a large number of geographic areas in both intracratonic and extracontinental basins. Because of their worldwide importance as a factor in petroleum-producing areas, the general distribution of known evaporite de-

posits in offshore areas around the world is shown on figure 10.

CONCLUSIONS

Review of the first quarter century of offshore development permits six salient conclusions:

1. At the end of the quarter-century that began in 1947, five offshore areas overshadow all others in the amount of petroleum discovered: The Persian Gulf, Lake Maracaibo, the northern Gulf of Mexico, the North Sea, and offshore southern California. Four of the areas share common characteristics: they are (1) either close

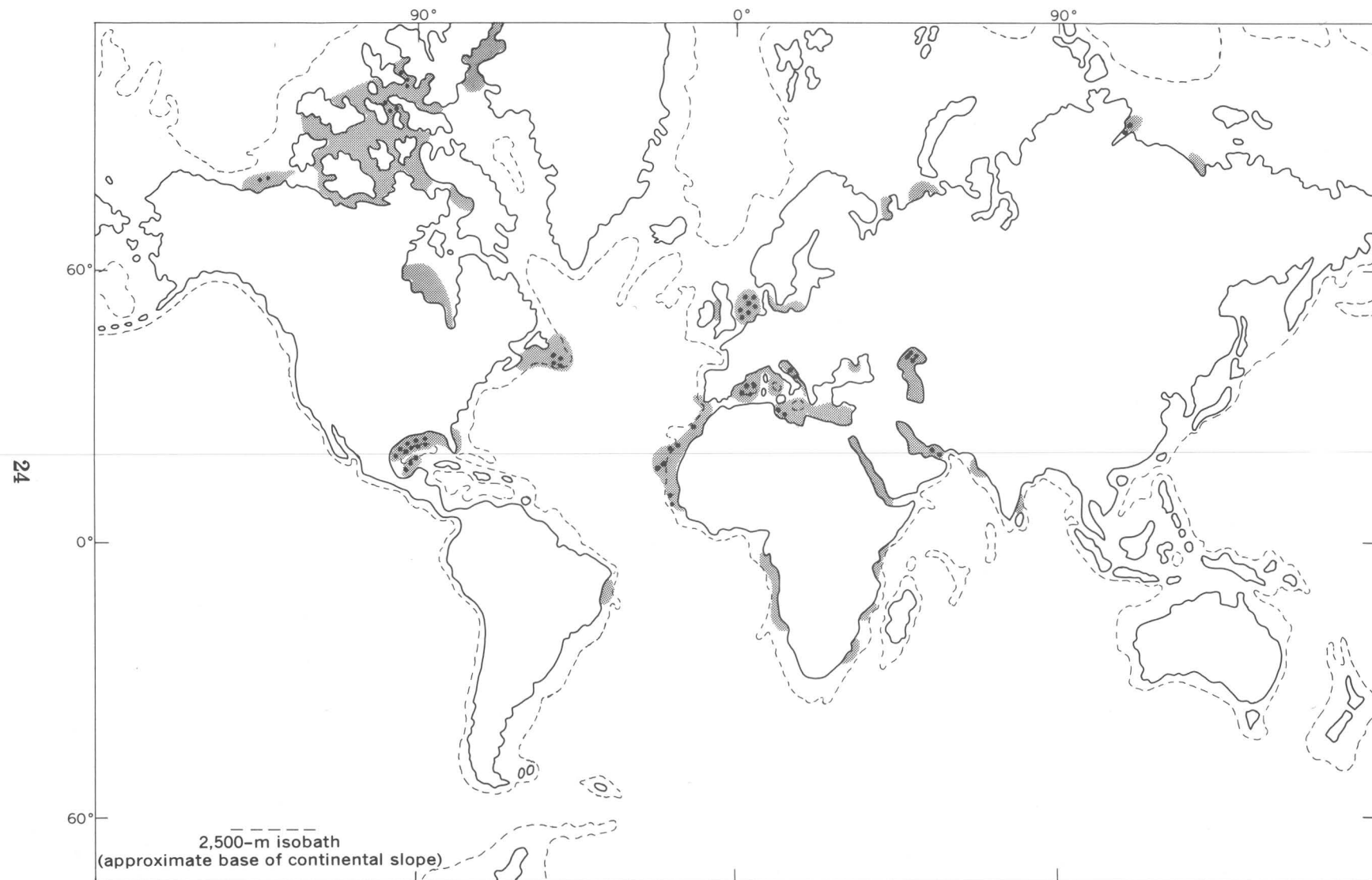


FIGURE 10.—Distribution of known major evaporite deposits offshore (shaded). Dots represent areas of salt diapirs. Adapted from McKelvey and Wang (1970).

to onland areas that were either already established as large petroleum producers or were known to have a large petroleum potential prior to 1947, or (2) extensions of large onshore fields.

Lake Maracaibo had large production before 1947, and its petroleum is not considered by some as proper for inclusion in offshore statistics, as its offshore fields are simply extensions of onshore fields beneath shallow lake waters. There is some validity to this contention. Consequently, of the five offshore areas having the largest reserves, only the central part of the North Sea basin is a newly discovered petroleum province.

Furthermore, Persian Gulf reserves are so large relative to all other areas, and the geology of the offshore producing fields there is so similar to the geology of the onland fields, that it must be classed as unique among the offshore producing areas. The likelihood of finding another Persian Gulf situation elsewhere in the offshore seems remote at this time, although recent discoveries in the North Sea have been spectacular. Nevertheless, none of the giants found there so far approaches Safaniya in estimated recoverable reserves.

If the oil discovered in the Persian Gulf and Lake Maracaibo are subtracted from the total of 172.8 billion barrels of estimated recoverable reserves listed in table 4, 50 billion barrels remain as the fruits of search to date for all other offshore areas—a respectable but not spectacular total considering the effort and capital expended.

2. As has been the situation for onland exploration for the past half-dozen years or more, the rate of finding new reserves offshore in areas apart from onshore producing areas is not keeping pace with the rate of increase of consumption of petroleum and petroleum products around the world.

For example, it is estimated that by 1985, when oil fields already discovered in the North Sea are expected to reach

full production capacity, the yearly supply available at that time from fully developed North Sea fields will meet only one-sixteenth of northwest Europe's projected yearly demand. Cast in the perspective of reserves versus production, the remaining oil reserves offshore at the present time, including Lake Maracaibo reserves, are approximately as much as the world total cumulative production of about 282 billion barrels through 1972.

Hubbert (1971) related cumulative worldwide oil production to periods of time. He stated (p. 63) that during the 80-year period from 1890 through 1970 the average rate of production increase has been 6.94 percent per year, with a doubling period of 10 years. The 102 years from 1857 to 1959 were required to produce the first half of the cumulative production; only the 10-year period from 1959 to 1969 was required for the second half. Within this frame of reference, remaining offshore oil reserves today are approximately 95 percent as much as worldwide production over the past 13 years. World consumption of oil in 1972 was about 20 billion barrels. Estimated consumption for 1975 is 23.8 billion barrels and for 1980, 31.3 billion barrels (McCaslin, 1973b, p. 5). Thus, in 1973, estimated remaining reserves of oil offshore would supply the world at the current rate of consumption for 6.4 years. United States estimated remaining offshore reserves are sufficient to supply domestic demands for 1.6 years at the 1973 rate of consumption.

3. The rate of discovery worldwide must be increased substantially if the offshore is to provide a substantial new supply of petroleum. During the past 25 years the rate of discovery of petroleum offshore has averaged about 7 billion barrels per year. However, most of the effort has come since 1957, and over the past 16 years the discovery rate has averaged closer to 10 billion barrels per year. Statistics on the number of barrels of oil discovered offshore relative to footage

drilled are not available. As already pointed out, the geology of much of the world's submerged continental margins remains relatively unknown. Therefore, the offshore search for petroleum must be classed as still in an early stage. Furthermore, the importance of giant petroleum fields in supplying most of the world's petroleum has been stressed.

The chronological profile of finding giant fields shown in figure 6 must be at least maintained if the reserves base is to keep pace with the rate of rise in consumption. A substantially increased effort of geologic research and exploration is needed, particularly over the outer parts of the margin—the slope and rise—which may contain the thicker parts of sedimentary basins whose thinner parts lie under the continental shelves. Intensified research and exploration on a worldwide scale is needed if we are to develop a more sophisticated understanding of the geology and tectonic processes that have molded the continental margins over the eons of geologic time. Such an effort can greatly increase our ability to select more efficiently, more accurately, and more quickly those areas of the offshore that have the best potential for resources, petroleum as well as hard minerals. The time to make this effort is now because the need for new supplies of energy obviously is urgent.

4. Efforts in the United States to examine in detail the geologic framework of the submerged continental margins and to appraise the petroleum resource potential therein have been far short of both the need and the potential. Somewhat less than 5 percent of the United States Continental Shelves has been studied in the detail necessary to make meaningful estimates of petroleum potential, not to mention that little or no serious investigation of the continental slope and rise has been made. Yet our submerged continental margins in total area are among the world's more extensive.
5. The current trend of exploration for offshore petroleum is into the deeper waters

of the outer edge of the continental shelves and beyond. This trend will inevitably mean increased development costs. However, this will be offset, to a degree difficult to determine at this time, by the use of subsea completion and production units. Development of subsea systems is now in an advanced stage of testing, and, it can be predicted with a fair degree of certainty that by the end of the next decade most offshore wells will be produced from underwater systems. Production operations on a large scale in water depths exceeding 600 feet (182 m) will almost certainly require subsea systems. Sea-surface platforms simply will be too costly and risky for producing in deep water. A resumé of the current status of underwater hardware for subsea production is given by McCaslin (1973b, p. 216–223). Advances and trends in offshore petroleum technology have been summarized by Wang (1971).

6. Geographic predictions based on geologic information about where new offshore petroleum provinces might lie are difficult to make at this time because knowledge is still limited. Some general corollaries can be drawn from the geologic resumé of fields shown in table 7. The largest reserves have been found in the small ocean basins, in areas of extensive evaporite deposition, in thick sequences of deltaic sediments, and in drowned intermontane basins. The extensive stretches of continental shelves such as those around much of Africa and South America have failed to yield large quantities of petroleum. However, these areas fall largely within those parts of the offshore where geologic conditions are not as yet well known.

REFERENCES CITED

- Albers, J. P., Carter, M. D., Clark, A. L., Coury, A. B., and Schweinfurth, S. P., 1973, Summary petroleum and selected mineral statistics for 120 countries, including offshore areas: U.S. Geol. Survey Prof. Paper 817, 149 p.
- Bleakley, W. B., 1973, Offshore operators looking deeper: *Oil and Gas Jour.*, v. 71, no. 18, p. 118–125.
- British Petroleum Company Limited, 1973, BP statis-

- tical review of the world oil industry, 1972: London, Britannic House, Baynard Press, 24 p.
- Critz, J. S., 1947, Oil possibilities on Gulf Coast [U.S.] continental shelf: *Oil Weekly*, v. 124, no. 6, p. 17-21.
- Drake, C. L., 1972, Future considerations concerning geodynamics: *Am. Assoc. Petroleum Geologists Bull.*, v. 56, no. 2, p. 260-268.
- Emery, K. O., 1969, The continental shelves: *Sci. American*, v. 221, no. 3, p. 107-122.
- Esso Production Research Co., 1972, Deepwater capabilities: Houston, Texas, 33 p.
- Halbouty, M. T., ed., 1970, Geology of giant petroleum fields: *Am. Assoc. Petroleum Geologists Mem.* 14, 573 p.
- Heater, W. E., 1956, Petroleum developments in Middle East and adjacent countries in 1955: *Am. Assoc. Petroleum Geologists Bull.*, v. 40, no. 7, p. 1633-1656.
- Hedberg, H. D., 1970, Continental margins from viewpoint of the petroleum geologist: *Am. Assoc. Petroleum Geologists Bull.*, v. 54, no. 1, p. 1-43.
- Hendricks, T. A., 1965, Resources of oil, gas, and natural gas liquids in the United States and the world: *U.S. Geol. Survey Circ.* 522, 20 p.
- Hubbert, M. K., 1971, The energy resources of the earth: *Sci. American*, v. 224, no. 3, p. 61-70.
- Klemme, H. D., 1971a, Trends in basin development—possible economic implications: *World Petroleum*, v. 42, no. 10, p. 47-51; 54-56.
- 1971b, What giants and their basins have in common: *Oil and Gas Jour.*, v. 69, no. 9, p. 85-90.
- 1971c, To find a giant, find the right basin: *Oil and Gas Jour.*, v. 69, no. 10, p. 103-110.
- 1971d, Look in Permian reservoirs or younger to find supergiants: *Oil and Gas Jour.*, v. 69, no. 11, p. 96-100.
- Maher, J. C., 1971, Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf with a section on stratigraphy, by J. C. Maher and E. R. Applin: *U.S. Geol. Survey Prof. Paper* 659, 98 p.
- McCaslin, J. C., 1972, Offshore exploration is moving around the globe: *Oil and Gas Jour.*, v. 70, no. 50, p. 106-119.
- 1973a, World offshore oil production soars: *Oil and Gas Jour.*, v. 71, no. 18, p. 126-135.
- ed., 1973b, *International Petroleum Encyclopedia 1973*: Tulsa, Okla. Petroleum Publishing Co., 440 p.
- McKelvey, V. E., Stoertz, G. E., and Vedder, J. G., 1969, Subsea physiographic provinces and their mineral potential, in *Subsea mineral resources and problems related to their development*: *U.S. Geol. Survey Circ.* 619, p. 1-10.
- McKelvey, V. E., and Wang, F. F. H., 1970, World sub-sea mineral resources [preliminary maps]: *U.S. Geol. Survey Misc. Geol. Inv. Map I-632* [2d printing, slightly revised; 1st printing, 1969]
- Ocean Industry, 1972, 1972-73 Directory of marine drilling rigs: *Ocean Industry*, v. 7, no. 9, p. 75-120.
- 1973, Gulf of Mexico lease sale: *Ocean Industry*, v. 8, no. 1, p. 30.
- Oil and Gas Journal, 1959, Petroleum panorama, an issue to commemorate oil's first one hundred years—Exploration: *Oil and Gas Jour.*, v. 57, no. 5, p. B1-B48.
- 1972, Vast North Sea reserves yet to be found: *Oil and Gas Jour.*, v. 70, no. 49, p. 33.
- 1972, Phillips getting set for \$200-million Ekofisk-to-U.K. line: *Oil and Gas Jour.*, v. 70, no. 49, p. 45.
- Petroleum Press Service, 1972, North Sea nightmares: *Petroleum Press Service*, v. 39, no. 11, p. 409-410.
- Seale, A. F. T., 1948, Discovering oil 12 miles offshore in the Gulf: *Oil and Gas Jour.*, v. 47, p. 113-116.
- Taylor, D. M., 1973, North Sea report overview: *Ocean Industry*, v. 8, no. 2, p. 61-63.
- Theobald, P. K., Schweinfurth, S. P., and Duncan, D. C., 1972, Energy resources of the United States: *U.S. Geol. Survey Circ.* 650, 27 p.
- U.S. Senate, 1945, Investigations of petroleum resources: *U.S. 79th Cong., Senate Inv. Committee, Proc.*, June 19-25.
- Wagner, F. J., compiler, 1972, Foreign development papers, 1971: *Am. Assoc. Petroleum Geologists Bull.*, v. 56, no. 9, p. 1599-1870.
- Wang, Frank F. H., 1971, Latest advances in offshore petroleum technology, in *Natural Resources Forum*: New York, United Nations, v. 1, no. 1, 77 p.
- Weber, George, ed., 1972, *International Petroleum Encyclopedia 1972*: Tulsa, Okla., Petroleum Publishing Co., 448 p.
- Weeks, L. G., 1952, Factors of sedimentary basin development that control oil occurrence: *Am. Assoc. Petroleum Geologists Bull.*, v. 36, no. 11, p. 2071-2124.
- 1969, Offshore petroleum developments and resources: *Jour. Petroleum Technology*, v. 21, p. 377-385.
- 1973a, Hydrocarbons, in *Economic significance in terms of sea-bed mineral resources, of the various limits proposed for national jurisdiction*: United Nations, General Assembly, Rept. of the Secretary General, Committee on the Peaceful Uses of the Seabed and Ocean Floor Beyond the Limits of National Jurisdiction, UN Rept. A/AC.138/87, 4 June, 1973, p. 9-18.
- 1973b, Offshore success raises Far East/Oceania potential: *World Oil*, v. 176, no. 6, p. 87-94.
- 1973c, Mainland China, Russia oil search in infancy: *World Oil*, v. 176, no. 5, p. 94-95.
- 1973d, Amazon basin, North Sea spark South American, European play: *World Oil*, v. 176, no. 2, p. 32-35.
- 1973e, Accelerating demand challenges petroleum industry performance: *World Oil*, v. 176, no. 1, p. 42-44.
- World Oil*, 1948: v. 127, no. 10, p. 36.
- Yerkes, R. F., Wagner, H. C., and Yenne, K. A., 1969, Petroleum development in the region of the Santa Barbara channel in *Geology, petroleum development, and seismicity of the Santa Barbara channel region, California*: *U.S. Geol. Survey Prof. Paper* 679, p. 13-27.

