Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States

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CONTENTS

ILLUSTRATIONS

TABLES

Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States

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SUMMARY

The estimates in this report of undiscovered recoverable oil and gas resources for the United States were made: (1) by carefully reviewing a large amount of geological and geophysical information gathered on more than 100 different provinces by over 70 specialists within the Survey; (2) by applying a variety of resource appraisal techniques to each potential petroleum province; and (3) through group appraisals and the application of subjective probability procedures. These methods provide a range of estimates which are summarized in terms of low, high, and mean values for the various provinces and groups of provinces, or regions. The basic data and procedures used are documented and are being incorporated into a dynamic, data-intensive system that can be upgraded, updated, and reevaluated periodically. These data are open to public inspection.

In this study, the primary emphasis was placed on crude oil and natural gas in the onshore provinces and the provinces on the continental shelf out to water depths of 200 metres; estimates of natural gas liquids were derived independently by multiplying estimates of natural gas by factors determined from historical data. Excluded from consideration were oil shales, tar sands, and heavy hydrocarbons and tight gas sands not currently productive. Also excluded was offshore potential beyond 200 metres of water depth. All of these resources or areas for resource development have significant future potential measured in tens or hundreds of billions of barrels. Time did not permit assessment of their recoverability as a part of this study, but they will be the subject of accelerated study in the immediate future.

The estimates of undiscovered recoverable resources take into account relevant past history and experience and are based on assumptions that undiscovered recoverable resources will be found in the future under conditions represented by a continuation of price-cost relationships and technological trends generally prevailing in the recent years prior to 1974. Price-cost relationships since 1974 were not taken into account because of the yet undetermined effect these may have on resource estimates. Clearly a new pattern of exploration economics is now under development, and, in cooperation with the Bureau of Mines, work to determine the effect of this new pattern on discovery and recovery of oil and gas is beginning. Assuming an increase in price-cost ratio, undiscovered recoverable resource estimates will expand and, at some threshold level, recovery percentages on discovered petroleum may improve. The higher price-cost ratios existing in 1975, if they should continue or increase even higher, would likely increase estimates of both undiscovered recoverable resources and reserves significantly—some economists think perhaps by half again. This possible added potential is being considered in a follow-on study planned for completion within a year.

The terms used to categorize past, present, and future supplies of oil and gas essentially correspond to definitions jointly adopted by the U.S. Geological Survey and the Bureau of Mines in April 1974; however, specific terminology for oil and gas reporting has not yet been standardized. In the present study, the following are reported as separate quantities; cumulative production; measured, indicated, and inferred reserves (all of which fall into the identified category); and undiscovered recoverable resources. The category inferred reserves has been included by some estimators as part of the undiscovered resources.

In considering these quantities it is impor-

tant to distinguish between reserves and undiscovered recoverable resources. Reserves are identified resources known to be recoverable with current technology under present economic conditions. Undiscovered recoverable resources include deposits that are yet to be discovered but are assumed to be economically producible. Resources also include deposits that have been identified, but cannot now be extracted because of economic or technological factors as well as subeconomic deposits that are yet to be discovered.

Table 1 summarizes for the conterminous U.S. and Alaska, both onshore and offshore, the current estimates of measured, indicated, and inferred reserves and the undiscovered recoverable resources of crude oil, natural gas, and natural gas liquids. Cumulative production is also shown. The measured and indicated reserves are derived from estimates prepared by the American Petroleum Institute (API) and the American Gas Association (AGA). The inferred reserves are identified as to field location but have not yet been defined by drilling. The undiscovered recoverable resources are reported as a range of values derived by computer analysis of lognormal distribution curves. Within the probability levels of 95 percent and 5 percent, the range of total undiscovered recoverable oil resources is 50 to 127 billion barrels. The range of undiscovered recoverable gas is 322 to 655 trillion cubic feet, and the range of undiscovered recoverable natural gas liquids is 11 to 22 billion barrels. Smaller and larger volumes, respectively, would be associated with probabilities of more than 95 percent and less than 5 percent. The regional probability curves included with this report show the magnitude of estimates for any selected range. For totally unexplored frontier areas, the absence of already discovered indigenous or adjacent recoverable hydrocarbons render uncertainty sufficiently great to weaken probability judgments at either high or low levels, and in those areas estimates at the 75 and 25 percent levels are shown as more applicable for some planning purposes.

The distribution by regions of the estimated undiscovered recoverable resources of crude oil and natural gas is shown as a range of values in figure 1.

The user of these data should be aware that the forecasts recorded for measured, indicated, and inferred reserves are single-number estimates of these quantities, derived from API and AGA statistics. By contrast, undiscovered recoverable resources are treated here as uncertain quantities, the degree of uncertainty about each being expressed in the form of probabilities.

For planning purposes, it is desirable to report probabilities for total recoverable resources; e.g., the probability that total recoverable resources are less than a given number or lie between two numbers. An intuitively plausible approximation, given that only single number estimates for measured, indicated, and inferred reserves are available, is to add these estimates (in this case, 62 billion barrels of oil) to the end points of an interval of values of undiscovered recoverable resources (in this case, 50–127 billion barrels of oil) and then assert that the probability assigned to this interval for undiscovered recoverable resources is equal to the probability that total recoverable resources lie in the interval so translated. *This is correct only under the assumption that measured, indicated, and inferred reserves are known with certainty and have values equal to the single-number estimates cited.* Given this assumption, the probability that the remaining total recoverable resources of crude oil lie between 112 billion barrels and 189 billion barrels is 90 percent. At the 1974 level of domestic production of 3.04 billion barrels, this is equivalent to a 37 to 62 year production life. Current production makes up only about two thirds of crude oil consumption.

Performing a similar computation using the sum of single-number estimates of measured reserves of natural gas and of inferred reserves of natural gas (in this case, 399 trillion cubic feet of gas) and adding this single-number estimate to the end points of a range of values of undiscovered recoverable resources (in this case, 322–655 trillion cubic feet of gas), the probability that the remaining total recoverable resources of natural gas lie in the range of 721 trillion cubic feet to 1,054 trillion cubic feet is also 90 percent. At the 1974 production level of 21.3 trillion cubic feet, this is equivalent to a 36 to 51 year production life.

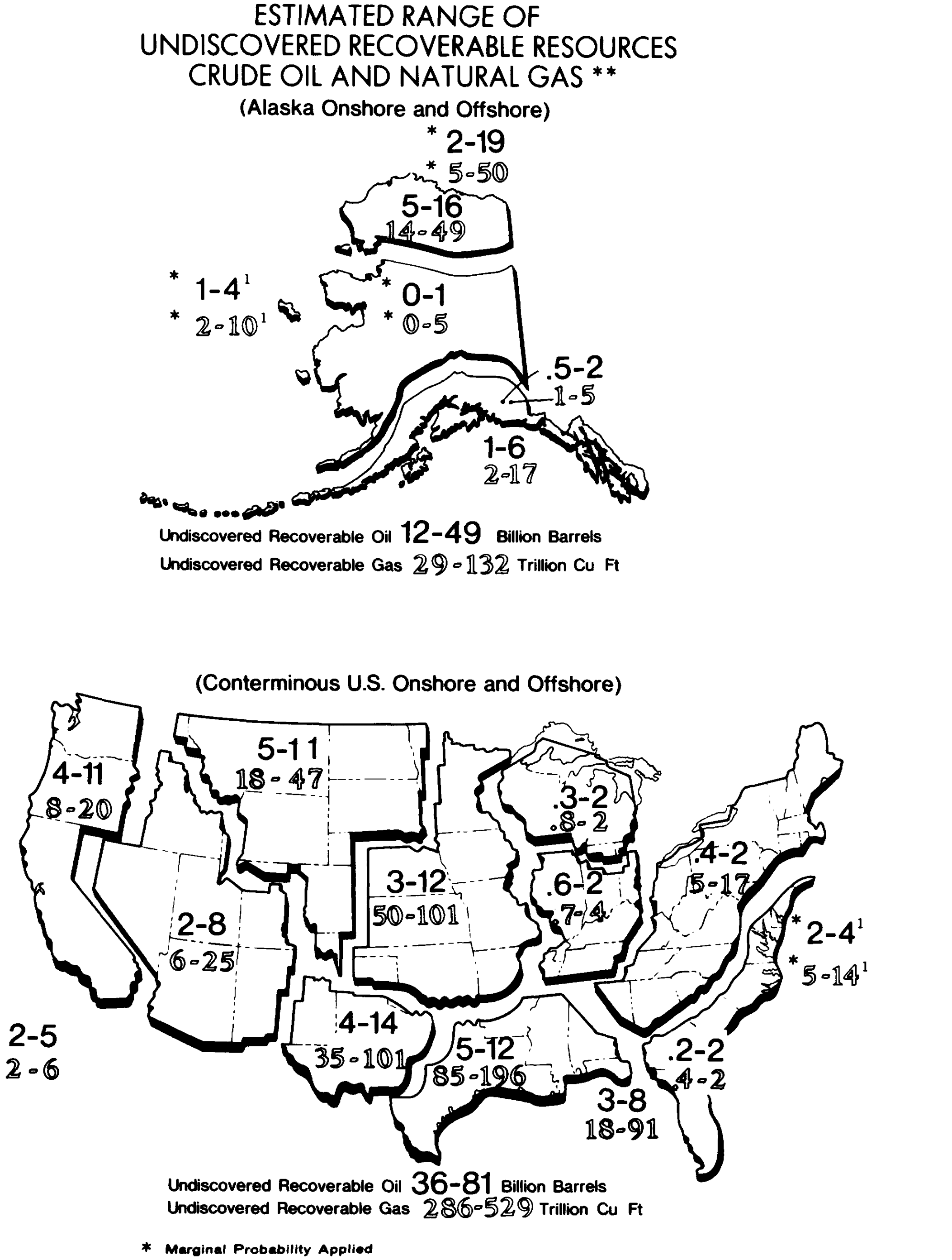

FIGURE 1.—Undiscovered recoverable resources of crude oil and natural gas for the United States. Reported as a range of values at 95–5 percent probability in billions of barrels for oil and trillions of cubic feet for gas.

[1] Estimates reported at the 75 and 25 percent probability levels because, in these frontier areas, these levels are judged to be more applicable for some planning purposes. It can also be noted that in frontier areas, lacking discovered indigenous or adjacent recoverable hydrocarbons, uncertainty is sufficiently great as to weaken probability estimates at extreme ranges. For purposes of comparison with other recorded ranges, the 95–5 percent probability range in the Bering Sea is 0–8 billion barrels of oil and 0–18 trillion cubic feet of gas; in the offshore Atlantic it is 0–6 billion barrels of oil and 0–22 trillion cubic feet of gas.

Table 1.—*Production, reserves, and undiscovered recoverable resources of crude oil, natural gas, and natural gas liquids for the United States, December 31, 1974 (onshore and offshore to water depth of 200 metres)*

Area	Cumulative Production	Reserves			Undiscovered Recoverable Resources
		Demonstrated		Inferred[4]	Range[5,6] (95%-5%)
		Measured[2]	Indicated[3]		
Crude Oil [1] (billions of barrels)					
Lower 48 Onshore----------	99.892	21.086	4.315	14.3	29 - 64
Alaska Onshore------------	0.154	9.944	0.013	6.1	6 - 19
Total Onshore-----------	100.046	31.030	4.328	20.4	36 - 81
Lower 48 Offshore---------	5.634	3.070	0.308	2.6	5 - 18
Alaska Offshore-----------	0.456	0.150	Negligible	0.1	3 - 31
Total Offshore----------	6.090	3.220	0.308	2.7	10 - 49
Total Onshore and Offshore------------	106.136	34.250	4.636	23.1	50 - 127
Natural Gas [1] (Trillions of cubic feet)					
Lower 48 Onshore----------	446.366	169.454	Not Applicable	119.4	246 - 453
Alaska Onshore------------	0.482	31.722		14.7	16 - 57
Total Onshore-----------	446.848	201.176		134.1	264 - 506
Lower 48 Offshore---------	33.553	35.811		67.4	26 - 111
Alaska Offshore-----------	0.423	0.145		0.1	8 - 80
Total Offshore----------	33.976	35.956		67.5	42 - 181
Total Onshore and Offshore------------	480.824	237.132		201.6	322 - 655
Natural Gas Liquids (billions of barrels)					
Total Onshore and Offshore-	15.730	6.350	Not Applicable	6	[7] 11 - 22

1 Cumulative production and estimates of reserves and resources reflect an assumed recovery of about 32 percent of the oil and 80 percent of the gas-in-place. Some portion of the remaining oil-in-place is recoverable through application of improved recovery techniques. Estimates are based on figures released by the American Petroleum Institute (API) and the American Gas Association (AGA) in April 1975.

2 Identified resources that can be economically extracted with existing technology. Estimates are the "proved reserves" of the API and AGA.

3 Identified resources, economically recoverable if known fluid injection technology is applied. Estimates are from the API.

4 Resources estimated to be recoverable in the future as a result of extensions, revisions of estimates, and new pays in known fields beyond those shown in indicated reserves.

5 The low value of the range is the quantity associated with a 95 percent probability (19 in 20 chance) that there is at least this amount. The high value is the quantity with a 5 percent probability (1 in 20 chance) that there is at least this amount. Totals for the low and high values are not obtained by arithmetic summation; they are derived by statistical methods.

6 The reader is cautioned against averaging ranges. Statistical mean values are shown in tables 4 and 5.

7 The calculated estimates of undiscovered recoverable resources are derived from natural gas estimates by applying historical NGL/Natural Gas ratios. These figures suggest that if added to crude oil estimates, natural gas liquids would increase the estimates of petroleum liquids by approximately 20 percent.

INTRODUCTION

In September 1974 the Resource Appraisal Group of the Branch of Oil and Gas Resources, U.S. Geological Survey, was asked to aid the Federal Energy Administration (FEA) in its legal responsibility to generate by June 1975 an independent appraisal of the undiscovered oil and gas resources of the United States, both onshore and offshore. Under the leadership of Harry Thomsen, the Resource Appraisal Group accelerated its ongoing efforts to develop sound appraisal methods and procedures that would permit the systematic collection and evaluation of basic data from petroleum provinces throughout the Nation. The results are summarized in this report.

Great uncertainties are inherent in estimating undiscovered quantities of oil and gas. The estimates in this report are derived from judgments based on a variety of geologic data, records of exploration successes and failures, production histories, assumptions concerning economic and technological conditions, and several appraisal methods. Because of the subjective variability in all these factors, estimates by various experts may differ considerably even when they have access to the same general information. A follow-on phase of this work is now being started to quantify the economic and technological conditions that affect resource appraisal and to integrate this understanding with the oil and gas potential of individual provinces.

ACKNOWLEDGMENTS

As a result of the urgency imposed by the legislative charge of the FEA, the Resource Appraisal Group obtained the assistance of other geologists in the U.S. Geological Survey who have broad experience and expertise in the particular areas of the United States which are either productive or potential future petroleum provinces. Significant contributions were made by over 70 geologists from the Branch of Oil and Gas Resources, the Branch of Alaskan Geology, the Branch of Pacific-Arctic Marine Geology, the Branch of Atlantic-Gulf of Mexico Marine Geology, and the Conservation Division.

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In addition to those listed above, we are indebted to G. M. Kaufman, Professor of Operations Research and Management, Massachusetts Institute of Technology, for his advice and assistance in developing methods of handling subjective probability estimates made by the Resource Appraisal Group, and to J. R. Century, consultant, for his assistance in the preparation of maps showing well control, oil and gas fields, and regional geology for many of the producing provinces in the Lower 48 States. We are grateful to V. E. McKelvey, R. P. Sheldon, and C. D. Masters for their critical reviews of the manuscript and for their helpful suggestions. Finally, we wish to express our sincere appreciation to P. R. Rose for his guidance and wholehearted support.

SOURCES OF DATA

Data were obtained through three main sources: verbal and written contributions from over 70 geologists from various divisions and branches of the U.S. Geological Survey; published references consisting of geological information, exploration and production history data and maps; and unpublished U.S. Geological Survey materials.

Published sources of production and reserve data are listed in the "Selected References" at the end of this report. Chief among these are the American Petroleum Institute–American Gas Association–Canadian Petroleum Association annual reports on reserves and production through 1974. Also used were publications of the American Petroleum Institute, Independent Petroleum Association of North America, International Oil Scouts Association, Potential Gas Committee, and States of Alaska and California. Only major data sources on regional geology and map materials are listed in the references to provide an insight into the materials studied and used. Numerous published geologic reports and maps which were used in this study are not cited because of their great number. They were, nevertheless, important and key contributions to the understanding of the geology of specific areas.

Basin evaluation maps were generated from the Petroleum Information Corporation's Well History Control System (computerized data banks) for many of the producing provinces of the lower 48

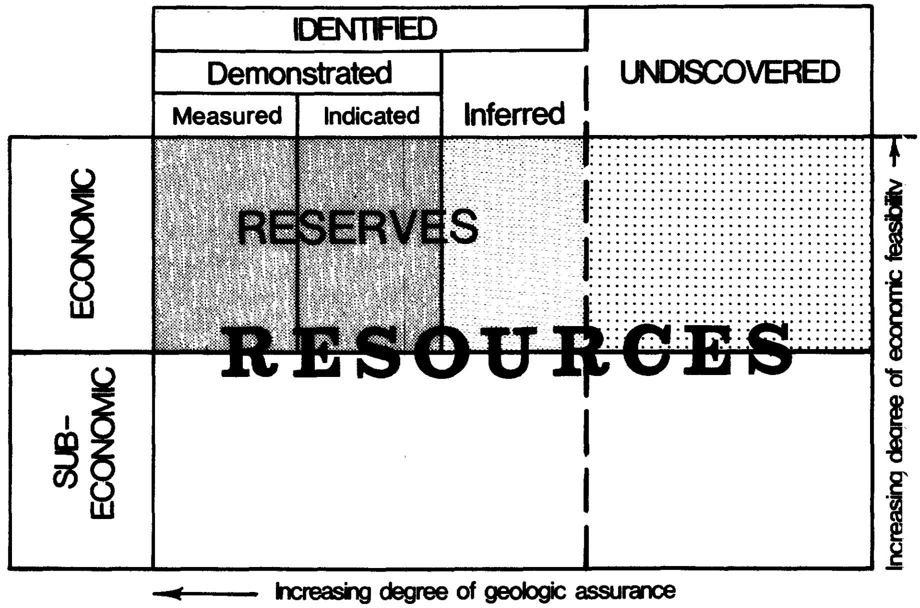


FIGURE 2.—Diagrammatic representation of petroleum resource classification by the U.S. Geological Survey and the U.S. Bureau of Mines (modified from McKelvey, 1973).

States. These maps, showing well density, oil and gas fields, and productive or tested stratigraphic units, provided background materials for province appraisals. Cumulative production data for several provinces were derived from the U.S. Geological Survey Oil and Gas Pool computer data bank at Norman, Oklahoma.

GUIDELINES AND CONCEPTS FOR RESOURCE APPRAISAL

DEFINITIONS OF RESOURCE TERMS

The following list defines the terms used in figure 2 and in this study. Some are modified from published definitions (McKelvey, 1973, 1974a, 1974b) to apply specifically to the commodities oil, natural gas, and natural gas liquids. In this study, price-cost relationships and technological trends generally prevailing in the recent years prior to 1974 are assumed.

Resources.—Concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.

Economic resources.—Those resources, both identified and undiscovered, which are estimated to be economically recoverable.

Subeconomic resources.—Identified and undiscovered resources that are not presently recoverable because of technological and economic factors but which may be recoverable in the future.

Identified resources.—Specific accumulations of economic resources whose location, quality, and quantity are estimated from geologic evidence supported in part by engineering measurements.

Identified subeconomic resources.—Known resources that may become recoverable as a result of changes in technological and economic conditions.

Undiscovered resources.—Quantities of a resource estimated to exist outside of known fields on the basis of broad geologic knowledge and theory.

Undiscovered recoverable resources.—Those economic resources, yet undiscovered, which are estimated to exist in favorable geologic settings.

Reserves.—That portion of the identified resource which can be economically extracted.

Measured reserves.—That part of the identified resource which can be economically extracted using existing technology, and whose amount is estimated from geologic evidence supported directly by engineering measurements. In this study, they are considered to be equivalent to API and AGA *proved reserves.*

Indicated reserves.—Reserves that include additional recoveries in known reservoirs (in excess of the measured reserves) which engineering knowledge and judgment indicate will be economically available by application of fluid injection, whether or not such a program is currently installed (API, 1974). In this study *indicated reserves* are equivalent to API *indicated additional reserves.*

Demonstrated reserves.—A collective term for the sum of measured and indicated reserves.

Inferred reserves.—Reserves in addition to demonstrated reserves eventually to be added to known fields through extensions, revisions, and new pays. (See Appendix for explanation of derivation of inferred reserves quantities used in this study.)

Cumulative production.—The sum of the production for the current year and the actual production for each of the prior years.

COMMODITIES INCLUDED IN THE RESOURCE APPRAISAL ESTIMATES

Commodities included in this appraisal are crude oil, natural gas, and natural gas liquids (NGL). Crude (unrefined) oil is a natural mixture of hydrocarbons occurring underground in a liquid state in porous-rock reservoirs and remaining in a liquid state as it flows from a well at atmospheric pressure. Natural gas is a mixture of hydrocarbons occurring as: a "gas cap" in contact with and above an oil deposit within a reservoir; dissolved in solution with the crude oil within the reservoir; or as dry gas that is not associated with or in contact with crude oil within a reservoir. The American Gas Association (1974) defines natural gas liquids as those hydrocarbons occurring within the natural gas in a reservoir which are separated from the natural gas as liquids at the surface through the process of condensation, absorption or adsorption, or other methods in field separators, scrubbers, gas processing plants, and cycling plants.

In 1974, the United States natural gas liquids production was 24 percent that of crude oil, and NGL proved (measured) reserves were 19 percent of those of oil reserves.

The following commodities were not included or were included only in part in this report:

Heavy oils.—Oils whose specific gravity and viscosity (fluidity) are too low for economic extraction by conventional primary and secondary production methods. These resources are included with reserves of crude oil in areas that are currently producing but are excluded in areas that are not developed or are abandoned.

Tight gas sands.—Gas resources in tight sands are included in areas that are currently producing and are excluded in areas not developed or abandoned.

Oil shale.—Resources of this commodity are not included in this appraisal.

Tar sands.—Resources of tar sands are not included in this appraisal.

Gas occluded in coal.—Resources of this commodity are not included in this appraisal.

ROLE OF TECHNOLOGY AND ECONOMICS IN RESOURCE APPRAISAL

In making estimates of undiscovered *recoverable* oil and gas resources, it is necessary to make fundamental assumptions pertaining to economics and technology. The estimates of undiscovered recoverable resources take into account relevant past history and experience and are based on assumptions that undiscovered recoverable resources will be found in the future under conditions represented by a continuation of price-cost relationships and technological trends generally prevailing in the recent years prior to 1974. Price-cost relationships since 1974 were *not* taken into account because of the yet undetermined effect these may have on resource estimates. If fundamental changes in cost-price relationships are imposed or if radical improvements in technology occur, estimates of recoverable resources will be affected accordingly.

These assumed conditions permit the appraisal of recoverable oil and gas resources to be made on the basis of: (1) relevant past history and experience concerning recovery

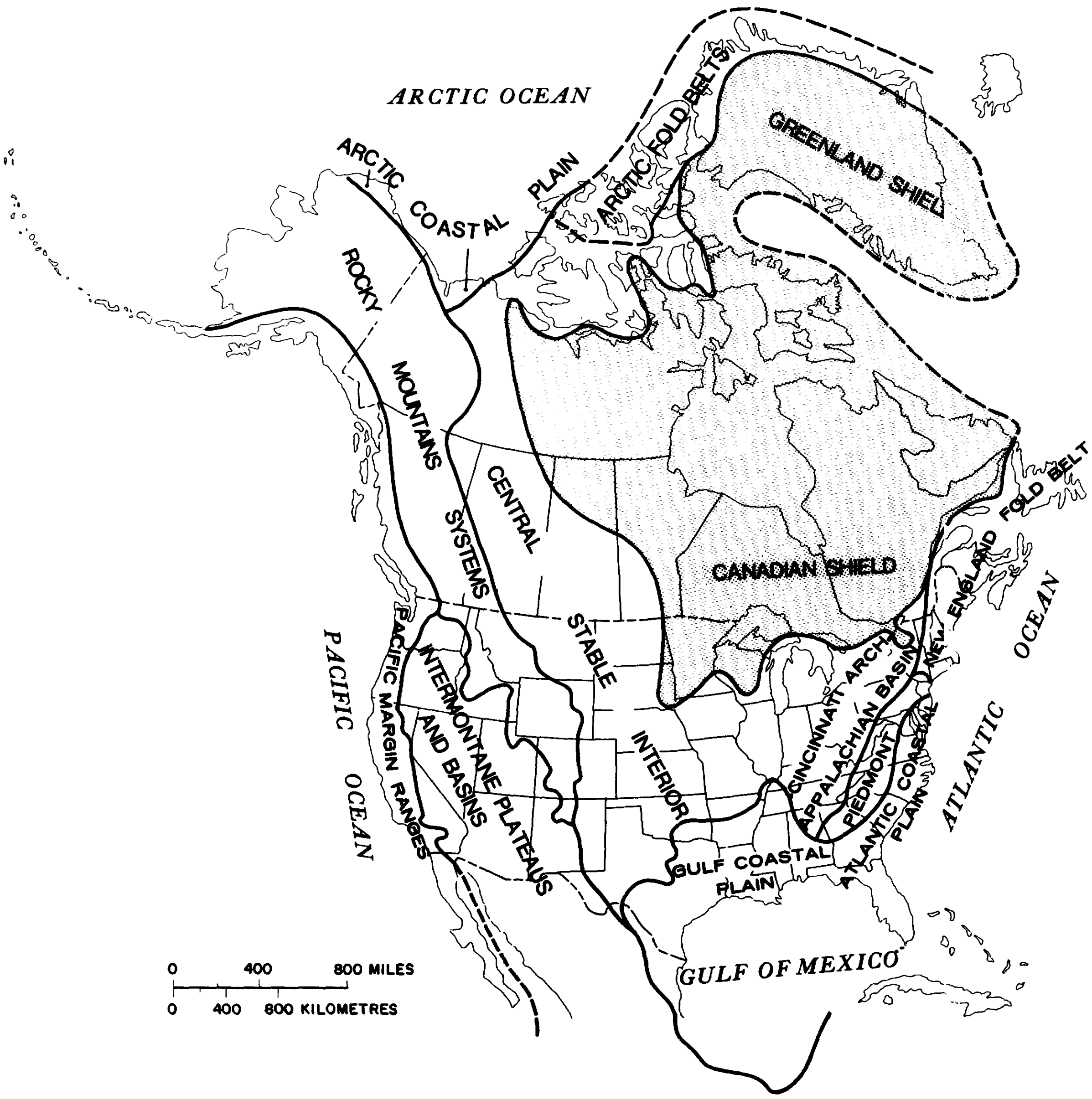


FIGURE 3.—Tectonic map of North America showing generalized structural elements (modified from Eardley, 1962).

factors; (2) the geology favorable to the occurrence of producible hydrocarbons; and (3) the size and type of reservoirs which have been found, developed, and produced.

Recoverable resource potential as reported here for the frontier basins of Alaska, and to some extent the offshore areas of the Lower 48 States, is especially uncertain. Many of the frontier basins will have very severe economic constraints under which oil and gas may be recovered. A certain amount of the recoverable oil and gas in basins used for analogs, but which lie in areas of favorable economics (such as the Lower 48 States), may not be economically recoverable in the Arctic or offshore basins; this fact was taken into consideration in the estimating process.

GEOLOGIC FRAMEWORK

Interpretation of the geology of all or any part of a potential petroleum province provides the basis for resource discovery and measure-

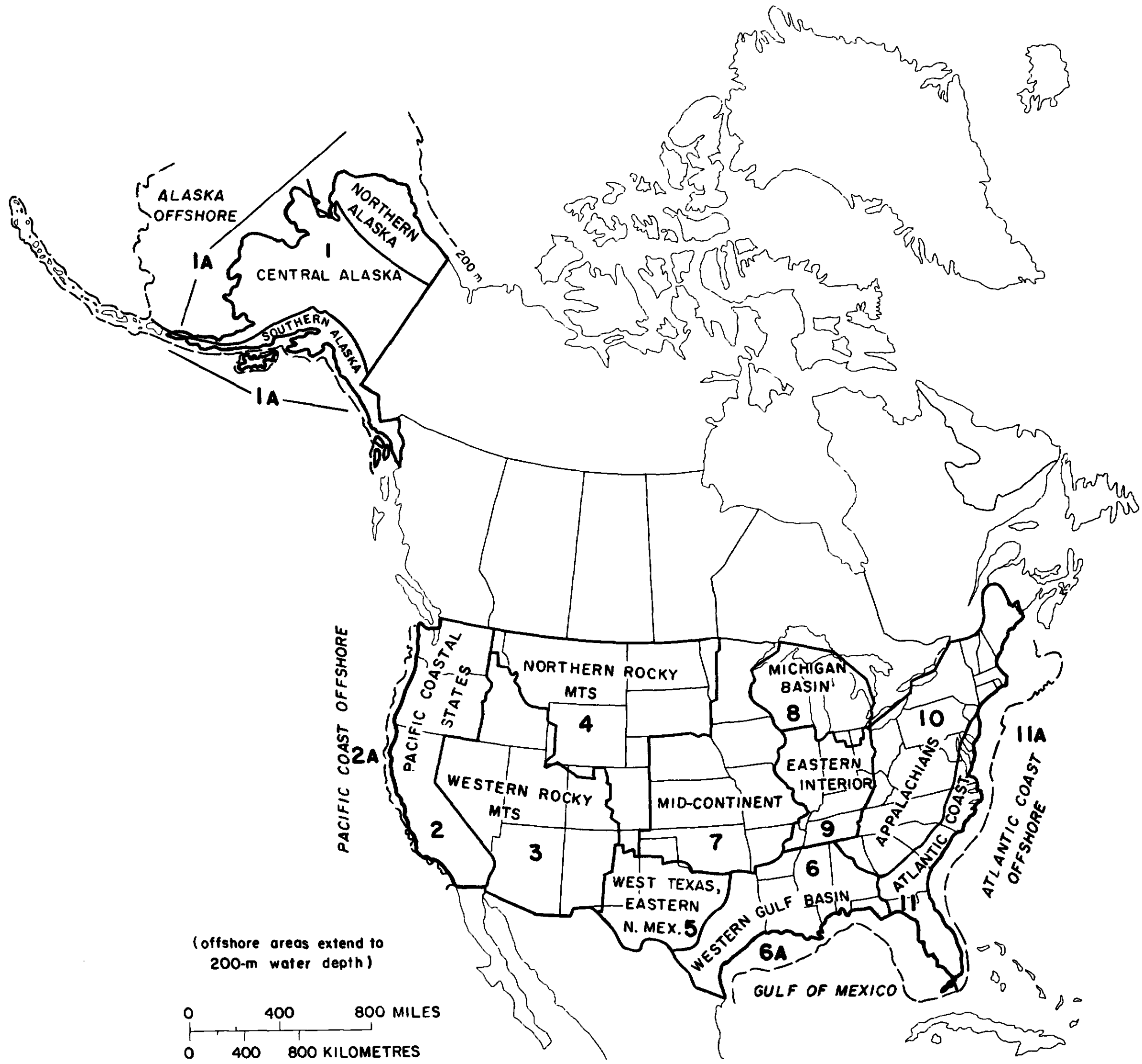


FIGURE 4.—Index map of North America showing the boundaries of the 15 regions, onshore and offshore, covered in this report.

ment. The following discussion provides a broad outline of the geology of the United States as it relates to known and prospective petroleum potential. The descriptions, onshore and offshore, are generally from east to west, and are keyed to major geologic structural elements of North America (fig. 3). Within, and in part coinciding with these elements, are the locations of the 11 onshore and 4 offshore productive and prospective regions appraised in this report (fig. 4). These regions correspond closely to province boundaries established in AAPG Memoir 15 (Cram, 1971). Region 1 (Alaska) includes three major structural elements; Regions 2 and 3 encompass the Pacific Margin Ranges and Intermontane Plateaus and Basins; Regions 4, 5, 7, 8, and 9 lie generally within the Central Stable Interior of the Midcontinent; Region 10 includes the Appalachian basin; and Regions 6 and 11 correspond respectively to the Gulf and Atlantic Coastal Plains. The offshore regions are 1A, Alaska; 2A, Pacific Coastal States; 6A, Gulf of Mexico; and 11A, Atlantic Coastal States.

Eastern part

The oil and gas resources of the northeastern and north-central parts of the United States are concentrated in fields on and adjacent to the Cincinnati arch (fig. 3), a southward extension of the eastern part of the Canadian shield from the west end of Lake Erie to central Tennessee. The fields of eastern Indiana and northwestern Ohio are related to the crest of the Cincinnati arch, whereas the productive Appalachian basin adjoins the arch on its east side, and the Michigan and Illinois basins flank it on the west. The oil and gas in this area occur in rocks of Paleozoic age (table 2). The oldest reservoirs are sandstones and fractured carbonate rocks of Cambrian, Silurian, and Devonian age. The youngest productive beds are porous sandstones and carbonate rocks of Mississippian and Pennsylvanian age.

East of the Appalachian basin, crystalline rocks of the Piedmont belt separate the Atlantic Coastal Plain sediments from the other onshore sedimentary basins except to the south, where the sediments of the Atlantic Coastal Plain overlap the rocks of the Piedmont and merge with the sediments of the Gulf Coastal Plain.

Central part

In the Central Stable Interior Region of the Mid-continent, a western prong of the Canadian shield extends southward mostly in the subsurface from Lake Superior to central Missouri. The southern part of the region consists of a series of basins and uplifts that begin in northwestern Missouri and extend southwestward to central and west Texas. These basins are productive in southeastern Kansas and central Arkansas and are highly productive in the Ardmore and Anadarko basins of Oklahoma and in the West Texas Permian basin, as well as in central and southwest Kansas. The principal productive rocks are Cambrian and Ordovician sandstones and carbonates; Silurian and Devonian carbonates; Mississippian and Pennsylvanian sandstones and carbonate reefs; and Permian sandstones, granite wash, porous bedded carbonates, and reefs.

Another series of basins and uplifts extends westward to the Rocky Mountains' front with the highly productive Delaware basin of southeastern New Mexico at the southern end. Farther north, the essentially barren Tucumcari and Raton basins are followed by the moderately productive Denver and Powder River Basins, and this trend continues northward into Canada through the Sweetgrass arch area of Montana. The productive Williston basin lies in this region, east of the Sweetgrass arch. The principal production in this trend comes from the Paleozoic rocks in the Delaware basin, the Cretaceous in the Denver basin, Upper Paleozoic and Cretaceous in the Powder River Basin, and Paleozoic rocks in the Williston basin.

Southern part

South of the area of predominantly Paleozoic production, the highly productive Mesozoic and Tertiary strata of the gulf coast cover the older strata from the panhandle of Florida to the Mexican border. These strata lie in a wedge that thickens southward from a thin edge in northeast Texas, southern Arkansas, and central Mississippi to more than 50,000 feet below the Gulf of Mexico. There are seven major productive trends in the gulf coastal region that are made up of progressively younger strata from north to south, ranging in age from Lower Cretaceous to Quaternary.

Western part

Within the Rocky Mountains, and extending into the eastern part of the Intermontane Plateaus and Basins, are several productive basins extending from the San Juan Basin in northwestern New Mexico to the Bighorn Basin in Montana and Wyoming. Production in these basins comes from reservoirs ranging in age from Paleozoic through Mesozoic to early Tertiary.

West of this productive trend are large areas of essentially nonproductive rocks that extend to the Pacific coast. Exceptions are in California, where the moderately productive Sacramento basin, the more productive San Joaquin, Cuyama, Santa Maria and Ventura basins, and the highly productive Los Angeles basin are present. These basins produce mostly from sandstones that range in age from Late Cretaceous to Quaternary.

TABLE 2.—*Major stratigraphic and time divisions (modified from Geologic Names Committee, U.S. Geological Survey, 1972)*

Subdivisions in use by the U.S. Geological Survey		Age estimates of boundaries (in millions years before present)
Era or Erathem	System or Period	
CENOZOIC	Quaternary	
		1.5-2
	Tertiary	
		65
MESOZOIC	Cretaceous	
		136
	Jurassic	
		190-195
	Triassic	
		225
PALEOZOIC	Permian	
		280
	Pennsylvanian	
		320
	Mississippian	
		345
	Devonian	
		395
	Silurian	
		430-440
	Ordovician	
		ca.500
	Cambrian	
		570
PRECAMBRIAN		4,500 ±

Alaska

Most Alaska onshore sedimentary strata are moderately to highly deformed, and most prospective provinces contain sections of more than 15,000 feet of sedimentary rocks. Carbonate rocks and sandstones of Late Paleozoic age and sandstones of Mesozoic age are moderately to highly productive in the foothills and coastal plain of northern Alaska. Sandstones of Tertiary age are productive in Cook Inlet in southern Alaska. Prospective rocks in other provinces are mostly Mesozoic to Tertiary sandstones. Paleozoic and older sedimentary rocks are prospective in the Yukon-Porcupine province of eastern central Alaska.

OFFSHORE UNITED STATES

The eastern part of the U.S. continental margin offshore to a water depth of 200 metres, essentially the outer edge of the Continental Shelf, extends from the Canadian border off the Atlantic coast southwestward to include the southern tip of Florida. The northern portion is underlain by clastic sediments which thicken southward to more than 40,000 feet in the Baltimore Canyon Trough, beyond which they thin southward and interfinger with carbonate sediments of Mesozoic and Cenozoic age flanking the Florida Peninsula. None of the sediments off the eastern coast of the United States has been drilled.

Although Mesozoic carbonate rocks of the Florida platform contain moderately to highly productive reservoirs onshore, no production has been found offshore to date. The Cenozoic carbonate rocks grade westward into clastic sediments that are highly productive off the coast of Louisiana and moderately productive off the coast of Texas.

The basin of the southern California borderlands and Santa Barbara Channel, which lie north of Mexico along the Pacific coast, are highly productive, or potentially productive, from Cenozoic clastic rocks in offshore extensions of the Los Angeles and Ventura basins. The clastic sediments off the coast of northern California, Oregon, and Washington are unproductive to date.

Alaska offshore areas contain extensions of onshore carbonate and clastic rocks of Paleozoic age and clastic rocks of Mesozoic age. These may have major potential under the Arctic Ocean. Thick sediments of clastic rocks of Tertiary age are also prospective in basins under the Arctic Ocean, Bering Sea, and Pacific margin of southern Alaska. Rocks of the same age are productive under Cook Inlet in southern Alaska.

REGION AND PROVINCE LOCATIONS AND BOUNDARIES

Appraisal of the Nation's petroleum resources requires that the entire country be covered on a systematic regional basis. Regional boundaries were established to facilitate this and to orient the reader with reference to the geographic distribution of those resources. Fifteen regions, offshore and onshore, are treated in this report and are shown on the accompanying index map of North America (fig. 4). These regions correspond closely to province boundaries established in AAPG Memoir 15 (Cram, 1971). They include Alaska and regions of the conterminous 48 States. Hawaii, thought to have insignificant oil and gas potential, is excluded. The majority of the regions consists of two or more individual geologic provinces (figs. 5, 6) which are the basic elements for this appraisal. Provinces usually exhibit certain common geologic features characteristic of the region they occupy. A total of 102 separate onshore and offshore provinces were individually appraised.

In order to provide a ready basis for comparison with studies of petroleum resources published by the American Association of Petroleum Geologists (Cram, 1971) and the National Petroleum Council (1970, 1973), the region and province boundaries established for the onshore in this study were designed to generally conform with their boundaries, except locally, where appropriate treatment dictated otherwise, Similarly, the numbering system used for these regions parallels that of the AAPG and the NPC.

Onshore region boundaries were drawn in specific detail to coincide wherever possible with local political boundaries, such as State and county lines, but also to approximate the

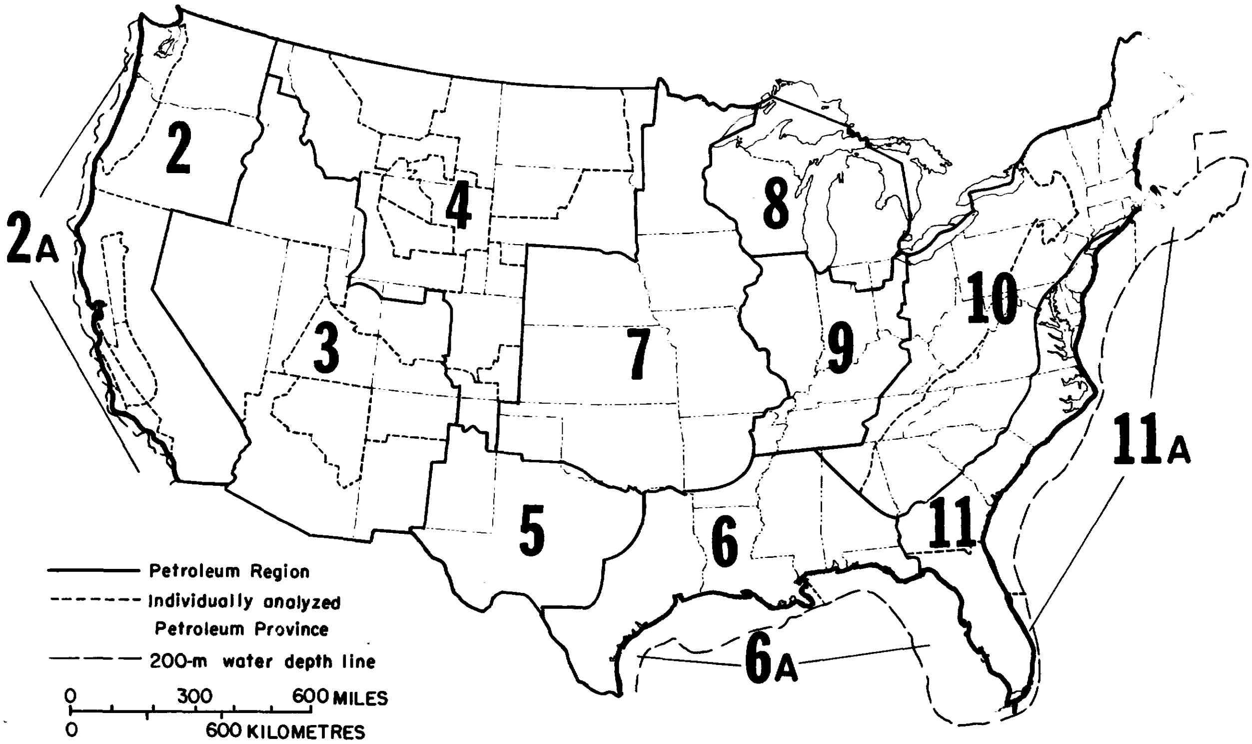


FIGURE 5.—Index map of the conterminous Lower 48 United States showing the regional boundaries:

Region 2, Pacific Coastal States;
Region 2A, Pacific Coastal States Offshore;
Region 3, Western Rocky Mountains;
Region 4, Northern Rocky Mountains;
Region 5, West Texas and Eastern New Mexico;
Region 6, Western Gulf Basin;
Region 6A, Gulf of Mexico;
Region 7, Mid-continent;
Region 8, Michigan Basin;
Region 9, Eastern Interior;
Region 10, Appalachian Basin;
Region 11, Atlantic Coast;
Region 11A, Atlantic Coastal States Offshore.

basic natural geologic boundaries. This was done in order to facilitate use of production, reserve, and other data which are generally published for political subdivisions by various State and Federal agencies and private sources.

Onshore province boundaries within the regions, those elements shown on figures 5 and 6, are based fundamentally on known limits of natural geologic provinces and are drawn in detail along local political boundaries, with the exception of the Alaskan provinces which are unmodified by political subdivisions.

Province boundaries used within the offshore regions were also made to approximate natural geologic boundaries wherever possible; however, it was necessary to utilize arbitrarily straight lines in some instances.

Only the Continental Shelf out to 200 metres of water depth was treated within the offshore areas in this report. Present technology and economics allow for ready exploration and development of petroleum resources of offshore areas out to water depths of 200 metres (660 ft) in most areas, except for those having extreme sea and ice conditions. Industry is already actively exploring in water depths greater than 200 metres, although actual drilling at these depths has been limited to date.

With reference to the international boundaries of the offshore regions, the United States has not yet resolved its Continental Shelf boundaries with its neighboring States. For purposes of this report, it has been necessary to make certain arbitrary assumptions about the extent of areas potentially subject to U.S. jurisdiction. The lines used in preparing this report are for purposes of illustration only, and do not necessarily reflect the position or views

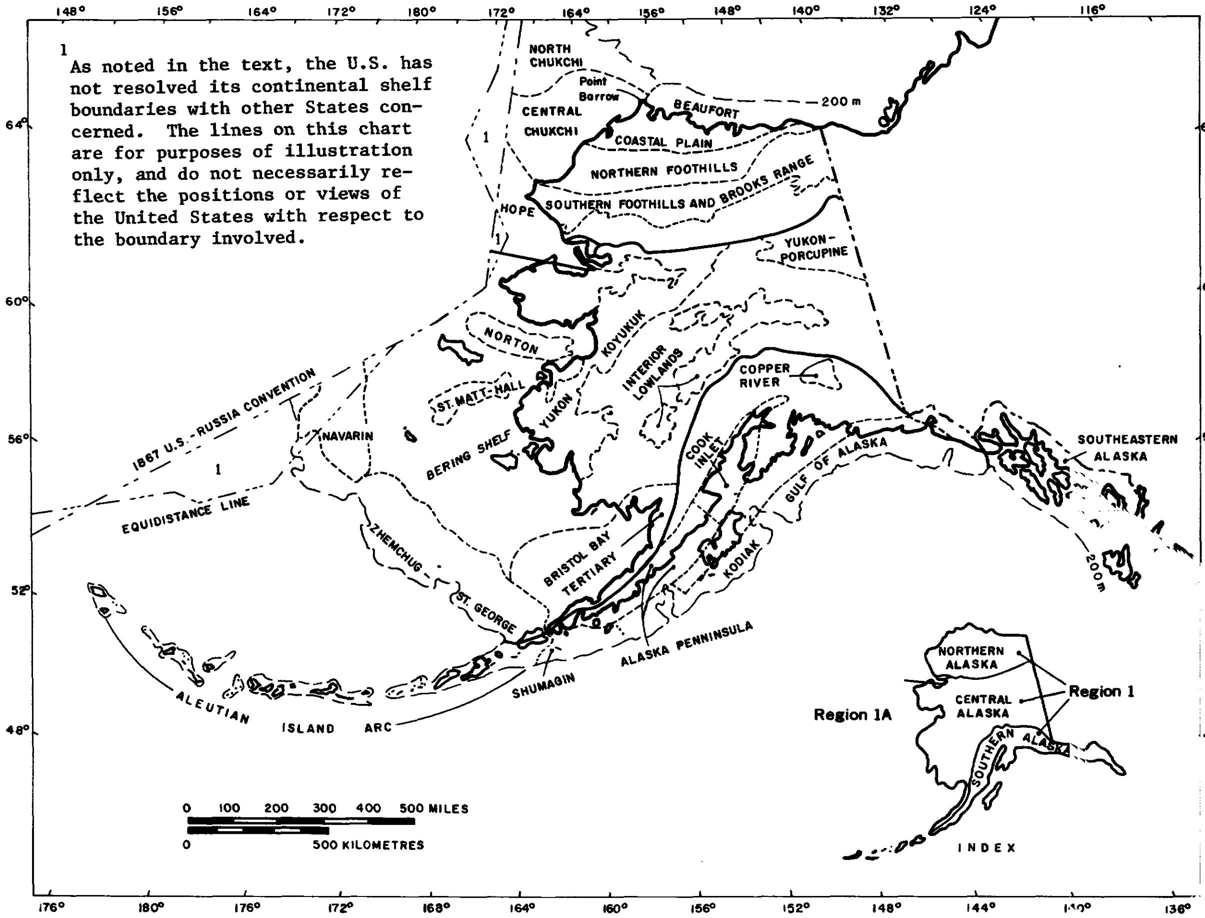


FIGURE 6.—Index map of Alaska showing the boundaries of the major onshore and offshore petroleum provinces.

of the United States with respect to the location of the Continental Shelf boundaries between the United States and other States concerned. The United States expressly reserves its rights, and those of its nationals, in all areas in which the Continental Shelf boundary has not been resolved, and these illustrative lines are used without prejudice to such rights.

In this resource assessment, no exclusion of lands was made on the basis of current or future availability for resource development, either in terms of existing or proposed reservations, sanctuaries, or other withheld areas.

SEDIMENTARY ROCK AREAS AND VOLUMES

Areas of prospective sedimentary rock were measured and the volume of contained sedimentary rock calculated (table 3) within each province and region.

Principal among the several base maps used in compilation is the "Tectonic Map of North America" (King, 1969). Map areas planimetered from this source for the most part show small deviations of scale owing to the type of map projection. Thus, measured areas with few exceptions fall within 6 percent of actual global-surface measurements. Measurements at the western edge of the Bering Sea Continental Shelf and the westernmost Alaska Peninsula and the Aleutian Islands locally exceed true area by as much as 10 percent. Even in these areas, however, the province areas and derived rock volumes reported here generally exceed true dimensions by less than 8 percent. Measurements on other maps, when checked, fell within 5 percent of actual global-surface measurement.

TABLE 3.—*Sedimentary rock area and volume by regions*

ONSHORE			OFFSHORE (Water depths 0-200 metres)			TOTAL	
Region	Area in 1000 mi^2	Volume in 1000 mi^3	Region	Area in 1000 mi^2	Volume in 1000 mi^3	Area in 1000 mi^2	Volume in 1000 mi^3
1. Alaska	252.2	644.7	1A. Alaska	318.1	501.7	570.3	1,146.4
2. Pacific Coastal States	125.5	192.1	2A. Pacific Coastal States	18.4	32.0	143.9	224.1
3. Western Rocky Mountains	329.9	549.1				329.9	549.1
4. Northern Rocky Mountains	360.6	591.6				360.6	591.6
5. West Texas and Eastern New Mexico	193.4	283.8				193.4	283.8
6. Western Gulf Basin	238.7	774.8	6A. Gulf of Mexico	112.8	570.0	351.5	1,344.8
7. Mid-Continent	446.6	324.2				446.6	324.2
8. Michigan Basin	122.0	108.0				122.0	108.0
9. Eastern Interior	166.2	204.0				166.2	204.0
10. Appalachians	205.4	501.4				205.4	501.4
11. Eastern Gulf and Atlantic Coastal Plain	109.4	127.8	11A. Atlantic Coastal States	102.3	233.0	211.7	360.8
Total Lower 48 Onshore	2,297.7	3,656.8	Total Lower 48 Offshore	233.5	835.0	2,531.2	4,491.8
Total Onshore United States	2,549.9	4,301.5	Total Offshore United States	551.6	1,336.7	3,101.5	5,638.2

Uplifted areas of crystalline or metamorphic rock were excluded from sedimentary areas as nonpotential, as were sedimentary rocks which were strongly deformed or altered to the point of being potentially nonproductive for hydrocarbons. Such rocks were likewise excluded from vertical rock sections, thus providing a "basement" or floor to an otherwise prospective thickness of sedimentary rock.

In Regions 1A, 4, 7, and 8, additional areas of very thin sediment cover, with no production history, were considered nonprospective and excluded from reported sediment areas and volumes; these areas are peripheral to the Canadian shield and that part of the Bering Shelf lying outside of the recognized basinal areas.

Throughout essentially all regions, with minor exceptions in some of the onshore provinces, only the sedimentary rock sections less than 30,000 feet in depth were considered potentially prospective and calculated for the reported total rock volumes. This selection was made on the basis of limiting factors of economics and drilling technology, as well as degradation of reservoirs at depth and instability and destruction of certain hydrocarbons themselves at temperatures and pressures generally encountered at these depths. The contained volumes of sediments otherwise were treated as having petroleum potential, qualified by geologic factors of probable reservoir quality, generation of hydrocarbons, associated trapping potential, and other factors related to petroleum occurrence.

FACTORS RELATED TO HYDROCARBON OCCURRENCE AND EXPLORATION

CHARACTERISTICS OF THE HABITAT OF HYDROCARBONS

A petroliferous province must have: (1) an adequate thickness of sedimentary rocks; (2) source beds containing considerable dispersed organic matter; (3) a suitable environment for the maturation of organic matter; (4) porous and permeable reservoir beds; (5) hydrodynamic conditions favorable for both early migration and ultimate entrapment of oil and gas; (6) a favorable thermal history; (7) adequate trapping mechanisms; and (8) suitable timing of petroleum generation and migration in relation to the development of traps. Many other features are favorable but not absolutely necessary. Examples of favorable indications in unexplored basins are: the presence of oil and gas seeps, a varied sequence of rock types, some organically rich marine sediments as source beds for the generation of oil and associated gas, nonmarine organically rich sediments for genesis of nonassociated gas, structural features that show progressive growth through geologic time, unconformities, and the presence of evaporite deposits. For areas in an early stage of exploration, important indicators are: shows of oil and gas in noncommercial wells, presence of saline or sulfate water in potential reservoirs, commercial production, a favorable ratio between wells drilled and oil and gas discoveries, and traps that are detectable by conventional geological and geophysical methods.

TRAP TYPES

Most of the oil and gas fields onshore in the Lower 48 States occur in structural traps, such as anticlines, salt domes, and fault traps. However, many are in stratigraphic traps such as reefs, porosity pinchouts, or the truncated edges of porous strata. The super-giant Hugoton gas field and the East Texas oil field (each the largest in its own category in the Lower 48 States) are at least partly stratigraphic in the nature of their trapping mechanism. Paleozoic reef traps are particularly abundant in salt and other evaporite basins, such as the Michigan, Delaware, and Paradox basins and the Jurassic reef trend from northeast Texas to the panhandle of Florida. In addition, salt domes and salt anticlines are important productive structures. In onshore Alaska, fields occur in anticlinal and fault traps as well as combination traps like the Prudhoe Bay field which consists of structure and erosional truncation, sealed by impervious rocks.

The distribution of oil and gas fields of the United States, including Alaska and the Continental Shelves, is shown on figure 7. The concentration of these oil and gas fields ranges from dense in heavily explored areas (such as the Appalachian region, Mid-continent, gulf coast, Permian basin, and Los Angeles basin) through locally dense in partly explored areas like the Continental Shelf of the Gulf of Mexico and offshore southern California, to scattered in lightly explored areas, such as northern Alaska and the undrilled Atlantic Continental Shelf.

METHODOLOGY

INTRODUCTION AND REVIEW OF BASIC RESOURCE APPRAISAL METHODS

There are many methods for estimating petroleum potential, and each requires a certain level of knowledge or degree of information. Each method with its recognized limitations can produce relevant results, but no single technique has universal application. The strengths and weaknesses of each technique must be considered in choosing the method or methods to be used in making an estimate of the petroleum potential of a specific area.

In the last two decades the many estimates of petroleum resources that have been made fall into three basic categories. The successful application of these methods requires some knowledge of the geology of the sedimentary province being evaluated. These three basic methods are as follows:

I. Performance or behavioristic extrapolation methods based upon historical data,

II. Volumetric-yield methods, and

III. Combined methods—geological and statistical models.

A fuller discussion of these three basic categories follows:

I. Performance or behavioristic extrapolation methods based upon historical data.

These methods are based upon the extrapolation of past experience such as discovery rates, cumulative production or productive capacity curves, and the fitting of past performances by various mathematical derivations into logistic or growth curves which are projected into the future. These techniques are not valid in frontier basins where little history exists or in any area that is not a geologic and economic replica of the historical model. Generally speaking they are most applicable to the later stages of exploration in a mature area. Well known examples of these models are: M. K. Hubbert's growth curve projections (1962, 1974); C. L. Moore's rate of discovery curves (1966); and C. R. Pelto's rate of discovery curves (1973).

II. Volumetric-yield methods.

There are a wide variety of ways in which volumetric estimating techniques have been used in the past. These range from worldwide average yields in barrels of oil or cubic feet of gas per cubic mile of sedimentary rock or per square mile of surface area applied uniformly

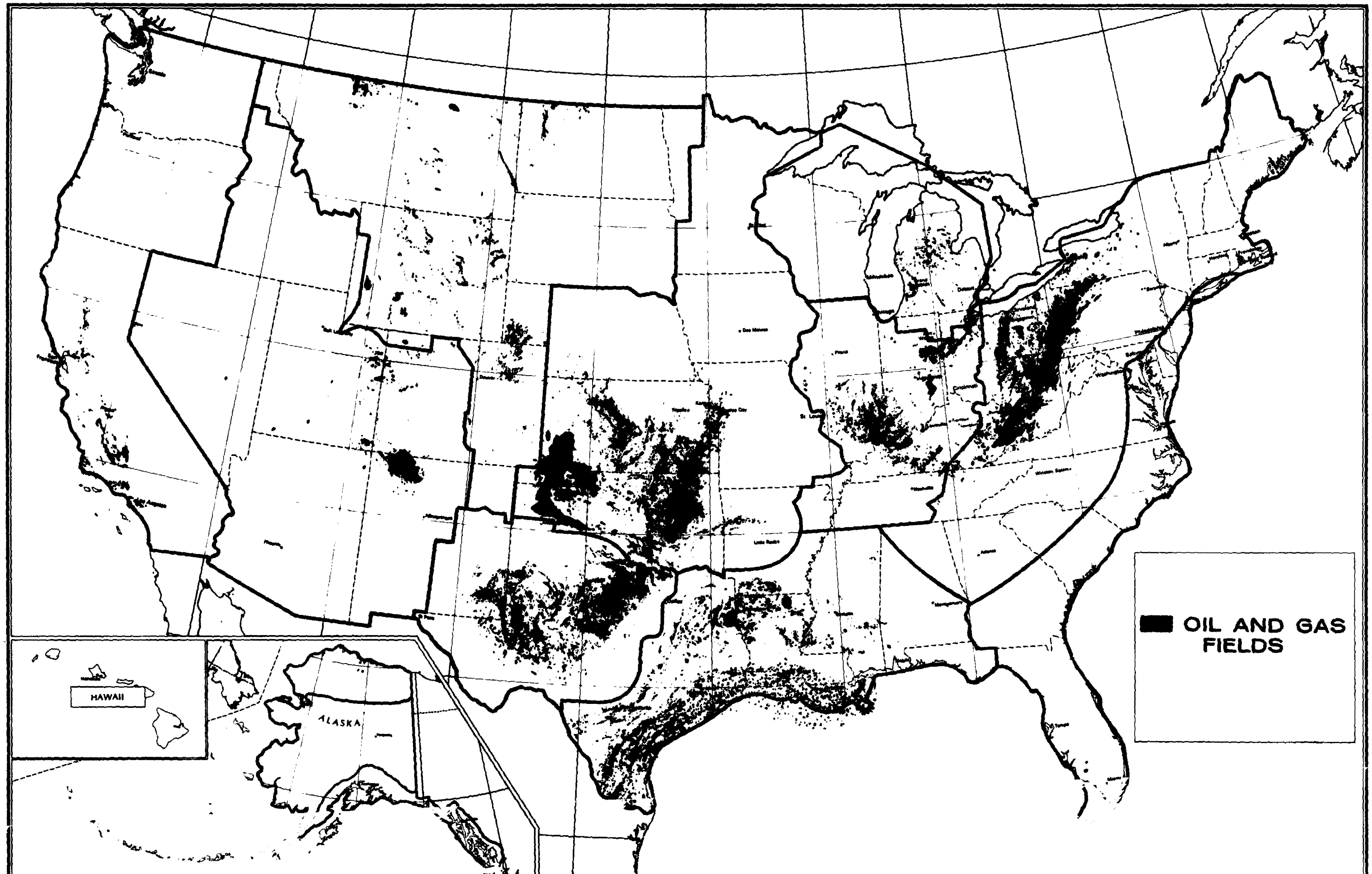


FIGURE 7.—Map of the United States showing the oil and gas fields and the regional boundaries (modified from the U.S. Geological Survey, 1967).

over a sedimentary rock area to more sophisticated analyses where the yields from a geologically analogous basin have been used to provide a basis of comparison. The pioneer works by Weeks (1950), Zapp (1962), and Hendricks (1965) are illustrative of these techniques.

Where a yield factor based upon geologic analogs is used in this report, it is done in the context of a reasonably sound consideration of the geology of the province and the selection of a geologically analogous basin or province.

III. Combined methods—geological and statistical models.

These methods consist of more sophisticated techniques which require a large amount of data as well as complicated mathematical and computer methods for handling the information input. These may involve:

1. Basin evaluation studies with geologic models,
2. Play analysis techniques,
3. Statistical and economic models, decisionmaking models, and
4. Comprehensive petroleum province analog systems.

APPRAISAL PROCEDURES FOR THIS REPORT

GENERAL

Estimates of recoverable oil and gas resources are based upon a series of resource appraisal techniques. These techniques all have the common characteristic of having been selected on the basis of the *available* geologic information for each province or region.

The techniques used include: (1) an extrapolation of known producibility into untested sediments of similar geology for a well-developed area; (2) volumetric techniques using geologic analogs and setting upper and lower yield limits through comparisons with a number of known areas; (3) volumetric estimates with an arbitrary general yield factor applied when direct analogs were unknown; (4) Hendricks' (1965) potential-area categories; and (5) comprehensive comparisons of all known published estimates for each area to all estimates generated by the above methods.

SPECIFIC METHODOLOGY USED BY THE RESOURCE APPRAISAL GROUP

Geological appraisal procedures

Geological data formats were provided to the geologist making the primary geologic analysis in a specific geological province so that he would accomplish the following:

1. Provide a summary of the available information, including the interpretive geology.
2. Provide an inventory of the information base in a province, such as maps, logs, and reports.
3. Quantify the summarized information needed to characterize the basic geology of the province, describe the basic field and reservoir information, and describe the production, reserves, and resource information for the province.
4. In short, provide the basic input essential to the various methods of resource appraisal that would be applied by the Resource Appraisal Group to each of the provinces.

Two versions of the data formats were used: a long form to be used for the more maturely developed and productive provinces, consisting of approximately 85 basic categories of information, and a shorter version designed for the less maturely explored or frontier and offshore areas, consisting of approximately 60 basic categories of information. An example of the short form is given in the Appendix with data from the Michigan basin, compiled for illustrative purposes.

Approximately 70 U.S. Geological Survey geologists provided basic geologic data for the province, or provinces, in their respective areas of expertise, and for which they were responsible for the compilation and assembling of all the basic geological data.

Each of the province data formats was reviewed critically by the Resource Appraisal Group and rechecked with the area experts. Special emphasis was placed upon accuracy of: areal determinations of provinces by planimetry using various base maps; determinations of thickness and volumes of sediments in each of the provinces; and the selection of yield values by analog basins or provinces. One-page province summary sheets were compiled for each province by a Resource Appraisal Group representative. (See form 3, Appendix, for an example of the province summary sheet for the Michigan basin.)

The most complete and up-to-date information available was compiled for each province on oil, natural gas, and natural gas liquids for the following classes: cumulative production, measured reserves, indicated reserves, and the total cumulative production and identified reserves (see Definitions of Resource Terms).

Initial resource appraisal procedures

In this phase of the resource appraisal procedure, all of the above geological data summary reports and total production and reserve information for a particular province were assigned to one of the members of the Resource Appraisal Group. These data were then subjected to a series of resource appraisal methods.

A series of geological and volumetric-yield analog procedures was first applied to each province to determine a range of hydrocarbon yield values. These were calculated for in-place estimates, total recoverable resources, and remaining undiscovered recoverable resources. Other procedures were also used, such as extrapolating known producibility into untested portions of a province, or more arbitrary yield factors were used when direct analogs were unknown or uncertain. In addition, a series of Hendricks' productive-area categories was calculated to evaluate a range of potential for each of the three commodities. Finally, all published and documented resource appraisal estimates were compiled on a special summary form (see form 4–A, Appendix) with all of the above estimates that were calculated for each of the methods. These documented estimates usually consisted of the following sources: American Association of Petroleum Geologists, Memoir 15, 1971; National Petroleum Council Estimates, 1973; Potential Gas Committee, 1973; and U.S. Geological Survey or other area or province expert's estimates.

The Resource Appraisal Group representative for each region made a comprehensive comparison of all of the above information and appraisals and then, assuming the occurrence of oil and gas in commercial quantities, made an initial resource appraisal by a subjective probability technique as follows:

1. A low resource estimate corresponding to a 95 percent probability that there is *at least* that amount.
2. A high resource estimate with a 5 percent probability that there is *at least* that amount.
3. A modal estimate of the resource which the estimator associates with the highest probability of occurrence that there will be that amount.
4. A statistical mean which is calculated by adding the low value, the high value, and the modal value and dividing the sum by 3.

These estimates were recorded on the resource appraisal summary sheets for use in the final evaluation by the Resource Appraisal Group Committee. (See Appendix for example of the resource appraisal summary sheets for the Michigan basin (forms 4–A and 4–B)).

Final resource appraisal procedures used by the Resource Appraisal Group Committee

Meetings of the Resource Appraisal Group Committee and the appropriate geologic representatives were held to complete the final resource appraisal estimates for each of the provinces. The representative for each province or region presented a comprehensive summary of the geology and pertinent information related to an evaluation of the province's or region's petroleum potential. A collective review was made by the committee of all the summary sheets and data formats, all the other estimators' figures, and the detailed evaluation of the Resource Appraisal Group representative's evaluation procedures as previously described.

Following the detailed reviews, each member of the committee and the appropriate representatives and area experts individually made their resource appraisal estimates for the province by the subjective probability procedures described in the previous section:

(a) A low estimate with 95 percent probability,
(b) A high estimate with 5 percent probability,
(c) A modal estimate with the highest

probability, and

(d) A calculated statistical mean.

All the evaluators' individual estimates (a, b, c, and d) were posted for review. If there were any major differences in these estimates, the reasons for the differences were discussed and resolved, and a group consensus arrived at for a range of estimates as defined in (a) through (d) above.

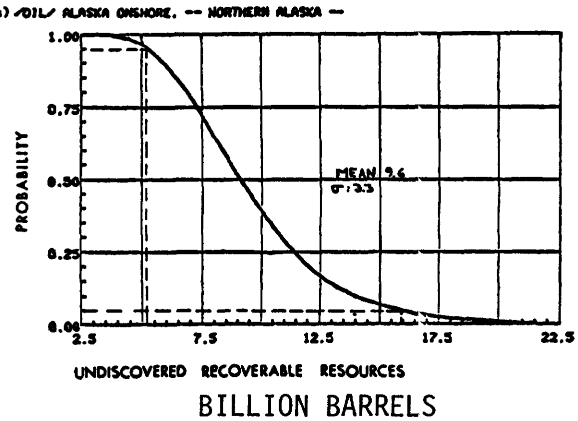
The last phase of the resource appraisal procedure was a review of the Resource Appraisal Group's estimates by the respective representative and the U.S. Geological Survey geologist doing the initial geology for each province. In those provinces where there was a major difference of opinion between the Resource Appraisal Group's estimates and the original geologist's evaluations, the entire resource appraisal procedure was reevaluated and analyzed to resolve the differences.

The final figures as arrived at by the Resource Appraisal Group for the low (95 percent), high (5 percent), and modal estimates and the calculated statistical mean are the estimates that were then statistically analyzed, as discussed below in the Monte Carlo simulation procedures, and were finally incorporated into this report.

METHODOLOGY FOR PROCESSING PROBABILISTIC ASSESSMENTS OF UNDISCOVERED HYDROCARBON RESOURCES

The procedures just described for estimating the undiscovered oil and gas for each of the 102 U.S. petroleum provinces involved subjective probabilities (Raiffa, 1968). Judgments were expressed by the Resource Appraisal Group Committee for each province as percentile assessments, plus the assessment of a modal value and a calculated statistical mean. These values were computerized and processed as probability distributions by lognormal curves (Kaufman, 1962).

Percentile assessments in this study were limited to judgment of quantities associated with the 5 and 95 percent range. These moderate intervals were selected to realistically account for at least 90 percent of the range of the probable undiscovered oil and gas resources for each province. An example of such a cumulative probability distribution curve follows:

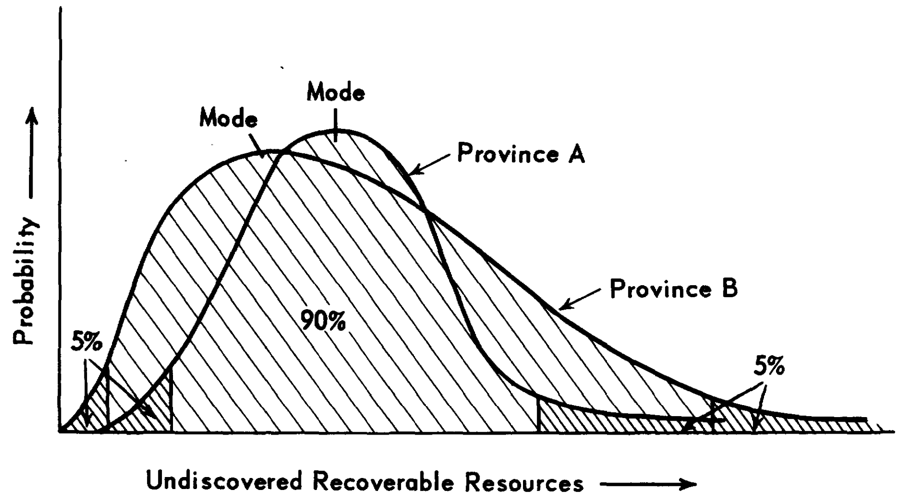


Probability distributions—Monte Carlo techniques

In order to translate these separate probability judgments into a form useful for evaluating resource assessments for total regions and for the total United States, and to determine statistically valid ranges of resource estimate summations, the following procedures were developed for the U.S. Geological Survey by Gordon M. Kaufman of the Alfred P. Sloan School of Management at Massachusetts Institute of Technology:

1. Lognormal probability distributions were computed for the assessment for each province. A lognormal distribution has the following qualitative characteristics:
   - (a) The values can range from zero to infinity;
   - (b) It has one mode on the distribution curve;
   - (c) It is positively skewed (a long right tail);
   - (d) A mean and variance exist; and
   - (e) It is reasonably flexible in shape with at least two and no more than three parameters.

   The following diagram, showing two probability density functions, illustrates why ranges cannot be summed arithmetically or averaged to determine the mean.



The lognormal distributions were used for all provinces except the few for which the group assessments of modes placed these modes closer to the 5 than to the 95 percentiles. These exceptions were assessed by subjective probability procedures by the Resource Appraisal Group.

The first step then was to fit a lognormal distribution to the assessments for each province for which the mode was closer to the 95 than to the 5 percentile. In order to account for the possibility that the percentiles are not spaced far enough apart, the Resource Appraisal Group's assessments were fitted in three ways to the lognormal curve, and that fitted distribution giving the largest spread between the 95 and 5 percentiles was chosen.

2. Monte Carlo techniques were utilized for aggregating the probability distribution of the sums of undiscovered oil and gas resources in regions consisting of two or more provinces and the probability distributions of the sums of the total undiscovered U.S. oil and gas resources in the 15 onshore and offshore regions and for the total United States.

   Once the assessments for each individual province were fitted with a distribution, the probability function in each region composed of two or more provinces was computed by Monte Carlo techniques, assuming mutual independence among provinces. Following the assessments for each region, a Monte Carlo approximation was calculated for the total aggregated undiscovered oil and gas for all onshore areas of the United States, and an aggregate for all the offshore areas, respectively. A Monte Carlo approximation was then computed for an aggregation of the entire United States to give the ranges and mean values for the undiscovered oil and gas resources. The high and low ranges of estimated resources determined for each of the above aggregates are determined independently and cannot be arithmetically summed for a total. Only the aggregated range of values for the total United States obtained by the Monte Carlo technique is valid.

Software systems for implementation of (1) and (2) above were devised to include graphic displays of the probability distributions for undiscovered oil and gas resources by province, by region, and by totals for the United States offshore and onshore areas, as well as the numerical computation of parameters such as the 1, 5, 25, 50, 75, 95, and 99 percentiles, mean, mode, median, and standard deviation of these distributions as shown in computer graphic display such as those illustrated in figure 8.

Marginal probability

In the initial resource appraisal for a given province, an assumption was made that oil and gas occurred in commercial quantities (see p. 21). This assumption cannot be made with certainty in frontier areas in which no petro-

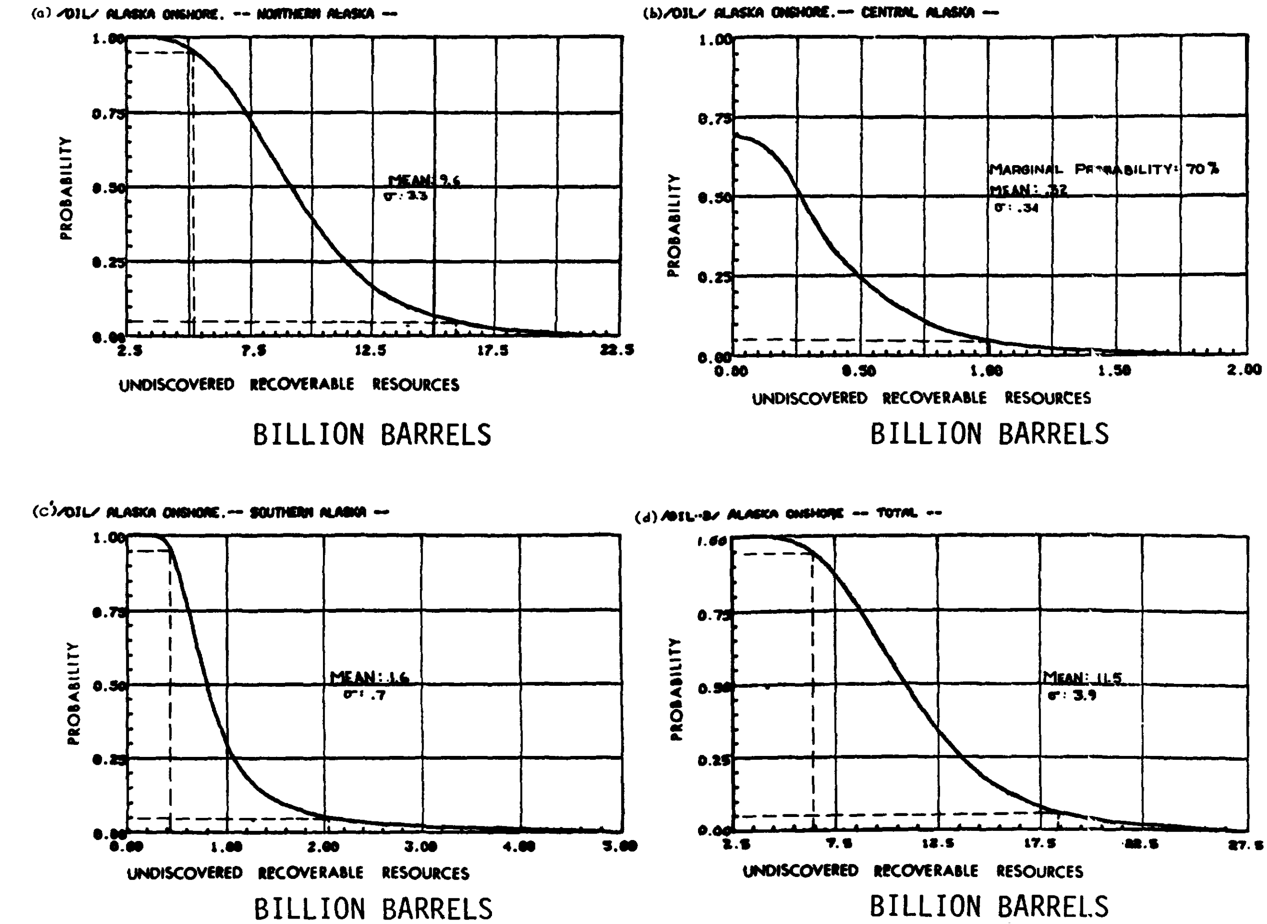


FIGURE 8.—Probability distributions by Monte Carlo analysis on undiscovered recoverable resources for Alaska: Aggregate probability distributions for three onshore subregions and the total Alaska onshore.

leum has been discovered to date. It was necessary, therefore, to assign a marginal probability to the event "Commercial oil found" and to the event "Commercial gas found" (Spurr and Bonini, 1973). These marginal probabilities were determined by consensus of the Resource Appraisal Group Committee. They were then applied to the estimated subjective probability judgments of the undiscovered recoverable resources to determine a final probability distribution of those resources.

Marginal probability can best be described by referring to the graph in figure 8 (graph b). At the present time there has been no oil or gas found in the onshore provinces of central Alaska. The probability of finding oil and/or gas in commercial quantities was calculated as approximately 70 percent (corresponding to a 30 percent probability of finding *no* oil or gas in commercial quantities). This marginal probability was obtained by utilizing the Monte Carlo approximation technique to aggregate the individual provinces, assuming mutual independence among provinces.

The following example illustrates the logic used in the computer program to determine the marginal probability for the aggregated (Monte Carlo) central Alaska subregion:

(a) For the Yukon-Porcupine province the probability of *no* commercial oil or gas is 70 percent; that is, $1-0.3=0.7$.

(b) For the Yukon-Koyukuk province the probability of *no* commercial oil or gas is 75 percent; that is, $1-0.25=0.75$.

(c) Interior Lowlands province (negligible amounts) probability distribution not calculated.

(d) For the Bristol Bay Tertiary province the probability of *no* commercial oil or gas is 60 percent; that is, $1-0.4=0.6$.

The total probability of *no* commercial oil or gas for the three provinces is $0.70\times0.75\times0.60=0.315$, or 31.5 percent. The marginal probability of any success at all in the total subregion is $1-0.315=0.685$, or 68.5 percent. Therefore, reading the probability distribution graph (fig. 8b) for central Alaska onshore at the 95 percent level would give a zero reading, as the probability of success is less than 70 percent for this subregion.

Alaskan examples

Region 1, onshore Alaska, is described here and shown in figure 8 for illustrative purposes. The region was subdivided into three subregions, which in turn were further subdivided into 11 geological provinces. The 11 provinces were evaluated, and the probability distributions for oil and gas resources were determined for each.

The probability distributions for oil were aggregated by the Monte Carlo technique for each of the three subregions and for the total onshore Alaska region as follows:

1. Subregion aggregate: Alaska Onshore—Northern Alaska (fig. 8a) Provinces:
   - Arctic Coastal Plain
   - Northern Foothills
   - Southern Foothills and Brooks Range
2. Subregion aggregate: Central Alaska (fig. 8b)

Provinces	*Marginal Probability*
Yukon-Porcupine	30 percent
Yukon-Koyukuk	25 percent
Interior Lowlands	(Negligible amounts estimated)
Bristol Bay Tertiary	40 percent

3. Subregion aggregate: Southern Alaska (fig. 8c) Provinces:
   - Alaska Peninsula
   - Cook Inlet
   - Copper River Basin
   - Gulf of Alaska
4. Total region aggregate: Alaska Onshore (fig. 8d) Provinces: All of the above 11 provinces

The following information is noted on the graphs for each of the above four aggregated probability distribution for the undiscovered recoverable oil resources: mean and standard deviation and the 95 percent and 5 percent ranges.

SUMMARY OF APPRAISAL PROCEDURES

Individual and collective appraisals were made for each province or region using volumetric-yield procedures, basin analyses, producibility extrapolations, Hendricks' potential-area categories, and other published appraisals, thus encompassing the various estimates into an overall framework for appraisal. A lognormal distribution was fitted to the high, low, and modal values of the Resource Appraisal Group's assessments to compute the probability distribution for each province. Monte Carlo approximation techniques were applied to derive the probability function for the amount of undiscovered oil and gas in each region composed of two or more provinces and for the summation of subtotals and totals of the regions in the United States.

METHODOLOGY FOR ESTIMATING NATURAL GAS LIQUIDS RESOURCES

Estimates of undiscovered recoverable natural gas liquids were not made in the same manner as those for crude oil and natural gas; by definition, they are derived from and dependent upon natural gas production. Historical ratios of cumulative production (American Petroleum Institute, American Gas Association, 1974) of natural gas liquids in barrels per million cubic feet of natural gas were calculated for each region. These factors were then applied to estimates of undiscovered natural gas resources for each region to obtain regional estimates of undiscovered recoverable resources of natural gas liquids. Where no historical data were available to calculate a NGL/natural gas ratio, or where it was felt that future development would substantially affect the calculated factor, the national average of 33 barrels of NGL per million cubic feet of natural gas was used. Results of these calculations are reported in the summary section for undiscovered recoverable natural gas liquid resources.

METHODOLOGY FOR ESTIMATING INFERRED RESERVES

In this study, a ratio of API–AGA inferred + indicated reserves to proved (measured) reserves was calculated for each of the 11 onshore regions and the total U.S. averages for onshore and offshore areas, respectively, by extrapolating the rate of growth of discovered volumes for each given region by use of Hubbert's alpha correction factors which are based upon the time lapse since the initial year of discovery for the respective States involved (Hubbert, 1974). The regional factors were determined by combining the data for API States and districts given in the Appendix. The inferred reserves for most of the regions were calculated by applying these ratios to 1972 estimates of proved (measured) reserves for each region (using data from the latest American Petroleum Institute sources) and subtracting out the value for indicated reserves from the total inferred plus indicated reserves.

A description and explanation of the procedures used to calculate the inferred plus indicated reserves for the United States is provided in the Appendix with complete documentation. The Resources Appraisal Group derived from these calculations ratios both for oil and gas for the 15 regions appraised in this report. The wide variability in the data used to determine the growth curves of Hubbert (1974) plus the fact that the measured (API and AGA proved) reserves portion of that data represent estimates cause a significant degree of uncertainty in the calculated estimates of inferred plus indicated reserves. This uncertainty is compounded by the fact that these estimates were derived from API State or regional data and the growth curves were determined using total United States data.

PETROLEUM RESOURCES OF THE UNITED STATES

SUMMARY OF RESULTS

This report summarizes the estimates of undiscovered recoverable resources of oil, natural gas, and natural gas liquid resources of the United States as assessed by the U.S. Geological Survey's Resource Appraisal Group based on a geological evaluation of over 100 potential petroleum provinces for onshore Alaska and the conterminous Lower 48 States, and all offshore U.S. Continental Shelves to water depths of 200 metres.

The undiscovered oil and gas resource estimates made by the many contributors to this study are based on a series of procedures which led to subjective probability distributions; the common characteristic was that each procedure was based on a detailed geological evaluation of each respective province or region.

New knowledge generated by exploration programs and expert criticism of presently available data will, in the coming years, change these estimates either upward or downward.

All information about future oil and gas resources of the United States, along with information on past production and identified reserves, are summarized by four methods of presentation. These presentations, designed to report all resource estimates in perspective, are summarized and illustrated in the following pages by these four methods:

1. *Tables.*—Detailed tabulations for oil and natural gas compiled to show by regions: cumulative production, identified reserves, estimated undiscovered recoverable resources reported as a range of values (95 percent to 5 percent) and as a statistical mean.
2. *Maps.*—A series of pull-apart maps which show by regions for the conterminous Lower 48 States, onshore and offshore, and for Alaska, onshore and offshore, the cumulative production and demonstrated reserves and the ranges and statistical mean of undiscovered recoverable resources for oil and natural gas.
3. *Resource classification charts.*—A diagrammatic representation of oil and gas resources as classified by the U.S. Geological Survey and U.S. Bureau of Mines.
4. *Probability distributions.* — Probability functions, in graphic display, showing the amount of undiscovered oil and gas resources for each region, with subtotals and totals for the United States.

RESULTS—UNDISCOVERED RECOVERABLE OIL AND NATURAL GAS RESOURCES

Tables 4 and 5 show detailed tabulations of total recoverable oil resources and total recoverable gas resources for the United States. The cumulative production, identified reserves, and estimated undiscovered resources are reported by regions, onshore and offshore, with onshore and offshore subtotals, and U.S. totals. The estimated ranges as reported by regions, subtotals, and U.S. totals were derived by the Monte Carlo simulation techniques discussed previously and illustrated later in this report. The 95 percent to 5 percent range represents a minimum value that is associated with a 19 in 20 chance that there is *at least* this amount and a maximum value that is associated with a 1 in 20 chance that there is *at least* that amount. The statistical mean is mathematically derived from the Monte Carlo technique. These figures may be mathematically totaled. Totals for the minimum and maximum values *are not obtained* by arithmetic summation.

The total U.S. cumulative oil production through 1974 is 106 billion barrels; measured and indicated reserves total 39 billion barrels; estimated inferred reserves are 23 billion barrels; and the undiscovered recoverable oil resources range from 50 to 127 billion barrels, with a mean of 82 billion barrels.

Cumulative production and measured (API proved) reserves and indicated reserve figures were derived from reported API–AGA estimates. States and districts were assigned to their respective regions, and, where allocations were required, State production statistics provided a basis for allocation of the API–AGA data.

The total U.S. cumulative natural gas production through 1974 is 481 trillion cubic feet; measured reserves total 237 trillion cubic feet; estimated inferred reserves are 202 trillion cubic feet; and the undiscovered recoverable gas resources range from 322 to 655 trillion cubic feet, with a mean of 484 trillion cubic feet.

The maps shown in figures 9 and 10 illustrate by regions the distribution of the *cumulative production* and *demonstrated reserves* of oil and natural gas for the United States, through 1974 onshore and offshore. Maps presented in figures 11 and 12 show the estimated range of values, at the 95 and 5 percent probability levels, and the statistical mean of the *undiscovered recoverable* oil and natural gas *resources* for the same regions as determined by the Monte Carlo simulation technique of aggregating the separate probability distributions for each province within a region.

In the case of the Bering Sea subregion in Alaska and the Atlantic coast offshore region, the probability of the presence of economically recoverable oil or gas, in the judgment of the authors, is less than 95 percent. The resource appraisal at the 95 percent probability level, therefore, is zero. In these totally unexplored frontier areas, however, the lack of discovered indigenous or adjacent recoverable hydrocarbons renders uncertainty sufficiently great that probability judgments at either high or low levels are weakened. For some planning purposes, therefore, estimates at the 75 and 25 percent levels are judged to be more applicable and are so shown on the maps and tables. For purposes of comparison with other areas, values at the 95 and 5 percent probability levels are shown in the footnote on page 33.

In figures 13 and 14, diagrammatic representations show total oil and natural gas resources of the United States within the framework of the U.S. Geological Survey's and the U.S. Bureau of Mines' resource classification system. Cumulative oil and natural gas production data through 1974 are recorded at the bottom of the charts. The economic recovery factor used was based on a current national average of approximately 32 percent for oil and 80 percent for natural gas (McCulloh, 1973). The subeconomic portion of the remaining resources for oil is estimated to be an additional 28 percent recoverable, for a total of 60 percent recovery (Geffen, 1975). Subeconomic identified resources of crude oil were calculated on the following assumptions: (1) that on the average, 32 percent of original oil-in-place is recoverable if there are no substantial changes in present economic relationships and known production technology, and (2) that ultimately the recovery factor could be as large as 60 percent. By definition, the sum of cumulative production to date, plus the current estimate of demonstrated reserves, will account for 32 percent of the original oil-in-place in *known* fields; an increase to 60 percent will allow another 28 percent to be recovered. As indicated in figure 13, that 28 percent, which is currently considered subeconomic, amounts to about 120 billion barrels. The inferred reserves are made up partly of revisions of current estimates and partly of "undiscovered" oil from future extensions and new pools in known fields. Assuming that all the inferred is "undiscovered," the 23.1 billion barrels, economically recoverable at the 32 percent recovery factor, would have a subeconomic component of about 20 billion barrels. Thus, the subeconomic identified category was estimated to be 120–140 billion barrels. Similarly, the subeconomic component of undiscovered resources was estimated to include 44–111 billion barrels.

It is extremely optimistic to assume that 60 percent of the oil-in-place will eventually be recovered. If it becomes a reality, it is likely to occur only through gradual development over an extended time period. The remaining 40 percent of oil-in-place is not included as it is considered to be nonrecoverable, in much the same sense as coal which is too thin to mine is excluded from recoverable resources.

Subeconomic identified and undiscovered resources of natural gas, shown in figure 14, were

TABLE 4.—*Production, reserves, and undiscovered recoverable* oil *resources for the United States, December 31, 1974 (billion barrels)*

Regions	Cumulative Production	Demonstrated Reserves		Total Cumulative Production + Demonstrated Reserves	Inferred Reserves [1]	Undiscovered Recoverable Resources	
		Measured	Indicated			Statistical Mean	Estimated Range [2] (95%-5%)
ONSHORE							
1. Alaska	0.154	9.944	0.013	10.111	[3]6.1	12	6 - 19
2. Pacific Coastal States	15.254	2.699	1.091	19.044	0.3	7	4 - 11
3. Western Rocky Mountains	1.115	0.417	0.089	1.621	0.7	4	2 - 8
4. Northern Rocky Mountains	6.021	1.461	0.256	7.738	1.2	7	5 - 11
5. West Texas and Eastern New Mexico	21.385	7.060	1.991	30.436	1.6	8	4 - 14
6. Western Gulf Basin	31.345	7.082	0.587	39.014	[4]8.6	8	5 - 12
7. Mid-Continent	17.203	1.805	0.211	19.219	1.3	6	3 - 12
8. Michigan Basin	0.645	0.082	0.008	0.735	0.2	1	0.3 - 2
9. Eastern Interior	4.346	0.283	0.009	4.638	0.3	1	0.6 - 2
10. Appalachians	2.539	0.155	0.067	2.761	[5]Negl.	1	0.4 - 2
11. Eastern Gulf and Atlantic Coastal Plain	0.039	0.042	0.006	0.087	0.1	1	0.2 - 2
Total Lower 48 Onshore	99.892	21.086	4.315	125.293	14.3	44	29 - 64
Total Onshore United States	100.046	31.030	4.328	135.404	20.4	56	37 - 81

OFFSHORE (0-200 metres)

1A. Alaska-------------------	0.456	0.150	[5] Negl.	0.606	[3] 0.1	15	3 - 31
2A. Pacific Coastal States----	1.499	0.858	0.258	2.615	0.2	3	2 - 5
6A. Gulf of Mexico-----------	4.135	2.212	0.050	6.397	2.4	5	3 - 8
11A. Atlantic Coastal States---	0.000	0.000	0.000	0.000	0.0	3	[6] 2 - 4
Total Lower 48 Offshore--	5.634	3.070	0.308	9.012	2.6	11	5 - 18
Total Offshore United States---------	6.090	3.220	0.308	9.618	2.7	26	10 - 49
Total Lower 48-------	105.526	24.156	4.623	134.305	16.9	55	36 - 81
Total Alaska----------	0.610	10.094	0.013	10.717	6.2	27	12 - 49
TOTAL UNITED STATES-	106.136	34.250	4.636	145.022	23.1	82	50 - 127

[1] Inferred reserves were derived for all regions based on historical data. (See Appendix).

[2] The low value of the range is the quantity associated with a 95 percent probability (19 in 20 chance) that there is at least this amount. The high value is the quantity with a 5 percent probability (1 in 20 chance) that there is at least this amount. Totals for the low and high values are not obtained by arithmetic summation; they are derived by statistical methods.

[3] Inferred reserves based on national onshore average.

[4] Inferred reserves based on data in AAPG Memoir 15 (1971).

[5] Negligible--less than 0.001 billion barrels for indicated reserves; less than 0.1 billion barrels for inferred reserves.

[6] Estimates reported at the 75 and 25 percent probability levels because, in this area, these levels are judged to be more applicable for some planning purposes. It can also be noted that in frontier areas, lacking discovered indigenous or adjacent recoverable hydrocarbons, uncertainty is sufficiently great as to weaken probability estimates at extreme ranges. For purposes of comparison with other recorded ranges, the 95-5 percent probability range in offshore Atlantic is 0-6 billion barrels of oil.

TABLE 5.—*Production, reserves, and undiscovered recoverable gas resources for the United States, December 31, 1974 (trillion cubic feet)*

Regions	Cumulative Production	Demonstrated Reserves	Total Cumulative Production + Demonstrated Reserves	Inferred Reserves[1]	Undiscovered Recoverable Resources	
		Measured			Statistical Mean	Estimated Range[2] (95%-5%)
ONSHORE						
1. Alaska-------------------	0.482	31.722	32.204	[3]14.7	32	16 - 57
2. Pacific Coastal States----	25.455	4.732	30.187	4.0	13	8 - 20
3. Western Rocky Mountains---	10.728	9.081	19.809	2.9	14	6 - 25
4. Northern Rocky Mountains--	11.485	6.754	18.240	5.3	29	18 - 47
5. West Texas and Eastern New Mexico---------------	58.686	24.624	83.310	23.3	70	35 - 101
6. Western Gulf Basin--------	197.899	81.903	279.802	58.7	133	85 - 196
7. Mid-Continent------------	107.700	34.150	141.850	20.6	72	50 - 101
8. Michigan Basin-----------	0.558	1.458	2.016	0.8	1	0.8 - 2
9. Eastern Interior----------	2.797	0.766	3.563	0.5	2	0.7 - 4
10. Appalachians-------------	31.057	5.985	37.042	3.3	10	5 - 17
11. Eastern Gulf and Atlantic Coastal Plain-----------	0.001	0.001	0.002	[4]Negl.	1	0.4 - 2
Total Lower 48 Onshore---	446.366	169.454	615.820	119.4	345	246 - 453
Total Onshore United States---------	446.848	201.176	648.024	134.1	377	264 - 506

OFFSHORE (0-200 metres)

1A. Alaska	0.423	0.145	0.568	[3] 0.1	44	8 - 80
2A. Pacific Coastal States	1.415	0.463	1.878	0.4	3	2 - 6
6A. Gulf of Mexico	32.138	35.348	67.486	27.0	50	18 - 91
11A. Atlantic Coastal States	0.000	0.000	0.000	0.0	10	[5] 5 - 14
Total Lower 48 Offshore	33.553	35.811	69.364	27.4	63	26 - 111
Total Offshore United States	33.976	35.956	69.932	27.5	107	42 - 181
Total Lower 48	479.919	205.265	685.184	146.8	408	286 - 529
Total Alaska	0.905	31.867	32.772	14.8	76	29 - 132
TOTAL UNITED STATES	480.824	237.132	717.956	161.6	484	322 - 655

[1] Inferred reserves were derived for all regions based on historical data (See Appendix).

[2] The low value of the range is the quantity associated with a 95 percent probability (19 in 20 chance) that there is at least this amount. The high value is the quantity with a 5 percent probability (1 in 20 chance) that there is at least this amount. Totals for the low and high values are not obtained by arithmetic summation; they are derived by statistical methods.

[3] Inferred reserves based on national onshore average.

[4] Negligible--less than 0.001 trillion cubic feet.

[5] Estimates reported at the 75 and 25 percent probability levels because, in this area, these levels are judged to be more applicable for some planning purposes. It can also be noted that in frontier areas, lacking discovered indigenous or adjacent recoverable hydrocarbons, uncertainty is sufficiently great as to weaken probability estimates at extreme ranges. For purposes of comparison with other recorded ranges, the 95-5 percent probability range in offshore Atlantic is 0-22 trillion cubic feet of gas.

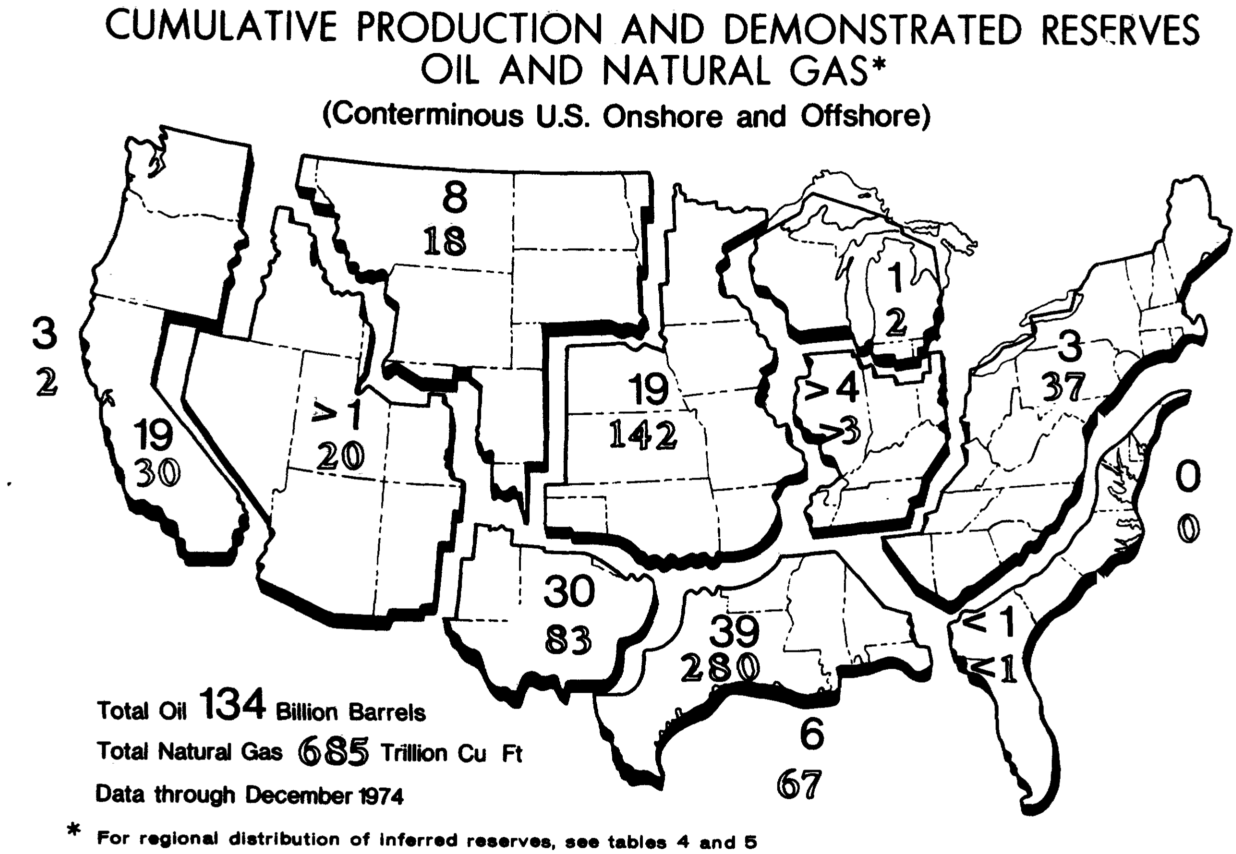


FIGURE 9.—Cumulative production and demonstrated reserves of oil and natural gas by regions for the conterminous United States, onshore and offshore to 200 metres.

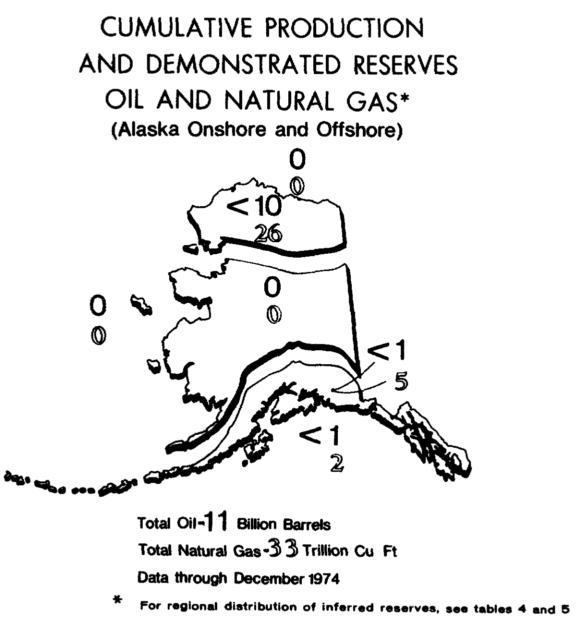


FIGURE 10.—Cumulative production and demonstrated reserves of oil and natural gas by regions for Alaska, onshore and offshore to 200 metres.

calculated by using the same general procedures described above for crude oil. However, it was assumed that the average recovery factor for gas is currently 80 percent and that, ultimately, the recovery factor could be as large as 90 percent (A. M. Derrick, verbal commun., El Paso Natural Gas Co., May 29, 1975). Thus, the subeconomic identified category was estimated to be 90–110 trillion cubic feet and the subeconomic component of undiscovered resources was estimated to be 40–82 trillion cubic feet.

The user of these data should be aware that the forecasts recorded for measured, indicated, and inferred reserves are *single-number point-estimates* of these quantities, derived from API–AGA statistics. By contrast, undiscovered recoverable resources are treated here as *uncertain quantities*, the degree of uncertainty about each being expressed in the form of *probabilities* derived from calibration of expert opinion. Thus, for example, the judgmental probability that undiscovered recoverable re-

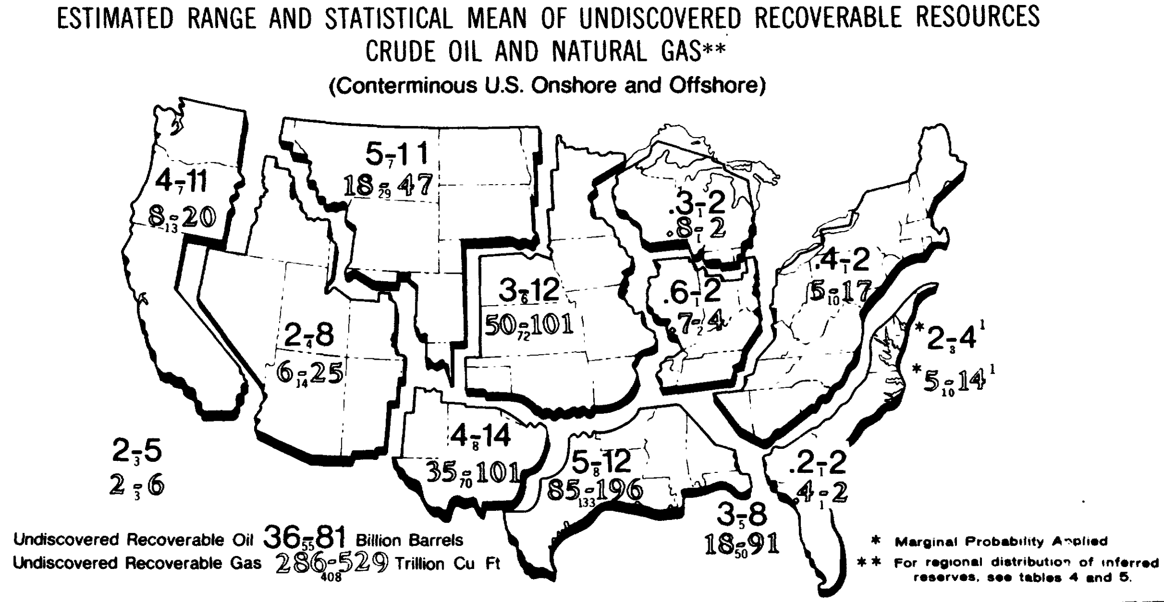


FIGURE 11.—Undiscovered recoverable resources of crude oil and natural gas for the conterminous United States, onshore and offshore to 200 metres. (Ranges of values were derived by Monte Carlo methods from estimates made by the Resource Appraisal Group and reported at 95–5 percent probability levels in billions of barrels for oil and trillions of cubic feet for gas.)

sources of crude oil lie between 50 billion barrels and 127 billion barrels is 90%, and the judgmental probability that undiscovered recoverable resources of natural gas lie between 322 trillion cubic feet and 655 trillion cubic feet is also 90%.

For planning purposes, it is desirable to report probabilities of events for *total recoverable resources*; e.g., the probability that total recoverable resources are less than a given number or between two numbers. In order to do this in a logical fashion, measured, indicated, and inferred reserves would each have to be treated as uncertain quantities, and probabilities for each would have to be assessed as was done for undiscovered recoverable resources. All four categories could then be combined by the same computational methods used to aggregate probability assessments for individual provinces into probability assessments for regions or for the United States as a whole.

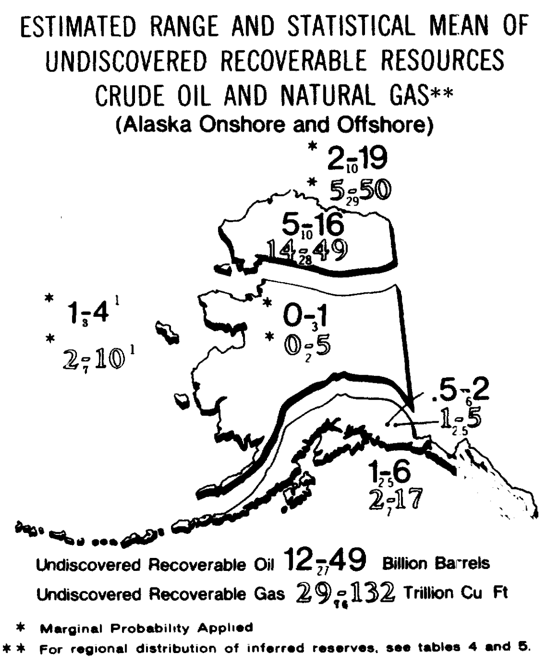
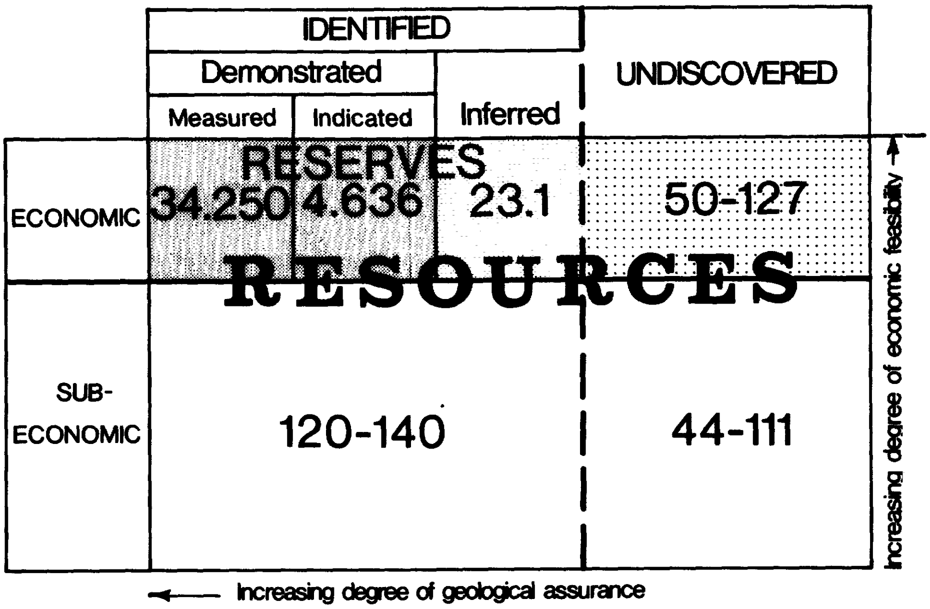


FIGURE 12.—Undiscovered recoverable resources of crude oil and natural gas for Alaska onshore and offshore to 200 metres. (Ranges of values were derived by Monte Carlo methods from estimates made by the Resource Appraisal Group and reported at 95–5 percent probability levels in billions of barrels for oil and trillions of cubic feet for gas.)

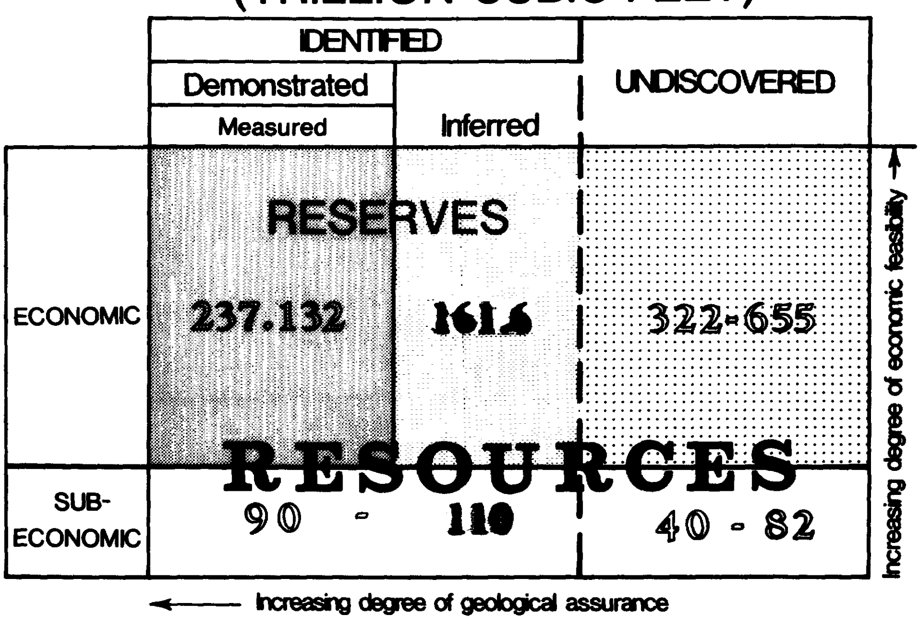
[1] Estimates reported at the 75 and 25 percent probability levels because, in these areas, these levels are judged to be more applicable for some planning purposes. It can also be noted that in frontier areas, lacking discovered indigenous or adjacent recoverable hydrocarbons, uncertainty is sufficiently great as to weaken probability estimates at extreme ranges. For purposes of comparison with other recorded ranges, the 95–5 percent probability range in offshore Atlantic is 0–6 billion barrels of oil and 0–22 trillion cubic feet of gas (fig. 11); in the Bering Sea it is 0–8 billion barrels of oil and 0–18 trillion cubic feet of gas (fig. 12).

CRUDE OIL RESOURCES OF THE UNITED STATES (BILLION BARRELS)



Total U.S. Cumulative Oil Production 106 Billion Barrels 12/31/74

NATURAL GAS RESOURCES OF THE UNITED STATES (TRILLION CUBIC FEET)



Total U.S. Cumulative Gas Production 481 Trillion Cu Ft 12/31/74

◀ FIGURE 13.—Diagrammatic representation of estimated crude oil resources using the U.S. Geological Survey's resource classification system (modified from McKelvey, 1973). Cumulative oil production is cited below the figure.

An intuitively plausible approximation, given that only single-number point-estimates for measured, indicated, and inferred reserves are available, is to add these point-estimates to the end points of an interval of values of undiscovered recoverable resources and then assert that the probability assigned to this interval for *undiscovered* recoverable resources is equal to the probability that *total* recoverable resources lie in the interval so translated. *This is correct only under a very special assumption; namely, that measured, indicated, and inferred reserves are known with certainty and have values equal to the point-estimates cited.* Given this assumption, the probability that remaining recoverable resources of crude oil lie between 112 billion barrels and 189 billion barrels is 90% [to compute the interval, add 62 billion barrels (the sum of point-estimates for measured, indicated, and inferred reserves) to the end points (50 billion and 127 billion barrels) of the 90% probability interval for undiscovered recoverable resources]. Doing a similar computation using 237 trillion cubic feet and 202 trillion cubic feet as point-estimates of measured reserves of natural gas and of inferred reserves of natural gas, respectively, the probability that total resources of natural gas lie in the interval 761 trillion cubic feet to 1,094 trillion cubic feet is also 90%.

With respect to crude oil, and taking into account that in fact there is *uncertainty* about measured, indicated, and inferred reserves, it is reasonable, without detailed calculations, to assert that the probability that total resources of crude oil lie in the interval 112 to 189 billion barrels is 90% *or smaller.* With respect to natural gas, and taking into account that in fact there is *uncertainty* about measured and inferred reserves, it is reasonable, without detailed calculations, to assert that the probability that total resources of natural gas lie in the interval *761* to *1,094* trillion cubic feet is 90% *or smaller.*

A slightly weaker assumption than asserting that measured, indicated, and inferred reserves are known with certainty and are equal to the point-estimates given them, is that each point-estimate equals the *mean value* of the uncertain quantities so estimated. Then the sum of point-estimates of measured, indicated, and inferred reserves plus the mean value of undiscovered recoverable resources can be interpreted as the mean value of total recoverable resources.

Probability distribution curves (from computer graphic display), showing the total amounts for undiscovered recoverable oil and gas resources (derived by the Monte Carlo aggregating technique for each of the 15 regions and for U.S. subtotals and totals), are shown in the following figures:

Undiscovered recoverable oil resources	*Figure*
Onshore Regions 1 through 11	15 to 20
Offshore Regions 1A through 11A	21 and 22
Total Lower 48 onshore and total Lower 48 offshore	31
Total onshore United States and total offshore United States	32
Total United States	33
Undiscovered recoverable gas resources	
Onshore Regions 1 through 11	23 to 28
Offshore Regions 1A through 11A	29 and 30
Total Lower 48 onshore and total Lower 48 offshore	34
Total onshore United States and total offshore United States	35
Total United States	36

The reported range of undiscovered resource estimates does not include the occurrence of volumes which may fall either above or below the 5 percent and 95 percent probabilities shown. Inspection of the regional probability curves included with this report shows the magnitude of estimates which could be made for any selected range. The total probability distribution ranges of 0 to 100 percent can be read directly from the curves.

◀ FIGURE 14.—Diagrammatic representation of estimated natural gas resources using the U.S. Geological Survey's resource classification system (modified from McKelvey, 1973). Cumulative gas production is cited below the figure.

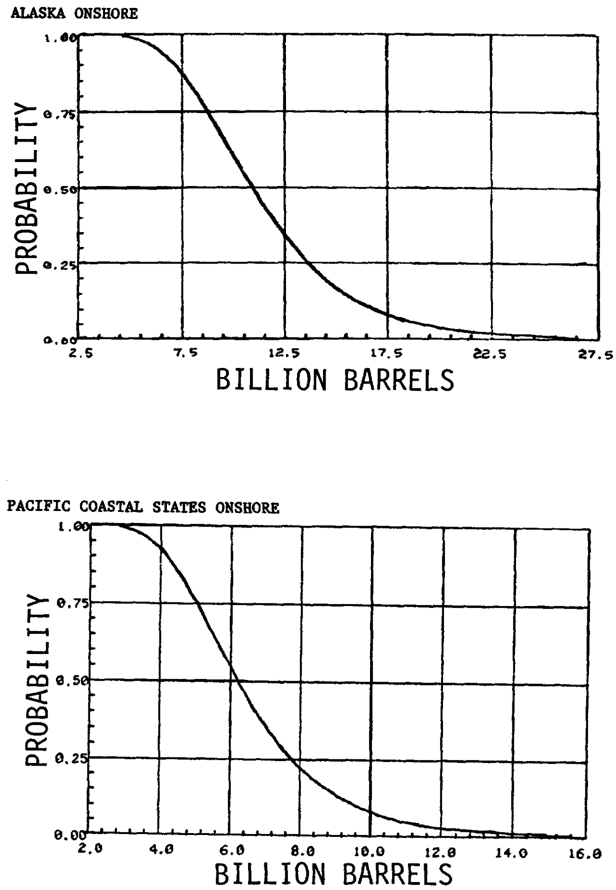


FIGURE 15.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore:
Region 1. Alaska.
Region 2. Pacific Coastal States.

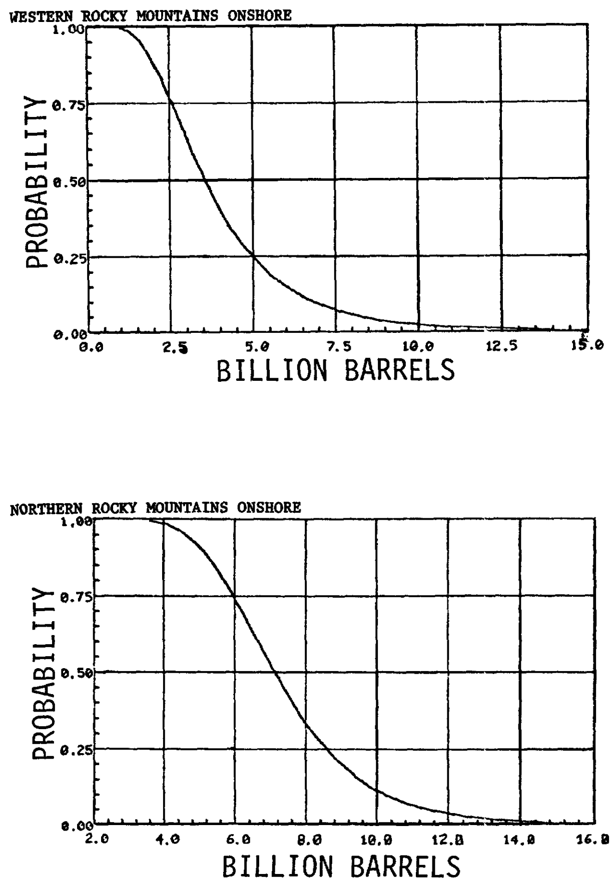


FIGURE 16.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore:
Region 3. Western Rocky Mountains.
Region 4. Northern Rocky Mountains.

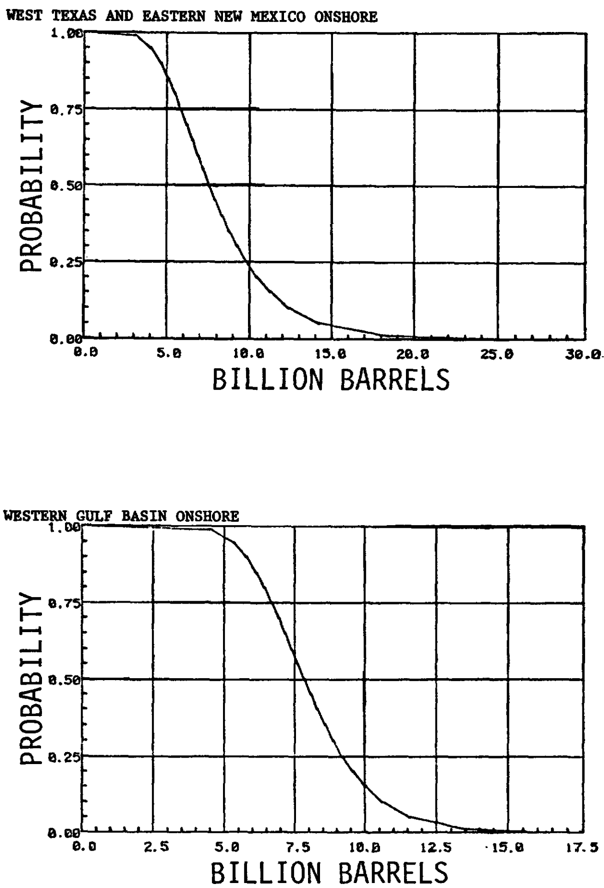


FIGURE 17.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore:
Region 5. West Texas and Eastern New Mexico.
Region 6. Western Gulf Basin.

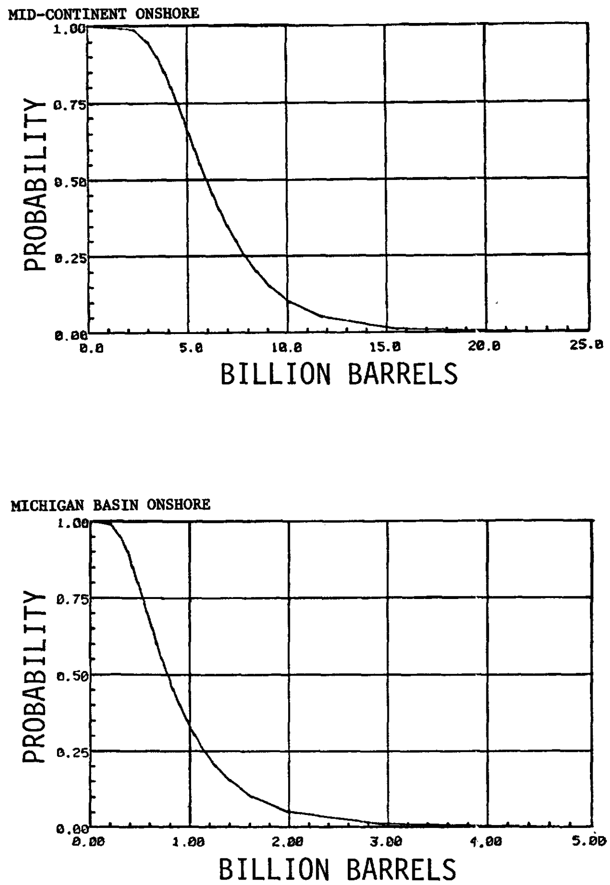


FIGURE 18.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore:
Region 7. Mid-continent.
Region 8. Michigan Basin.

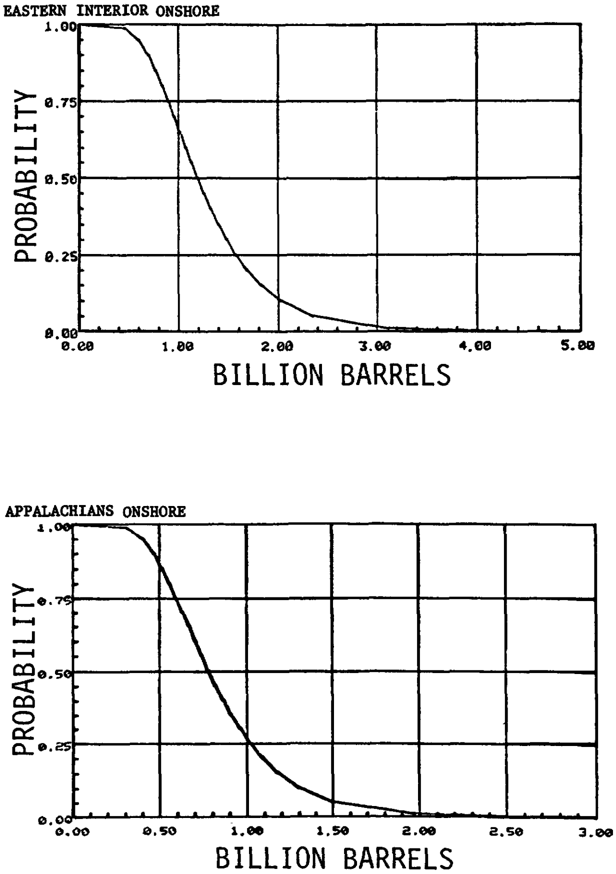


FIGURE 19.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore:
Region 9. Eastern Interior.
Region 10. Appalachians.

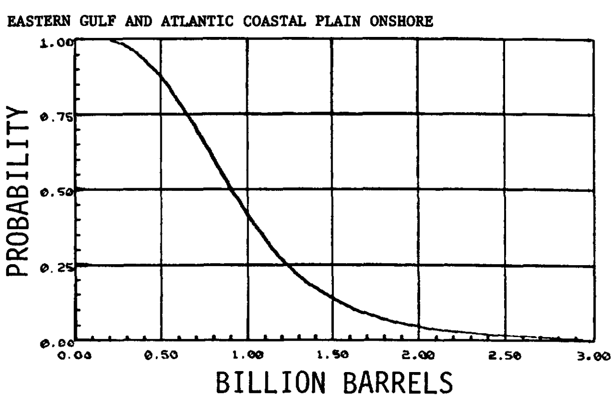


FIGURE 20.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore:
Region 11. Eastern Gulf and Atlantic Coastal Plain.

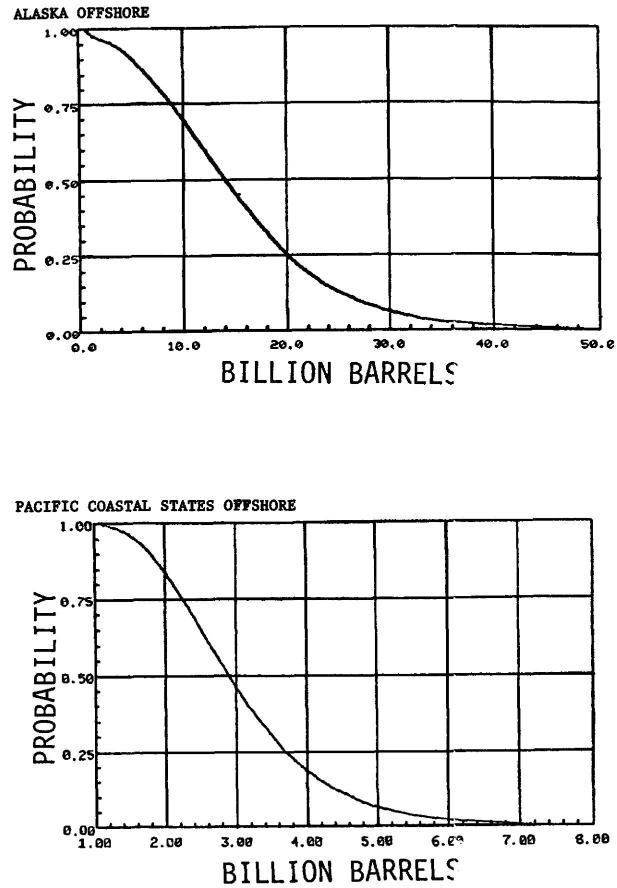


FIGURE 21.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for offshore:
Region 1A. Alaska (0–200 m).
Region 2A. Pacific Coastal States (0–200 m).

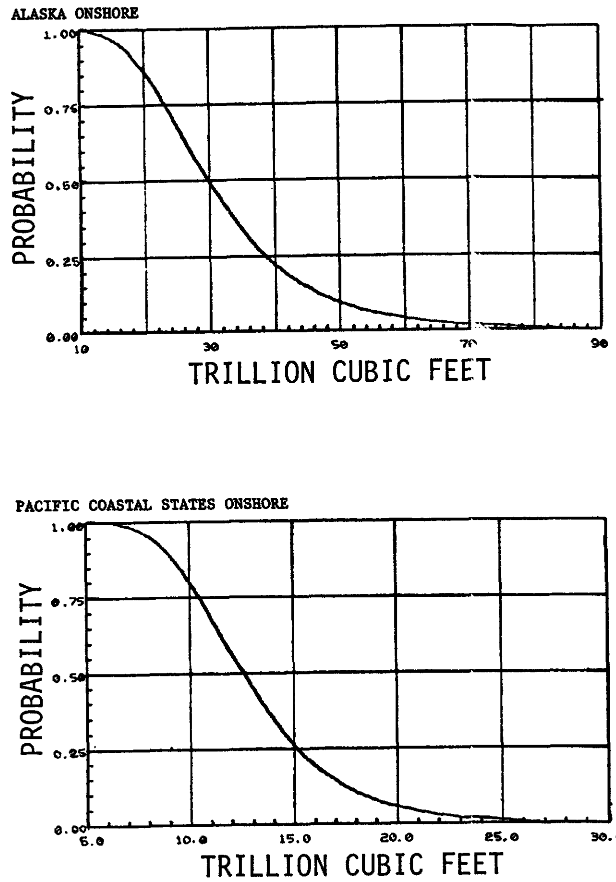


FIGURE 23.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for onshore:
Region 1. Alaska.
Region 2. Pacific Coastal States.

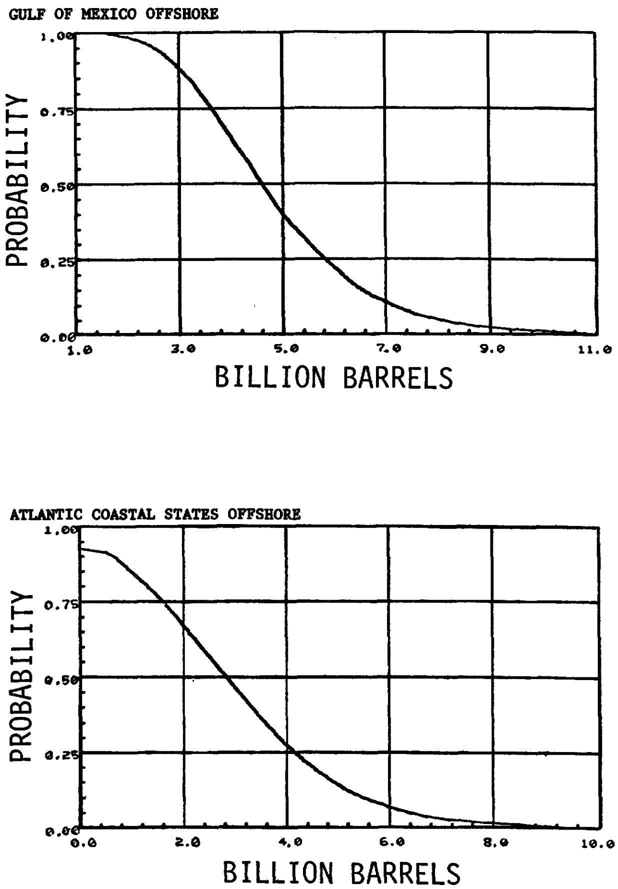
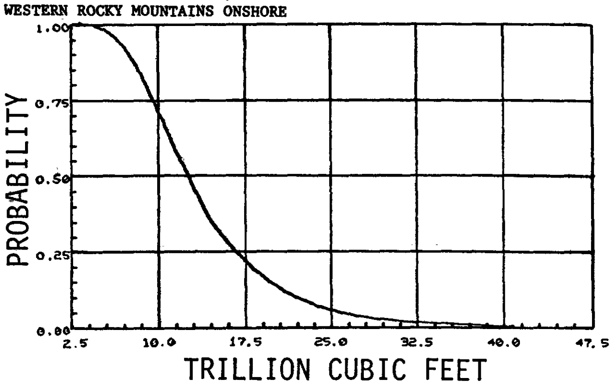


FIGURE 22.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for offshore:
Region 6A. Gulf of Mexico (0–200 m).
Region 11A. Atlantic Coastal States (0–200 m).



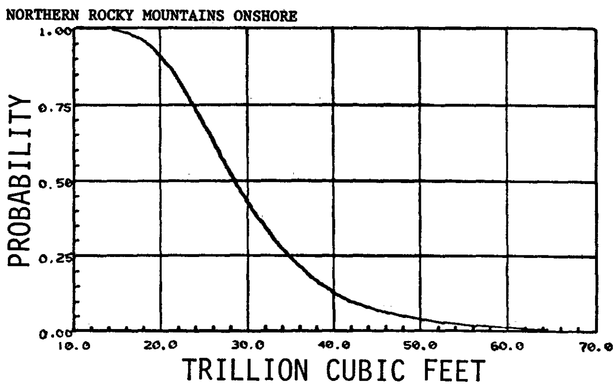
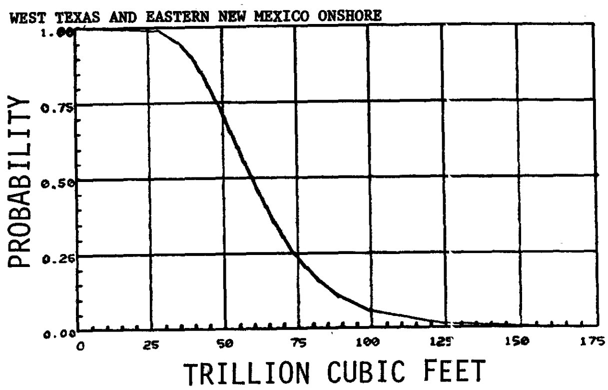


FIGURE 24.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for onshore:
Region 3. Western Rocky Mountains.
Region 4. Northern Rocky Mountains.



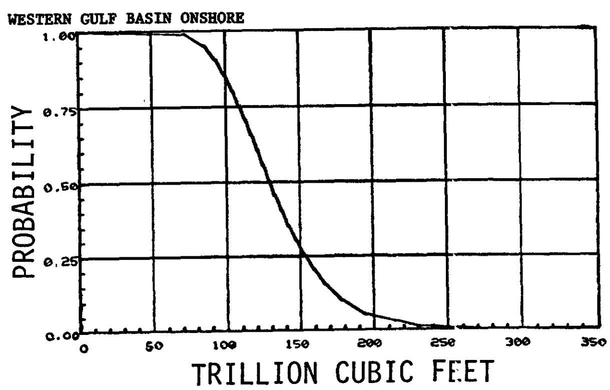


FIGURE 25.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for onshore:
Region 5. West Texas and Eastern New Mexico.
Region 6. Western Gulf Basin.

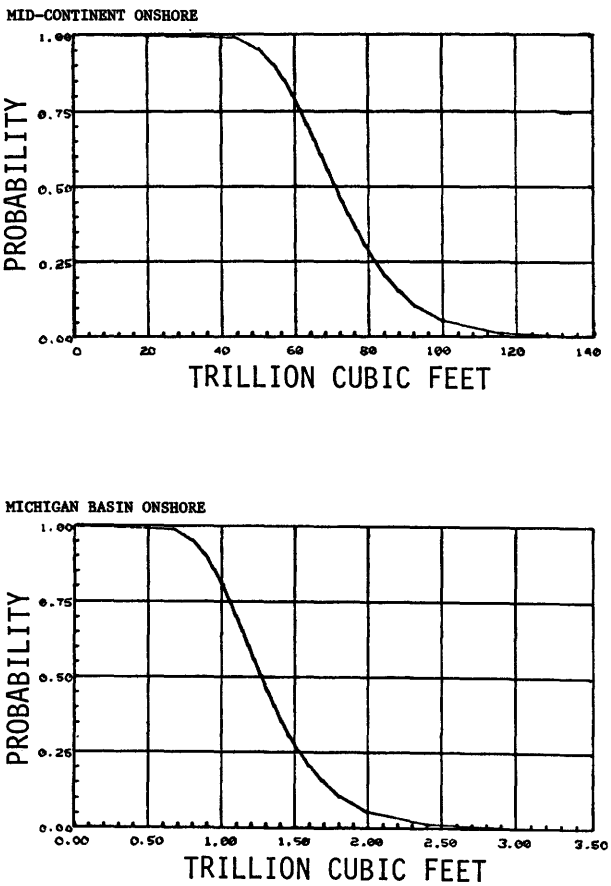


FIGURE 26.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for onshore:
Region 7. Mid-continent.
Region 8. Michigan Basin.

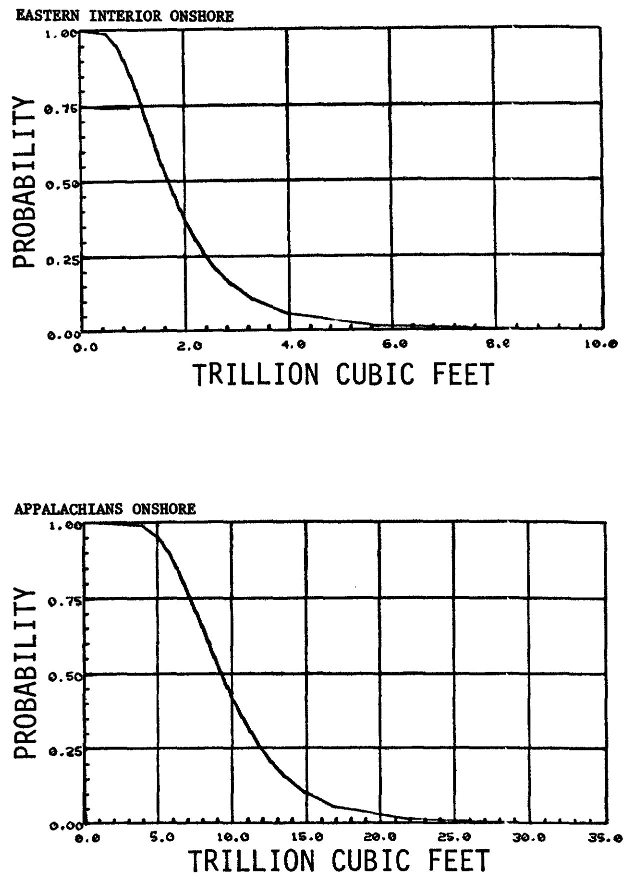


FIGURE 27.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for onshore:
Region 9. Eastern Interior.
Region 10. Appalachians.

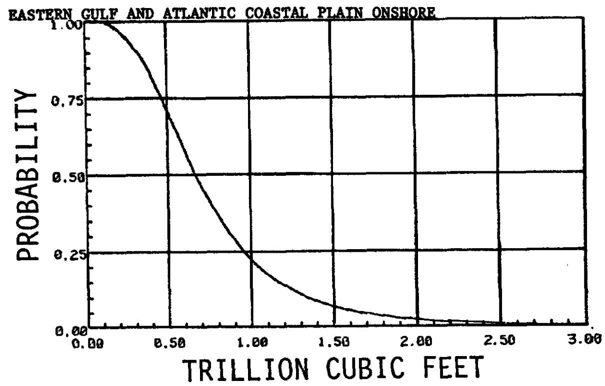


FIGURE 28.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for onshore:
Region 11. Eastern Gulf and Atlantic Coastal Plain.

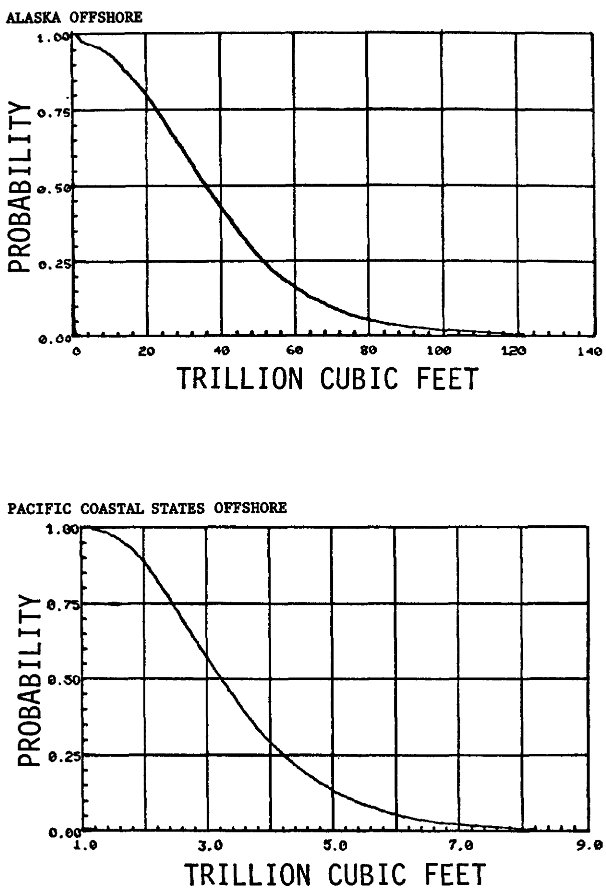


FIGURE 29.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for offshore:
Region 1A. Alaska (0–200 m).
Region 2A. Pacific Coastal States (0–200 m).

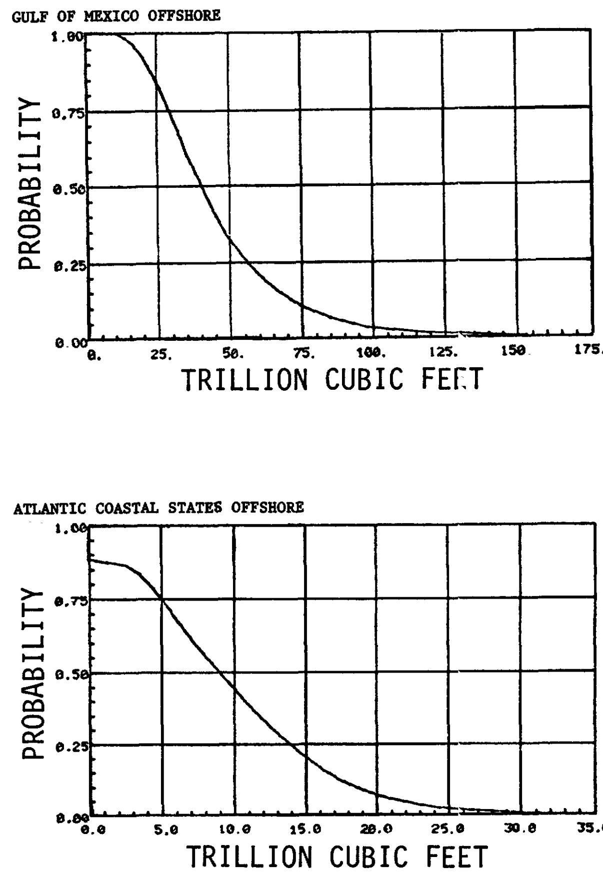


FIGURE 30.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for offshore:
Region 6A. Gulf of Mexico (0–200 m).
Region 11A. Atlantic Coastal States (0–200 m).

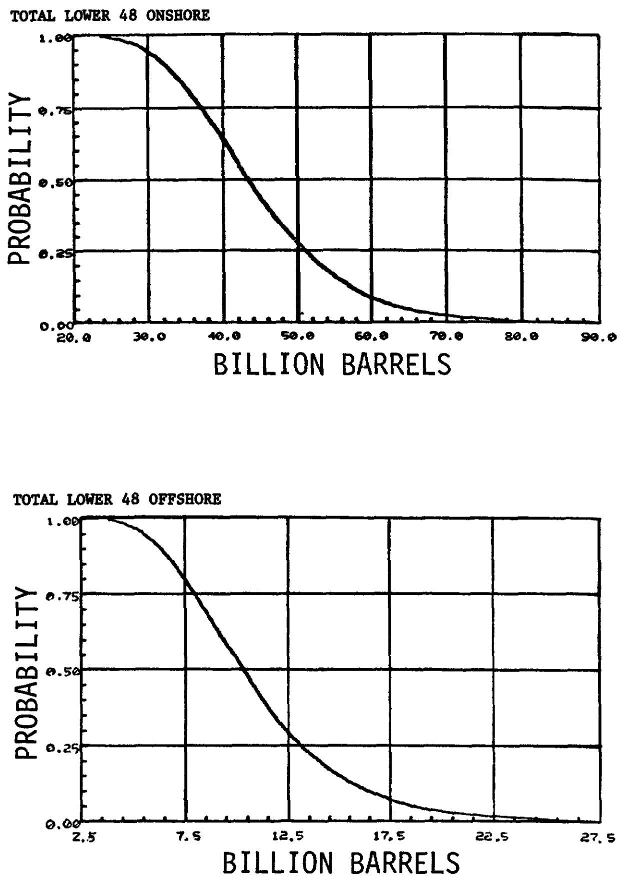


FIGURE 31.—Lognormal probability distribution of the Undiscovered Recoverable *Oil* Resources for onshore and offshore: Total Lower 48 onshore and total Lower 48 offshore (0–200 m).

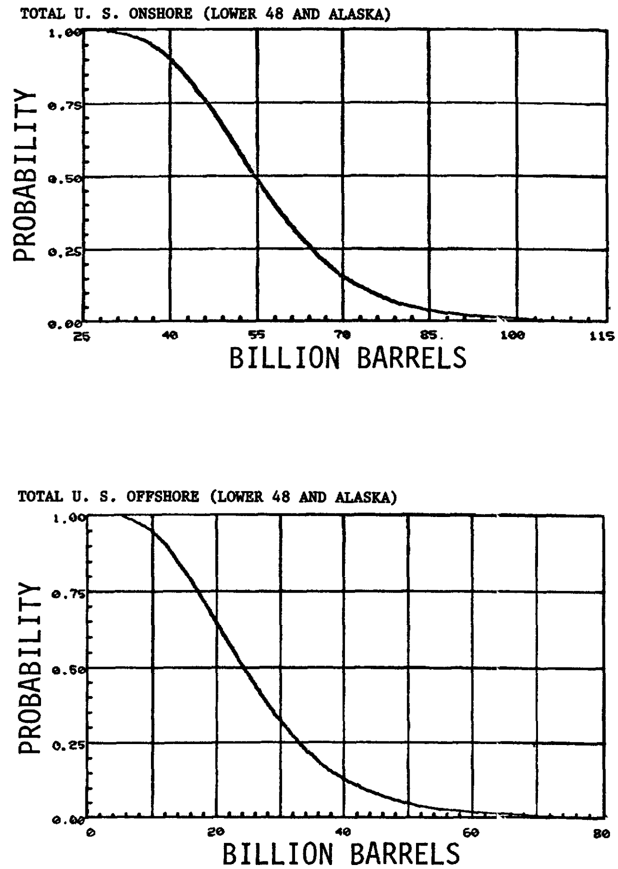


FIGURE 32.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for onshore and offshore: Total onshore United States (Lower 48 and Alaska) and total offshore United States (Lower 48 and Alaska, 0–200 m).

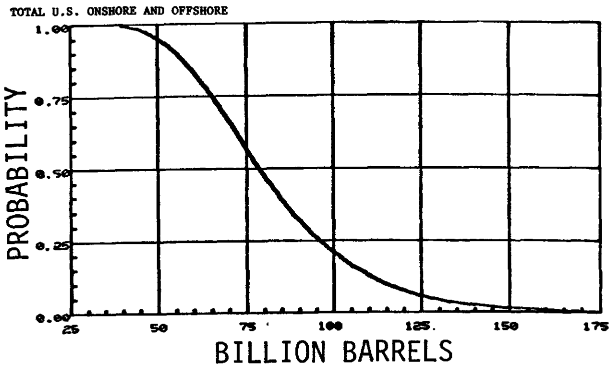
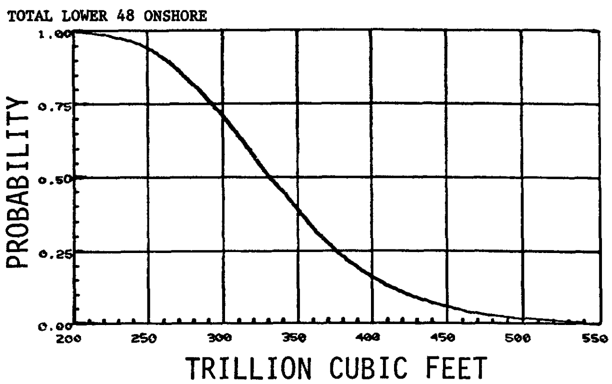


FIGURE 33.—Lognormal probability distributions of the Undiscovered Recoverable *Oil* Resources for total United States, onshore and offshore (0–200 m).



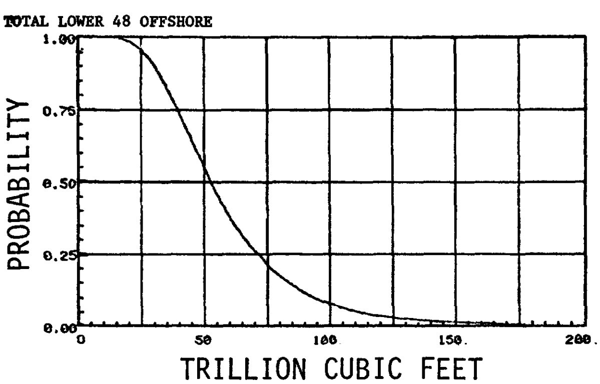
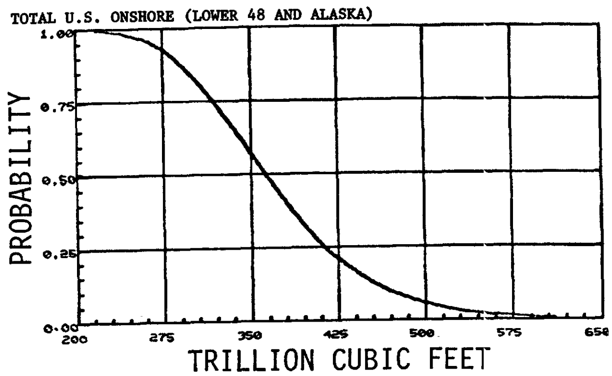


FIGURE 34.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for total Lower 48 onshore and total Lower 48 offshore (0–200 m).



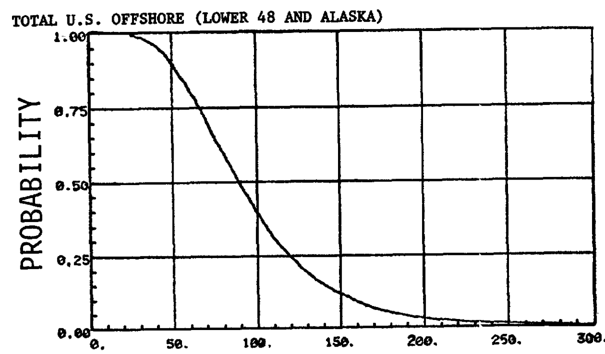


FIGURE 35.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for total onshore United States (Lower 48 and Alaska) and the total offshore United States (Lower 48 and Alaska, 0–200 m).

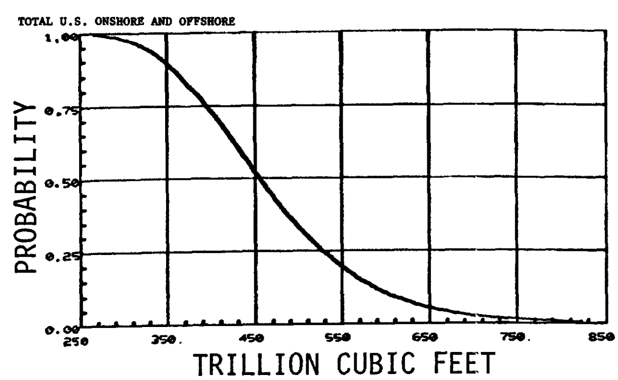


FIGURE 36.—Lognormal probability distributions of the Undiscovered Recoverable *Gas* Resources for total United States, onshore and offshore (0–200 m).

RESULTS—UNDISCOVERED RECOVERABLE NATURAL GAS LIQUIDS RESOURCES

Table 6 summarizes the results for undiscovered recoverable resource estimates of natural gas liquids in the United States derived from historical ratios based upon natural gas cumulative production.

The total undiscovered recoverable resources of NGL, calculated by applying different regional factors to the statistical mean estimates for gas, are 15.8 billion barrels. If the national average (33 barrels NGL per million cubic feet of gas) is applied, the resources are calculated to be 16.0 billion barrels.

Total U.S. NGL cumulative production to the end of 1974 was 15.73 billion barrels; measured reserves were 6.35 billion barrels; inferred reserves, estimated at 6 billion barrels; and the range for undiscovered recoverable resources, based on the calculated NGL/natural gas ratio is 11 to 22 billion barrels (Table 1, p. 4).

COMPARISON OF HYDROCARBON RESOURCE ESTIMATES IN THE UNITED STATES

There have been many past estimates of U.S. oil and gas resources. The many possible parameters which affect resource figures have not always been taken into consideration when different estimates were compared. Terminology has often been inadequately defined, and figures have been compared without ascertaining whether they were comparable. Some examples are: inclusion or deletion of important regions such as Alaska; varying offshore boundaries as determined by different water depths; inclusion or exclusion of natural gas liquids; and inclusion or exclusion of inferred (probable) reserves.

Figures 37 and 38 summarize and compare some of these estimates.

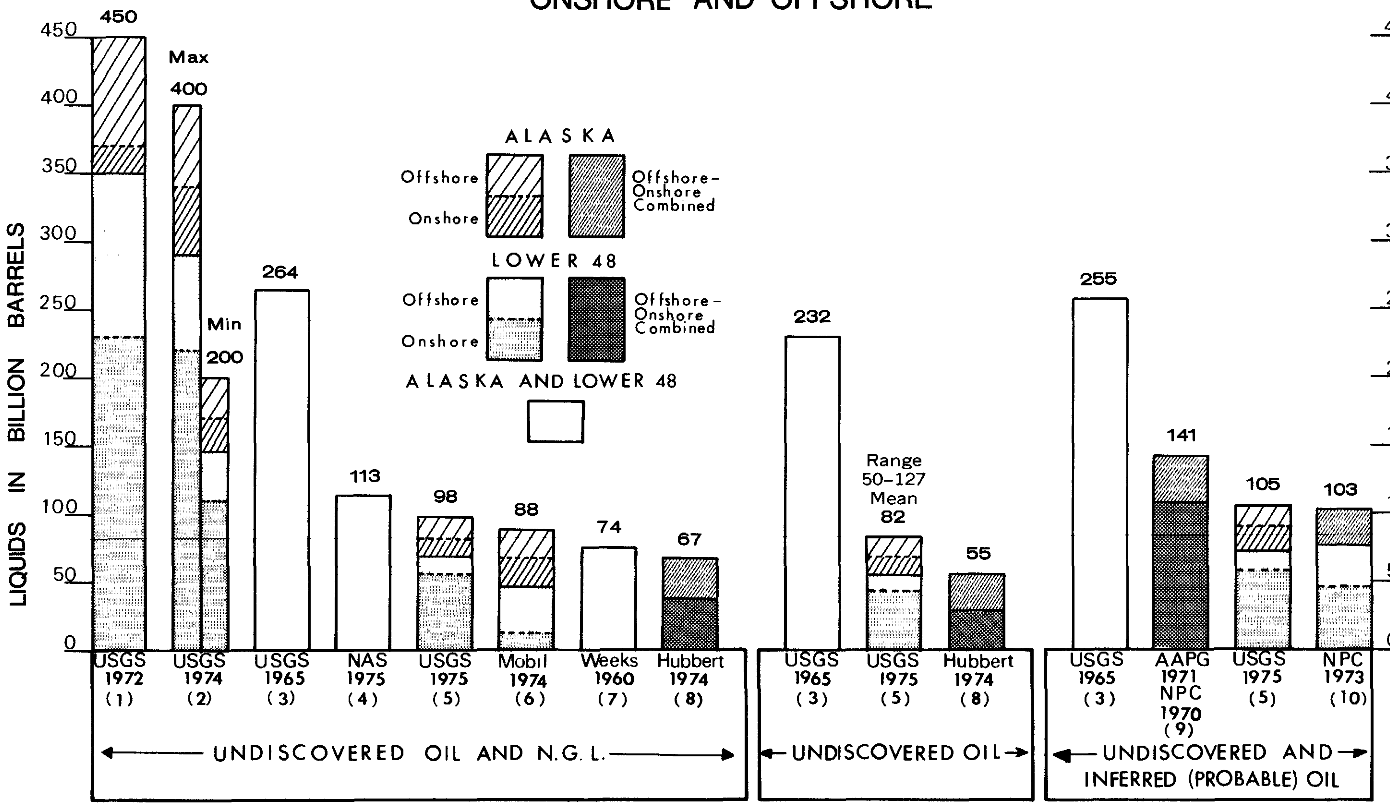
The first group of estimates in figure 37 depicts only those that specifically include total undiscovered recoverable liquid hydrocarbons

TABLE 6.—*Estimates of undiscovered recoverable resources for natural gas liquids in the United States*

Region	NGL/Gas Ratio bbls/MMCF	Undiscovered Recoverable Natural Gas-Statistical Mean (in trillions of cu ft)	Undiscovered Recoverable NGL (in billions of bbls)
		ONSHORE	
1. Alaska	[2] 33	32	1.1
2. Pacific Coastal States	41	13	0.5
3. Western Rocky Mountains[1] 4. Northern Rocky Mountains[1]	26	43	1.1
5. West Texas and Eastern New Mexico	50	70	3.5
6. Western Gulf Basin	33	133	4.4
7. Mid-Continent	31	72	2.2
8. Michigan Basin	27	1	-
9. Eastern Interior	[2] 33	2	0.1
10. Appalachians	8	10	0.1
11. Eastern Gulf and Atlantic Coastal Plain	[2] 33	1	-
Total Lower 48 Onshore		345	11.9
Total Onshore United States		377	13.0
		OFFSHORE (0-200 metres)	
1A. Alaska	[3] 25	44	1.1
2A. Pacific Coastal States	41	3	0.1
6A. Gulf of Mexico	25	50	1.3
11A. Atlantic Coastal States	[3] 25	10	0.3
Total Lower 48 Offshore		63	1.7
Total Offshore United States		107	2.8
Total United States	33	484	15.8

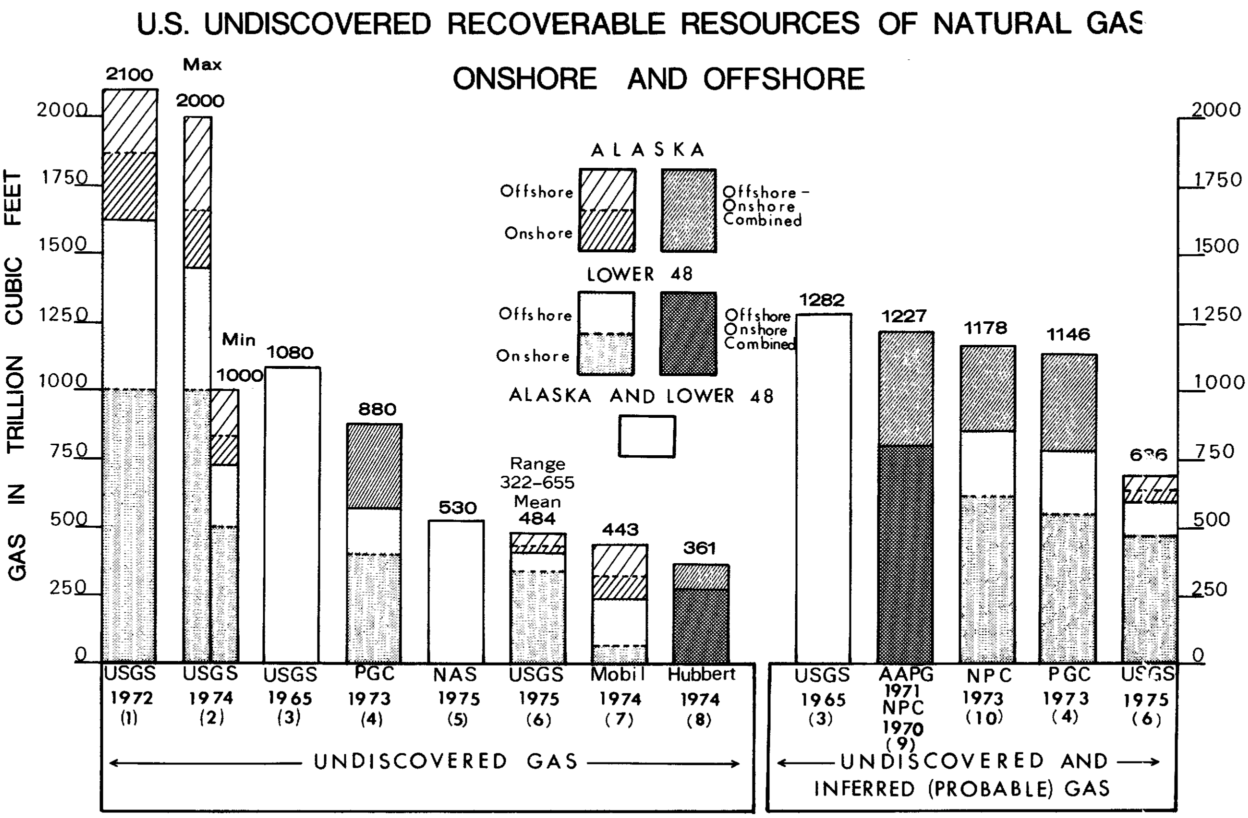
[1] Regions 3 and 4 were treated together because of data availability.
[2] Ratio assumed to be national average.
[3] Ratio assumed to be offshore average.

U.S. UNDISCOVERED RECOVERABLE RESOURCES OF LIQUID HYDROCARBONS ONSHORE AND OFFSHORE



(1) Theobald and others, U.S. Geol. Survey Circ 650, 1972. Includes water depth to 2,500 m (8,200 ft).
(2) U.S. Geol. Survey News Release, March 26, 1974. Includes water depth to 200 m (660 ft).
(3) Hendricks, U.S. Geol. Survey Circ. 522, 1965. Adjusted through 1974. Includes water depth to 200 m (660 ft).
(4) Nat'l. Academy of Sciences, "Mineral Resources and the Environment," 1975. (See National Research Council). Water depth not indicated.
(5) U.S. Geol. Survey "Mean", Oil and Gas Branch Resource Appraisal Group, 1975. Includes water depth to 200 m (660 ft).
(6) Mobil Oil Corp., Expected Value: Science, 12 July 1974. (See Gillette). Includes water depth to 1,830 m (6,000 ft).
(7) Weeks, L.G., Geotimes, July-Aug., 1960. Adjusted through 1974. Water depth not indicated.
(8) Hubbert, Senate Committee Report, 1974. Includes water depth to 200 m (660 ft).
(9) Am. Assoc. Petroleum Geologists Mem. 15, 1971. Also National Petroleum Council, "Future petroleum provinces of the United States," 1970. Some areas are excluded from this estimate. Includes water depth to 2,500 m (8,200 ft).
(10) National Petroleum Council, "U.S. Energy outlook -- oil and gas availability," 1973. Includes water depth to 2,500 m (8,200 ft).

FIGURE 37.—Comparative estimates of oil resources in the United States.



(1) Theobald and others, U.S. Geol. Survey Circ. 650, 1972. Includes water depth to 2,500 m (8,200 ft).
(2) U.S. Geol. Survey News Release, March 26, 1974. Includes water depth to 200 m (660 ft).
(3) Hendricks, U.S. Geol. Survey Circ. 522, 1965. Adjusted through 1974. Includes water depth to 200 m (660 ft).
(4) Potential Gas Committee, "Potential supply of natural gas in the United States," 1973. Includes water depth to 460 m (1,500 ft).
(5) Nat'l. Academy of Sciences, "Mineral Resources and the Environment," 1975. (See National Research Council). Water depth not indicated.
(6) U.S. Geol. Survey "Mean", Oil and Gas Branch Resource Appraisal Group, 1975. Includes water depth to 200 m (660 ft).
(7) Mobil Oil Corp., Expected Value: Science, 12 July 1974. (See Gillette). Includes water depth to 1,830 m (6,000 ft).
(8) Hubbert, Senate Committee Report, 1974. Includes water depth to 200 m (660 ft).
(9) Am. Assoc. Petroleum Geologists Mem. 15, 1971. Also National Petroleum Council, "Future petroleum provinces of the United States," 1970. Some areas are excluded from this estimate. Includes water depth to 2,500 m (8,200 ft).
(10) National Petroleum Council, "U.S. energy outlook -- oil and gas availability," 1973. Includes water depth to 2,500 m (8,200 ft).

Figure 38.—Comparative estimates of natural gas resources in the United States.

(crude oil plus natural gas liquids); the second group includes estimates for crude oil only; the third group depicts undiscovered recoverable resources of crude oil plus inferred (probable) reserves of crude oil.

Figure 38 shows the first group of estimates for undiscovered recoverable natural gas only; the second group includes inferred (probable) reserves.

All the estimates shown in figures 37 and 38 include at least the Continental Shelves to 200 metres water depth. Some estimates include offshore areas beyond 200 metres, as indicated.

Where possible, an attempt was made to subdivide the estimates into conterminous States (Lower 48) and Alaska, with a further breakdown into onshore and offshore.

Because the estimators reported their numbers with such a variability of parameters, the following explanations are provided for comparing the various calculated estimates:

Hubbert, M. King, 1974.—The undiscovered oil and gas resources for the conterminous United States (29 billion barrels of oil and 281 trillion cubic feet of gas) are shown in the text and graphs as of 1972 (Hubbert, p. 123, 125, 145, 146). The figures for Alaska were derived by applying Hubbert's factor (40 percent) for the degree of advancement of petroleum and natural gas discovery in Alaska to the ultimate amount to be produced (43 billion barrels oil and 134 trillion cubic feet; p. 153, 154), yielding 26 billion barrels oil and 80 trillion cubic feet of gas. NGL's were derived by application of the factor of 30,000 cubic feet gas/barrel of NGL (Hubbert, p. 151, 154) to undiscovered gas, yielding 9 billion barrels NGL for the conterminous United States and 3 billion barrels NGL for Alaska.

Hendricks, T. A., U.S. Geological Survey, 1965.—Cumulative production, proved remaining reserves, indicated reserves, and calculated inferred reserves, as of the end of 1974, were subtracted from Hendricks' total economically recoverable oil, natural gas, and natural gas liquids.

National Petroleum Council, 1970; American Association of Petroleum Geologists, 1971.—The total undiscovered recoverable *oil* resources reported (table 3, p. 24, Memoir 15) are the sum of the "possible" and "probable" for all regions and the "speculative" only for region 11 (Eastern Gulf and Atlantic Coast Plain, onshore and offshore). The total undiscovered recoverable *gas* resources are the sum of "possible," "probable," and "speculative" for all regions. The figures do not represent the estimated potential of the entire United States. Some of the areas excluded from the studies were the offshore of Alaska outside of Cook Inlet and Bristol Bay, the onshore and offshore of Washington and Oregon, and the offshore of central and northern California. Therefore these estimates may be understated in comparison with other estimates for the entire United States.

National Petroleum Council, 1973.—Remaining discoverable oil-in-place was reported. The amounts of undiscovered recoverable oil shown here were derived by applying primary recovery factors, as reported by the National Petroleum Council for each region, to their remaining discoverable oil-in-place numbers. The National Petroleum Council reports as remaining discoverable oil-in-place, the sum of probable, possible, and half of the speculative categories.

Weeks, L. G., 1960.—Cumulative production, proved remaining reserves, indicated reserves, and calculated inferred reserves at the end of 1974 were subtracted from Weeks' ultimate resources of liquid petroleum.

CONCLUSIONS

The oil and gas resource assessments presented in this report are the product of a careful analysis of a large quantity of fundamental data by many highly qualified geologists. The "new approach" used is in reality a combination of many individual approaches that have been used by previous estimators, standardized, and documented for public inspection. Sufficient data have been collected and analyzed to provide a well-founded, balanced appraisal of U.S. oil and natural gas resources; the results should be regarded as a first attempt to apply new methods to available information. These resource estimates are subject to revision as methodology improves, better data are acquired, technology changes, changing economic conditions are taken into account, and as deepwater areas are incorporated into the appraisal.

The primary purpose of this study was to estimate the amount of oil and gas available for discovery and recovery under conditions representing a continuation of historical trends of technology and economics; no attempt has been made to predict how much will be discovered, nor when discoveries will be made. The uncertainties involved are emphasized by reporting undiscovered recoverable resource estimates in terms of ranges of values, representing on the one hand a 19 in 20 chance that there is more than the low value and on the other hand, a 1 in 20 chance that there is at least as much as the high value. Thus, the current appraisals indicate that the estimated statisical mean of undiscovered recoverable resources of crude oil in the United States, onshore and offshore, amounts to 82 billion barrels, but this value lies within a range of 50 to 127 billion barrels. The corresponding figures for gas are: a statistical mean of 484 trillion cubic feet, within a range of

322 to 655 trillion cubic feet. In each case the mean value of the undiscovered recoverable quantity is on the order of one-half the amount which has been identified and produced to date (tables 4 and 5). The results also suggest that nearly one-half of the undiscovered recoverable oil resources and more than one-quarter of the undiscovered recoverable gas resources may occur in offshore regions of the United States and in the onshore frontier provinces of the State of Alaska. It is important to note that these resources are located in regions of difficult and costly operations—particularly in the hostile physical environment of the Arctic—and require long lead times for exploration and development.

The Resource Appraisal Group plans to continue development of an oil and gas resource appraisal system within the U.S. Geological Survey. A great quantity of geological and related data is available which still needs to be analyzed and integrated into the system. It is anticipated that activities will be focused on updating and adding critical information not only through our own efforts but by coordination with other interested groups. Special projects planned include such items as field size distribution studies, petroleum zone studies, development of penetration maps and cross sections to show locations and results of wells drilled, appraisal of deep-water potential, and acquisition and development of data banks and data systems. Economic studies also are needed and can be integrated into the system. As new data, new interpretations, and new procedures become available, the current estimates will be refined and revised.

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APPENDIX

54

RAG Province Number ____
AAPG Region Number X 8
Completion Date DEC. 18, 1974

EXPERIMENTAL EXPERIMENTAL

REVISED SHORT FORM FOR RESOURCE APPRAISAL AND EVALUATION BY GEOLOGIC PROVINCES

*I. IDENTITY AND LOCATION OF GEOLOGIC PROVINCE

*A. Name of Province or Basin(s): MICHIGAN BASIN

B. Geographic Location:

1. Country: U.S.; ALL OF STATE OF MICHIGAN; PARTS OF WISCONSIN, N. INDIANA AND NW OHIO; NE ILLINOIS

2. Location:

Latitude between parallels	N or S	N	4	1.	0
	and N or S	N	4	6.	5
Longitude between meridians	E or W	W	8	2.	0
	and E or W	W	8	9.	0

	Yes	No
Onshore:	X	
Offshore:	X	

C. Name of the author(s) of the form: B. M. MILLER

D. Date of completion of the form: DEC. / 15 / 1974

*Items preceded by an asterisk are explained in instruction sheets.

December 4, 1974

*E. Indicate the level or degree of knowledge concerning this province as a whole:

	Yes	No	
1. Surface geologic studies	X		
2. Drilling stages:			
a. No drilling (no seismic)			
b. No drilling (w/seismic)			
c. Early stage (immaturely explored)	X		(LATE SILURIAN AND ORDOVICIAN)
d. Intermediate stage (fairly well explored)	X		(MIDDLE AND LOWER DEV. AND UPPER SIL.)
e. Late stage (maturely explored)	X		(PENNSYLVANIAN, MISSISSIPPIAN, AND UPPER DEVONIAN)
3. Province well-explored to basement depths:			
a. Drilling only	MINOR		
b. Drilling and seismic	MINOR		
c. Seismic only	PROBABLE-BUT UNKNOWN		

*II. BASIC GEOLOGY BY PROVINCE

*A. Province geometry:

*1. Configuration of province: FAIRLY EQUIDIMENSIONAL (1:1)

*2. Area of province:

	Area(square mile)	Percent explored	Percent productive	% Area Underwater
Total Area of Sedimentary Rock Province:	122,000	65 %	≅ 25 - 35 %	≅ 15 - 20 %
Area with maximum depths to basement of:				
a. less than 5,000 feet	≅ 73,200	≅ 20 %	≅ 5 - 10 %	≅ 100 % of the area underwater
b. 5,000 to 10,000 feet	≅ 36,600	≅ 15 %	≅ 20 - 25 %	
c. 10,000 to 15,000 feet	≅ 12,200	< 1 %	0	
d. 15,000 to 20,000 feet				
e. 20,000 to 30,000 feet				
f. greater than 30,000 feet				
TOTAL	(122,000)			

NOTE: a through f should not exceed total area of province

*3. Thickness of sedimentary rock to basement:

	Minimum thickness	Average thickness	Maximum thickness
Total province:	0 (outcrops along flanks of basin)	4674'	14,000 - 15,000

*4. Estimated volume of sedimentary rock in total province: 108,000 cubic miles.

a. Estimate percent of rock volume in province that is:

(1) Drilled: ≅ 60 % %

(2) Explored. (by seismic, etc.): > 75 % %

*B. Geologic Age Relationships:

1. Give the range in age (by geologic periods) of the preserved sedimentary rock section:

a. From CAMBRIAN ~~to~~ THRU JURASSIC + PLEISTOCENE. (PREDOMINANTLY PALEOZOIC)

b. Missing sections: TRIASSIC THRU LOWER PLEISTOCENE

c. Age of basement: PRECAMBRIAN ; Lithology: IGNEOUS AND METAMORPHICS

2. Age of major tectonic episodes or orogenies affecting the sedimentary basin:

a. U. SILURIAN

b. DEVONIAN - 2 TO 3 PERIODS THRU OUT

c. LOWER AND MIDDLE ORDOVICIAN

d. ________

e. Is there evidence of recurrent structural growth? ✓ Yes ____ No

3. Age and type of major faulting:

Age	Type of faulting	Indicate whether faulting is related to: Production	Prospective Production	Not Related
a. DEVONIAN	NORMAL TO BASEMENT			NOT KNOWN TO BE
b. ORDOVICIAN (?)	GRABEN - NARROW AND LONG	✓ (SEVERAL FIELDS)		
c.				

*4. Age, maximum gross thickness and lithology of sedimentary rock of major producing horizons and/or prospective horizons:

Age	Maximum Gross Thickness	EST. VOL. CU. MI.	Lithology	Indicate: Productive	or Prospective
a. DEVONIAN	≅ 3655	7,300	CARBONATE	✓	
b. ORDOVICIAN	≅ 1360	5,000	CARBONATE	✓	
c. SILURIAN	≅ 1130	8,500	CARBONATE	✓	
d. MISSISSIPPIAN	≅ 760	3513	SANDSTONE	✓	
e. ORD. - CAMBRIAN	≅ 2300	16,000	SANDSTONE		✓
f.					
g.					

5. Time of hydrocarbon generation: PROBABLY ORDOVICIAN THRU DEVONIAN; POSSIBLY INTO THE MISSISSIPPIAN

*C. Stratigraphy and Lithology:

*1. Most abundant lithologies in the province and estimated percentage by volume of the total province.

Lithology	Marine or non-marine	Percent Volume
a. CARBONATE	MARINE	47 %
b. SANDSTONE	PRIMARILY MARINE - SOME NON-MARINE	23 %
c. SHALE	MARINE	18 %
d. EVAPORITES	MARINE	12 %

2. Ratio of marine to non-marine sedimentary rocks in the basin (by volume): ≅ 10 : 1

*3. Major regional unconformities: Number ≅ 12

Age	Magnitude
a. MISSISSIPPIAN-PENNSYLVANIAN	(≅4) WITHIN AND BETWEEN PERIODS
b. LATE SILURIAN AND EARLY DEVONIAN	3 WITHIN AND ONE BETWEEN PERIODS
c. DEVONIAN	2 OR 3 WITHIN PERIOD
d. CAMBRIAN-ORDOVICIAN	≅ 3 WITHIN AND ONE BETWEEN PERIODS
LATE PERMIAN	TRUNCATES MORE THAN ONE ERA.

4. Presence of exceptional geologic features; depositional or structural (such as reefs, deltas, salt domes or diapirs, strat pinchouts, etc.)

Types	Geologic Age	Associated Lithologies
a. REEFS	SILURIAN AND DEVONIAN	CARBONATES
b. SALT PINCHOUTS AND EVAP.	SILURIAN	EVAPORITES – RELATED TO CARBONATES
c. DOLOMITIZED ZONES	SILURIAN AND DEVONIAN	CARBONATES (REPLACEMENT DOLOMITES WITHIN LIMESTONES)
d.		
e.		

*5. The presence of known or potential stratigraphic traps:

Trap Type	Geologic Age	Indicate whether currently: Productive	Non-productive	Prospective
a. DOLOMITIZED CARBONATES	DEVONIAN ORDOVICIAN SILURIAN	✓	SOME ARE	✓
b.				
c. SAND PINCHOUTS	MISSISSIPPIAN	✓		✓ (MOSTLY GAS PRODUCTION)
d. REEFS (STRAT. - STRUCT.)	SILURIAN AND DEVONIAN	✓		✓
e.				

*6. The presence of known or potential structural traps:

Trap Type	Geologic Age of Origin	Productive	Non-productive	Prospective
		Indicate whether currently:		
a. ANTICLINAL	DEVONIAN	✓		✓
b. GRABEN FAULTING AND	} ORDOVICIAN OR	✓ (SEVERAL FIELDS - 1 IS LARGEST IN BASIN)		
c. ALTERED CARBONATES	} SILURIAN			
d.				
e.				

7. Evaporites and their relationships to major reservoirs:

	Present (Check one)	Act as seals to major reservoirs: Yes	No
a. No evaporites in section			
b. Evaporites above potential reservoirs			
c. Evaporites below potential reservoirs			
d. Evaporites above, below and within potential sections	✓	✓ (IN MINOR CASES)	MAJORITY

*D. Structural aspects:

*1. Type of basin (or basins) included within province (use Basin Classification in instructions):

INTERIOR BASIN; CRATON CENTER

61

2. Structural basin geometry:

	(Check one)
a. Asymmetrical	
b. Symmetrical--gentle slopes	✓ (NEARLY SO)
c. Symmetrical--steep slopes	
d. Information unavailable	

3. Presence of regional structural or erosional highs:

	Yes	No	Estimated Number
a. Known highs	✓		MANY
b. Suspected highs	✓		MAYBE RELATED TO BASEMENT

c. Characteristics of known regional highs:

Probable Nature or Origin	General Geometry	Estimated Magnitude (in feet)(i.e. closure, relief)
ANTICLINAL	NEARLY SYMMETRICAL	20-50 FT.

*E. Presence of Regional Producing Trends:

1. Number and gross area of major producing trends:

	Number			ROUGH ESTIMATES		Type of Trend:		
	Oil	Gas	Combined Oil and Gas	Gross Area (square miles)	Age of major reservoirs	Structural	Strat	Combination
a.			✓	21,380 SQ. MI.	DEVONIAN	✓	✓ (REEF)	✓
b.		✓		4270 SQ. MI.	MISS. AND PENN.		✓	
c.			✓	6405 SQ. MI.	SILURIAN			✓
d.			✓	6400 SQ. MI.	ORDOVICIAN			✓

F. Presence of current non-producible hydrocarbons in the province:

1. Presence of natural oil and gas seeps:

	Extent			
	None	Minor	Significant	Abundant
a. Oil		✓		
b. Gas		✓		
c. NGL				
d. Combinations of above				

2. Indicate whether the following are known to occur within the province:

	Yes	No	Unknown
a. Heavy oils (API gravity less than 12)		✓	
b. Tar sands		✓	
c. Oil shales		✓	
d. Tight gas sands			? (PROBABLE)
e. Other bitumen or solid hydrocarbons		✓	
f. Significant oil and gas shows	✓		

*III. FIELD AND RESERVOIR INFORMATION BY PROVINCE

*A. Producing reservoirs in order of importance of gross OIL potentials and/or prospective reservoirs:

Order	Geologic Age	Principal horizon or pay zone	Lithology	Maximum thickness of reservoir EST. THICKNESS	VOL. CU. MI.	Areal extent within province % or square miles	Indicate Productive or Prospective	THRU '67 Cumulative Production (BBLS)	Measured and/or Indicated Reserves (BBLS)
1	DEV.	DUNDEE-ROGERS CITY	CARBONATE	≅ 20'	1000	≅ 10%	PRODUCTIVE	325 mm	
2	DEV.	TRAVERSE	CARBONATE	≅ 125'	2000	≅ 20%	PRODUCTIVE	95 mm	
3	ORD.	TRENTON-BLACK RIVER	CARBONATE	≅ 60'	5000	≅ 6%	PRODUCTIVE	77 mm	
4	DEV.	DETROIT RIVER	CARBONATE	≅ 210'	4300	≅ 8%	PRODUCTIVE	43 mm	
5	SIL.	SALINA-NIAGARAN	CARBONATE	50'-60'	5500	≅ 5%	PRODUCTIVE	8 mm	
6	MISS.	BEREA	SANDSTONE	≅ 32'	?	≅ 3%	PRODUCTIVE	2 mm	
7	MISS.	MARSHELL	SANDSTONE	≅ 77'	?	≅ 3%	PRODUCTIVE	.073 mm	
8	ORD.	SUB.-TRENTON	CARBONATE		16,000	?	PROSPECTIVE	—	

*B. Producing reservoirs in order of importance of gross GAS and NATURAL GAS LIQUID potentials and/or prospective reservoirs:

NO DATA ON NGL

Order	Geologic Age	Principal horizon or pay zone	Lithology	Maximum thickness of reservoir	Areal extent within province % or square miles	Indicate Productive or Prospective	Cumulative Production GAS	Measured and/or Indicated Reserves	Cumulative Production NGL	Measured and/or Indicated Reserves
1	MISS.	STRAY-MARSHALL	SANDSTONE	≅ 60'	≅ 3%	PRODUCTIVE	214 bcf			
2	SIL.	SALINA-NIAGARAN	CARBONATE	≅ 60'	≅ 5%	PRODUCTIVE	165 bcf			
3	ORD.	TRENTON-BLACK RIVER	CARBONATE	≅ 60'	≅ 6%	PRODUCTIVE	86 bcf			
4	DEV.	DUNDEE-REED CITY	CARBONATE	≅ 20'	< 10%	PRODUCTIVE	49 bcf			
5	DEV.	DETROIT RIVER	CARBONATE	≅ 210'	≅ 8%	PRODUCTIVE	46 bcf			
6	MISS.	BEREA	SANDSTONE	16'	≅ 3%	PRODUCTIVE	10 bcf			
7	DEV.	TRAVERSE	CARBONATE	125'	≅ 20%	PRODUCTIVE	9 bcf			
8	DEV.	ANTRIM SHALE	SHALE	≅ 6'	?	PRODUCTIVE	345 MCF			
9	CENOZOIC	GLACIAL DRIFT	TILL	≅ 1'	?	PRODUCTIVE	8 MCF			
10	CAMBRIAN		SANDSTONE	400'-500'	?	PROSPECTIVE	—			

64

*C. Characterization of probable source beds:

Order	Geologic Age	Gross Maximum Thickness EST. "KNOWN"	Gross Maximum Volume Cu. Mi.	Lithology	Estimated Number of beds	Marine	Non-marine	Reasonable Proximity of Reservoir Beds Yes	No
1	DEV.	2000'- 3000'	>5200	MAJOR- CARBONATES MINOR- SHALES	3-4 FORMATIONS	✓		✓	
2	SIL.	2000'	>5000	CARB. - 50 SHALE - 50	5 FORMATIONS	✓		✓	
3	ORD.	1500'	>5400	SHALE - 60 CARB. - 40	3 FORMATIONS	✓		✓	
4									
5	MAY BE ADDITIONAL SOURCE BEDS IN THE MISS. AND DEVONIAN THAT ARE NOT LISTED HERE - BUT INFO. NOT AVAILABLE.								
6									
7									
8 TOTAL PROBABLE			> 15,600 Cu.Mi.						

*D. Characterization of major seals in the stratigraphic section:

Order	Geologic Age	Lithology	Significant Hydrodynamic conditions Yes	No	Seals Continuous	Discontinuous
1	DEV.	CARBONATE	PROBABLY		BOTH (OVER SIGNIFICANT AREAS)	
2	DEV.	MINOR SHALES	PROBABLY		BOTH	
3	SIL.	CARBONATE	PROBABLY		BOTH	
4	SIL.	EVAPORITES	PROBABLY		BOTH	
5	ORD.	SHALE	PROBABLY		BOTH	
6	ORD.	CARB.	PROBABLY		BOTH	
7						
8						

*E. Field size distributions by proven acres or areal extent in square miles:

1. Oil field sizes in the province:

	Proven area: Square miles	Proven area: Acres	Size in Recoverable Reserves (bbls)
a. Average	1.14	728	≅ 5 mill. bbls.
b. Most reasonable minimum	.02	10	< 1 mill. bbls.
c. Most reasonable maximum	18.3	11,700	> 150 mill. bbls.

2. Gas field sizes in the province:

	Proven area: Square mile	Proven area: Acres	Size in Recoverable Reserves (cuft)
a. Average	7.8	≅ 5000	≅ 30 bcf
b. Most reasonable minimum	3.9	≅ 2500	< 6 bcf
c. Most reasonable maximum	15.6	> 10,000	> 200 bcf

*3. Total number of oil and combined oil and gas fields discovered to date:

	MICH.	INDIANA (OIL ONLY)	OHIO (OIL ONLY)
a. fields	344 (JAN. 1/73)	26 FIELDS	11 FIELDS
b. pools	467 (JAN. 1/73)	?	?

*4. Total number of gas fields discovered to date:

	MICH.	INDIANA	OHIO
a. fields	166 (JAN. 1/73)	?	7 FIELDS
b. pools	186 (JAN. 1/73)		?

5. Recovery factor for crude oil in province:

a. Average recovery factor: 31.8 %

b. Most reasonable minimum recovery factor: ≅ 10 %

c. Most reasonable maximum recovery factor: ≅ 45 %

F. Indicate whether hydrodynamic conditions within the province are related to hydrocarbon occurrence: Yes ✓ (PROBABLY) No ________

G. Indicate whether the timing of hydrocarbon migration versus trapping is a major factor to the probable occurrence of oil and gas fields in the province: Yes ________ No ✓ PROBABLY NOT.

Comments: NO DETAILED INFORMATION AVAILABLE.

66

*IV. PRODUCTION, RESERVE AND RESOURCE INFORMATION BY PROVINCE

*A. Cumulative oil and gas production, reserves and resources:

	Crude Oil	Natural Gas Liquids	Natural Gas (Associated +	Non-Associated)
1. Total production	624,136,000		434,476 MILLION CUFT	
2. Measured reserves	81,028,000		1,296,815 MILLION CUFT	
3. Indicated reserves				
4. Inferred reserves				
5. Undiscovered recoverable resources				
6. Estimated original oil-in-place API	2,119,279,000			

B. Exploration and development information:

1. Date of first producing well:

a. Oil 1925 (FIRST SIGNIFICANT WELL) FIRST FIELD DIS. 1886 AND ABO.

b. Gas 1927

2. Date of first producing major field discovery: (LARGER THAN 100 MILL. BBLS.)

a. Oil 1957 \ COMBINATION

b. Gas 1957

3. Date of first well drilled within the province: LATE 1880's

4. Number of exploratory wells within the province at time of first discovery (either oil or gas): ________. ?

5. Number of exploratory wells within the province at time of first major discovery (either oil or gas): ?.

6. Total number of exploratory wells drilled to date: 13,800 (date): 1 / 1 / 73.

7. Total number of development wells drilled to date: 13,349 (date): 1 / 1 / 73.

JAN. 1/73
TOTAL WELLS ALL TIME:
OIL 11,298
GAS 2051
DRY 13,800
TOTAL: 27,149

8. Well density per square mile in province: .223.

9. Oldest beds penetrated in basin to date:

a. CAMBRIAN (PRECAMBRIAN BASEMENT) (geologic age). b. DRILLED 12,996' (JAN 1/73) (depth in feet)
EST. MAX. DEPTH 14,000 - 15,000

10. Deepest beds penetrated in basin to date:

a. ________ (geologic age) b. ________ (depth in feet)

V. RESOURCE ESTIMATES BY PROVINCE

A. Resource estimates that have been cited in the literature and other sources, relating to total hydrocarbons in the province.

	Sources of reference or data	Estimated amounts (bbls or cuft)	Indicate the units reported
1.	MEM. 15 - AAPG: (a)	1.8 BILL. BBLS.	METHOD: VOL. AND YIELD OF 50,000 bbls/cu. mi.
2.	(b)	.680 - 1.215 BILL. BBLS.	METHOD: YIELD/SQ. MI. OF PROVED PRODUCTIVE ACREAGE
3.	(c)	.673 - 1.223 BILL. BBLS.	METHOD: REC./SQ. MI. OF "ADEQUATELY" EXPLORED TERRITORY.
4.			

B. The evaluator's estimate of the resources within the province if different from the above values in A.

Amounts (bbls or cuft.)	Indicate method or source of information used
NEARER TO 1.0 BILL. BBLS. (remaining dis. rec. res.)	USE SMALLER YIELD FIGURES WITH VOL.; ≅ 12,000 bbls/cu. mi.

1. Qualitative Rating (zero, poor, fair, good, etc.): POOR TO FAIR

C. The evaluator's opinion as to the most similar producing (or non-producing) analog basin(s); and/or analog basins or provinces cited in the literature or other sources:

Name of Province or basin	Location	Inicate whether it is presently--			Source of Reference
		Producing	Non-producing	Prospective	
1. W. ALBERTA	ALBERTA, CANADA	✓			AUTHOR - B. MILLER
2. HUDSON BAY BASIN	CENTRAL CANADA			✓ (FAIR TO POOR)	AUTHOR - B. MILLER
3. ILLINOIS BASIN (PORTIONS OF THIS BASIN)	ILLINOIS	✓			MEM. 15/AAPG

FORM #3

Region #8
RAG No.

PROVINCE SUMMARY SHEET

PROVINCE MICHIGAN BASIN

*Stage of Exploration: Early SIL. & ORD. Intermediate DEV. & U.SIL. Late PENN., MISS., U.DEV.
*Area (Mi^2)-----Total Sed. Province: 122,000 % Productive ≅ 25 - 35%
Areas by Depth Units: 5000' ≅ 73,200 5000-10,000' ≅ 36,600
10,000'-15,000' ≅ 12,200 15,000-20,000'
20,000'-30,000' 30,000'

*Thickness of sediments (Ft.): Avg. 4,674 Max. 14,000 - 15,000

*Volume of sediments ($Mi.^3$) 108,000
Total Province:
% Drilled ≅ 60 %
% Explored > 75 %

Stratigraphic Age Range: From CAMBRIAN Through JURASSIC & PLEISTOCENE

*Producing and/or Prospective Horizons
Age: a. SILURIAN b. DEVONIAN c. ORD., ORD.-CAM. d. MISS.
Gross Thickness: ≅4,130 3,655 3,660 760 Total: 12,205

*Dominant Lithology (Total Province)
Type CARBONATE, SANDSTONE, SHALE, EVAPORITES
% of Volume 47% 23% 18% 12%
Ratio, Marine/non-marine ≅ 10:1

Types of Traps
Stratigraphic DOLOMITIZED CARBONATES, SAND PINCHOUTS, REEFS
Structural ANTICLINAL, GRABEN FAULTING AND ALTERED CARBONATES

*Structural Aspects
Type Basin INTERIOR BASIN, CRATON CENTER
Geometry SYMMETRICAL -- GENTLE SLOPES (NEARLY SO)

Indications of Hydrocarbons
Producing Trends MISS. & PENN. - GAS; DEV. TO ORD. - COMBINED OIL & GAS; TOT. GROSS AREA ≅ 38,455 $MI.^2$
Seeps, Tar Sands, etc. OIL & GAS SEEPS - MINOR EXTENT

Probable Source Beds (Age and Lithology) DEV. MAJOR - CARB. MINOR - SHALES, SIL. CARB. - 50 SHALE - 50, ORD. SHALE - 60 CARB. - 40

Major Seals (Age and Lithology) DEV. THROUGH ORD., CARBONATE, EVAPORITES, & SHALE

Field Size Distribution:	Avg.	R.Min.	R.Max.
Oil (mill.bbls):	≅ 5	< 1	> 150
Gas (bcf):	≅ 30	< 6	> 200

Nature of Hydrocarbons:	Avg.	R.Min.	R. Max.
API Gravity			
Sulfur Content			
*Recovery Factor	31.8	≅ 10	≅ 45

*Production, Reserves, & Resources:	Crude Oil	NGL	Nat. Gas
Cum. Production (bill.bbls.;tcf)	624,136,000 MILL.		434,476 MILL. CU FT.
Measured Reserves "	81,028,000 MILL.		1,296,815 MILL. CU FT.
Indicated Reserves "			
Inferred Reserves "			

*Wells Drilled to Date: 27,149 Date: 1 / 1 / 73
Exploratory Wells 13,800 (1/1/73)
Development Wells 13,349 (1/1/73)

*Resource Estimates (Undiscovered--In Billion BBLS or Trillion Cu.Ft.)
Recoverable In Place
Outside Sources (MEM 15) .673 - 1.223 BILL. BBLS., RECOVERABLE UNDISCOVERED RES.
U.S.G.S. Evaluator ≅ 1 BILL. BBLS., RECOVERABLE UNDISCOVERED RES.
Analogs W. ALBERTA, HUDSON BAY BASIN, ILLINOIS BASIN (PORTIONS OF THIS BASIN)
RAG Estimate

*Province Qualitative Rating: Oil GOOD Gas FAIR

Posted by: KURT CARLSON Date 2-13-75 Approved J. Miller Date 2-17-75

* Data most pertinent to resource appraisals. 2/4/75

FORM # 4-A REGION 8

Region #8 MICHIGAN BASIN AREA RAG No.
Province MICHIGAN BASIN AREA
Province Area 122,000 (mi^2) Province Volume: 108,000 (mi^3)

RESOURCE APPRAISAL --PROVINCE ESTIMATE

PRODUCTION AND RESERVES	OIL (Bill. BBLS)			NGL (Bill. BBLS)			GAS (TCF)		
Cumulative Production: 12/73 API →	.627			.011 ← API 12/72			→ .435 12/72		
Identified Reserves:									
Measured Reserves	.072			.025			1.549		
Indicated Reserves									
Inferred Reserves (I/P = 3.19)	≅ .229			≅ .009			≅ .802 (I/P = .518)		
Total (Cumulative & Identified):	.928			.045			2.786		

UNDISCOVERED RESOURCES Resource Appraisal Methods	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL EST. (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
METHOD I--VOLUMETRIC-ANALOG									
Analog 1: / Analog 2:									
Yield Factors: Michigan Basin / Illinois Basin									
Oil: 16,000 / 34,000 1.	5.400	1.728	.800	.108	.0864**	.0414	4.455	3.564	.778
Gas: 25 MM / 20 MM									
Rec. Factors: 32/80/80 2.	11.475	3.672	2.744	.086	.0691**	.0241	2.70	2.16 too	low —
METHOD IV: HENDRICKS' CATEGORIES									
Dis.-Rec. Factors: (25/50/50) Category #: 4	12.200	3.05	2.122	1.220	.610	.565	30.5	15.25	12.464
Category #: 3	30.500	7.625	6.697	2.440	1.220	1.175	61.0	30.50	27.714
							All gas figures too high		Cat. 5 too low
METHOD: (III Productive - Recovery) Procedure			1]						
Yield Factors: Oil: 2.3 MM/Mi² Gas: 4 MM/Mi²	4.294	1.379	.451	.109	.087	.042	3.413	2.730	Too Low
Prod.Area/Unexpl.Area: 229 Mi² / 7,527 Mi²	5.694	1.914	.986	.151	.121	.076	4.733	3.786	1.000
DOCUMENTED RESOURCE APPRAISAL ESTIMATES:	(UNDIS.)								
AAPG, Memoir 15, 1971 Possible	.650	.293 }	1.179						
Probable	.680	.306 }							
All Hydrocarbons Speculative	7.290	.380 }							
National Petroleum Council Estimates, 1973	1.290 undis. - in place —		.413						4.8 (6.00 in-place)
ANOGRE Estimates									
OTHER Method II 2]	5.003 — 6.722	1.601 — 2.151	.673 — 1.223 1]						

2] Hydrocarbons – but mostly oil data

Posted by DT Date 2-20-75 Approved B. Miller Date 12/21/74

1] Range is dependent upon assumption of excluding or including another Albion - Scipio trend.

** Conversion Factor: 32 bbls. NGL / 1 MM Cu.Ft. Gas (Hendricks, 1965)

DOCUMENTATION FOR RESOURCE APPRAISAL METHODS USED ON FORM 4-A

METHOD I
Volumetric - Analog

Analog I

Basin or Province Name: MICHIGAN BASIN (PRODUCTIVE AREAS)

Yield factors used: /Mi^3

OIL 16,000 GAS 33MM NGL PROPORTION

Recovery factors used: 32/80/80

Analog II

Basin or Province Name: ILLINOIS BASIN

Yield factors used:

OIL 34,000 GAS 20MM NGL PROPORTION

Recovery factors used: 32/80/80

METHOD II
Explored Area - Recovery Procedures

Areas Explored:

1. 6,943 Mi^2 PENN.-DEV.
2. 1,232 Mi^2 SIL.
3. 5,608 Mi^2 TRENTON & BLACK RIVER

Areas Unexplored:

1. 6,857 Mi^2 PENN.-DEV.
2. 18,840 Mi^2 SIL.
3. 35,622 Mi^2 TRENTON-BLACK RIVER

Yield per mi^2 of explored areas:

1. 397,315,157 BBLS./Mi^2 PENN.-DEV.
2. 373,333,440 BBLS./Mi^2 SIL.
3. 38,863,602 BBLS./Mi^2 T-BR. (A-S EXCLUDED)

588,796,038 BBLS./Mi^2 (A-S INCLUDED)

METHOD III
Productive Area - Recovery Procedure

Areas Productive (proved areas):

1. 172 Mi^2 PENN.-DEV.
2. 34 Mi^2 SIL.
3. 23 Mi^2 TRENTON-BLACK RIVER

Areas Unexplored:

1. 6,857 Mi^2 PENN.-DEV.
2. 528 Mi^2 SIL.
3. 36-142 Mi^2 T-B.R.

Yield per mi^2 of productive areas:

1. 2,338,963 BBLS./Mi^2 P-D.
2. 718,038 BBLS./Mi^2 SIL.
3. 1,019,908 - 4,030,194 BBLS./Mi^2 T-B.R.

1/ SEE FOOTNOTE - Pg. 4-A

REC. 32/80/80

METHOD IV
Hendricks' Categories

Category # 4

Discovery-Recovery Factors: .25/.50/.50

Modifications: NONE

Category # 3

Discovery-Recovery Factors: .25/.50/.50

Modifications: NONE

AAPG, Memoir 15, 1971: Tables: 10 Pages: 1160

NPC Estimates, 1973: Tables: 99; 292 Pages: 171, 367

ANOGRE Estimates:

Other Published Sources: Date: Pages:

Other Procedures:

DEFINITIONS FOR RESOURCE APPRAISAL METHODS USED ON FORM 4-B

REASONABLE MINIMUM -- That quantity which the estimator associates with a 95% probability that there is at least this amount.

MOST LIKELY -- That quantity which the estimator associates with the highest probability (of occurrence) that there will be this amount.

REASONABLE MAXIMUM -- That quantity which the estimator associates with a 5% probability that there is at least this amount.

EXPECTATION --Also called "EXPECTED VALUE" or "BEST ESTIMATE" -- A mathematical term. It is the only value we are entitled to add if we combine estimates of similar quantities in other provinces.

$$E = \frac{\text{R. Min.} + \text{M. L.} + \text{R. Max.}}{3} = \frac{50 + 300 + 850}{3} = 400$$

MARGINAL PROBABILITY -- That probability which the estimator would assign to his basic assumptions that oil and gas accumulations are actually present in the province to be evaluated.

2/27/75

FORM # 4-B

Region #8 MICHIGAN BASIN RAG No. ____
Province ____
Province Area 122,000 (mi^2)
Province Volume: 108,000 (mi^3)

RESOURCE APPRAISAL --PROVINCE ESTIMATE

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Total (Cumulative & Identified)	.928	.045	2.786

REGIONAL REPRESENTATIVE Resource Appraisal	OIL (Billion Barrels)			NGL (Billion Barrels)			GAS (Trillion Cubic Feet)		
	In-Place	Total Rec. Resource	Undiscovered Rec. Resource	In-Place	Total Rec. Resource	Undiscovered Rec. Resource	In-Place	Total Rec. Resource	Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")	3.681	1.178	.250 ANAL.	.113	.090	.045	4.4825	3.586	.800
b. Reasonable Max. (5% "at least")	9.15	2.928	2.000 #4	.681	.545	.500	5.983	4.786	2.000
c. Most Likely	5.40	1.728	.800 ANAL.	.181	.145	.100	4.858	3.886	1.100
d. Expectation: (a + b + c)/3	6.075	1.944	1.016	.325	.260	.215	5.108	4.086	1.300
Method:									
Rec.--Yield Factors:									
Classify: Hypothetical ___ Speculative ___									

Posted by B. Miller Date 2-28-75

RESOURCE APPRAISAL GROUP Recommended Appraisal:	OIL In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")	3.85	1.23	0.300				4.482	3.586	0.800
b. Reasonable Max. (5% "at least")	9.16	2.928	2.000				5.982	4.786	2.000
c. Most Likely	5.10	1.630	0.700				4.859	3.886	1.100
d. Expectation: (a + b + c)/3	6.03	1.928	1.000				5.107	4.086	1.300
Method:									
Rec.--Yield Factors:									
Marginal Probability: ____									

Posted by B. Miller for RAG committee Date March 7/75 Approved ____ Date ____

ESTIMATES OF INFERRED + INDICATED RESERVES FOR THE UNITED STATES BY STATES

By R. F. Mast and Janet Dingler

The best source of reserve data currently available is that published by the American Gas Association, the American Petroleum Institute, and the Canadian Petroleum Association (AGA, API, CPA, 1973). Figure 39 shows the assumed correlation between the AGA, API, CPA (1973) terminology and the modified U.S. Geological Survey mineral-resources terminology used in this report.

At any time after discovery, the estimated total amount of oil and gas reported by API-AGA to be recoverable from a field, or from a group of fields, is equal to the cumulative production + the estimated amount of proved (measured) reserves. This quantity is equivalent to current estimates of ultimate recovery made annually by the AGA–API (1973). As fields are developed and produced, this estimated API-AGA ultimate recovery tends to increase. Experience has shown that in the early years after discovery, revisions and extensions added to the API-AGA estimates of ultimate recovery tend to be large, whereas, in later years, as the fields reach full development, the revisions and extensions added tend to be smaller (Hubbert, 1967). With time the estimated API-AGA ultimate recovery approaches as a limit the actual amount of oil and gas that will eventually be produced. Increases in estimates of API-AGA ultimate recovery result primarily because:

1. Fields are continuously developed and new drilling proves additional reserves in known reservoirs, either within the old reservoir limits or in extensions to the field, and/or reservoir limits;

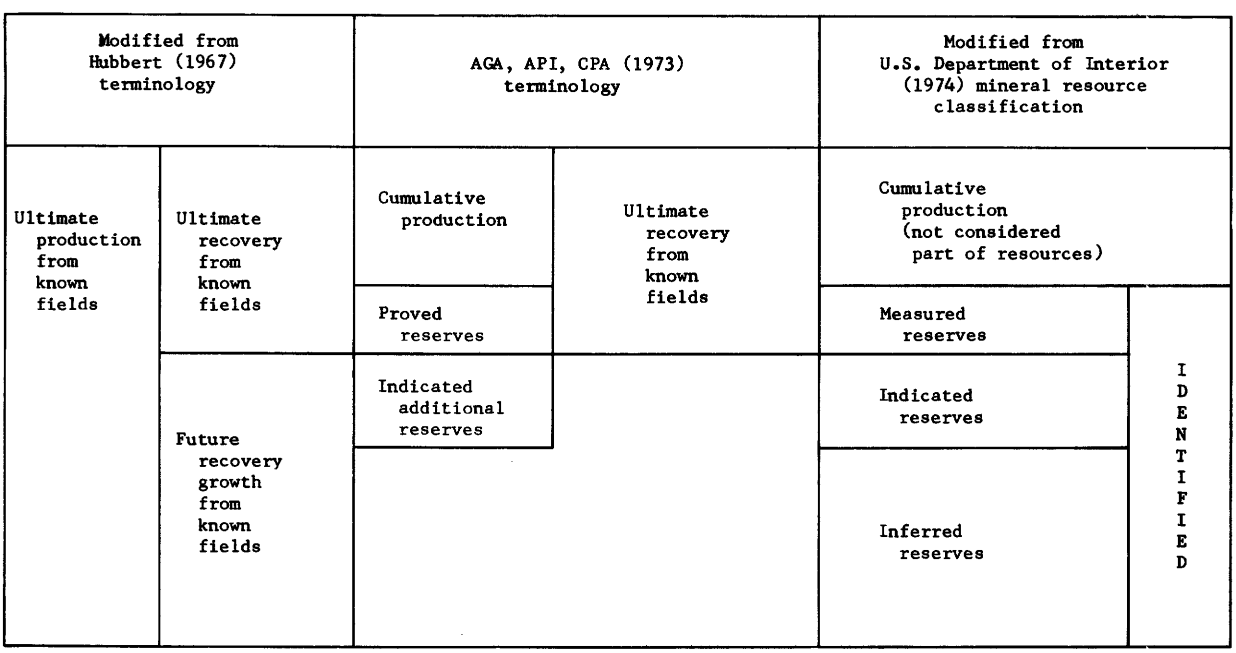

FIGURE 39.—Correlation of production and reserve terminology.

TABLE 7.—*Estimated Inferred + Indicated Reserves of crude oil for the United States through December 31, 1972*

[In thousands of barrels: derived by application of Hubbert's Correction Factors to API Ultimate Recovery for each State; *includes offshore]

State	Estimated ultimate production from known fields[11]	API cumulative production[11]	API proved reserves	Estimated inferred + indicated reserves	Inferred+indicated/ proved reserves
Alabama----------------	285,166	132,527	56,734	95,905	1.69
Arkansas---------------	1,616,003	1,339,464	113,100	163,439	1.44
California					
Coastal-------------	3,783,671 *	2,737,721 *	338,322 [2]	351,046 [1]	1.04
Los Angeles basin---	8,191,663 *	6,463,271 *	522,048 [4]	181,750 [3]	0.35
San Joaquin basin---	9,108,253	6,893,901	1,758,365	455,987	0.26
Colorado---------------	1,660,282	1,006,325	326,411	327,546	1.00
Florida----------------	789,637	40,702	208,149	540,786	2.60
Illinois---------------	3,316,788	2,939,632	174,883	202,273	1.16
Indiana----------------	511,520	435,120	29,383	47,017	1.60
Kansas-----------------	5,486,464	4,432,865	453,394	600,205	1.32
Kentucky---------------	710,784	602,563	48,193	60,028	1.24
Louisiana					
North---------------	2,326,706	1,785,824	281,451	259,431	0.92
South---------------	19,920,425 *	10,717,878 *	2,351,243 [6]	1,257,971 [5]	0.53
Michigan---------------	872,705	612,915	62,002	197,788	3.19
Mississippi------------	2,361,968	1,362,197	312,458	687,313	2.20
Montana----------------	1,421,936	790,344	241,248	390,344	1.62
Nebraska---------------	507,831	333,948	30,553	143,330	4.69
New Mexico					
Northwest-----------	245,392	145,575	24,246	75,571	3.12
Southeast-----------	3,971,715	2,720,692	558,347	692,676	1.24
New York---------------	233,252	223,842	9,246	164	0.02
North Dakota-----------	754,041	395,034	166,033	192,974	1.16
Ohio-------------------	1,030,213	785,383	127,385	117,445	0.92
Oklahoma---------------	12,834,742	10,665,828	1,303,004	865,910	0.66
Pennsylvania-----------	1,315,152	1,276,630	37,345	1,177	0.03
Texas Districts					
RR1-----------------	917,327	661,154	147,324	108,849	0.74
RR2-----------------	2,702,044	1,784,150	636,768	281,126	0.44
RR3-----------------	7,938,132 *	5,874,257 *	1,423,426 [8]	376,631 [7]	0.26
RR4-----------------	3,431,894 *	2,720,069 *	286,674 [10]	291,892 [9]	1.02
RR5-----------------	973,101	816,904	98,963	57,234	0.57
RR6-----------------	8,520,563	5,732,185	2,208,438	579,940	0.26
RR7B----------------	2,025,414	1,460,949	235,962	328,503	1.39
RR7C----------------	1,782,673	1,259,396	239,270	284,007	1.19
RR8-----------------	12,146,873	8,277,228	3,402,358	467,287	0.14
RR8A----------------	7,909,331	3,388,530	2,793,503	1,727,298	0.62

RR9----------------	3,270,728	2,623,006	324,018	323,704	1.00
RR10---------------	1,717,741	1,419,173	177,275	121,293	0.68
Utah------------------	1,126,984	439,486	244,397	443,101	1.81
West Virginia---------	545,217	504,975	34,040	6,202	0.18
Wyoming---------------	5,385,481	3,621,094	949,779	814,608	0.86
Miscellaneous----------	58,348	23,533	6,526	28,289	4.33
Total U.S. (onshore 48)-			22,742,264	14,148,040	0.62
Alaska *---------------	26,325,848	467,372	10,096,282	15,762,194	1.56
Gulf of Mexico---------	9,380,815	3,390,408	2,565,862	3,424,545	1.33

[1] Includes onshore inferred + indicated reserves only (offshore inferred + indicated reserves, 181,582 MBBL were estimated from onshore + offshore inferred + indicated reserves in the same proportion as offshore proved reserves to onshore + offshore proved reserves, and subtracted).

[2] Offshore proved reserves, 175,000 MBBL (Energy in California, January 1973), have been subtracted.

[3] Includes onshore inferred + indicated reserves only. (offshore inferred + indicated reserves, 264,593 MBBL were estimated from onshore + offshore inferred + indicated reserves in the same proportion as offshore proved reserves to onshore + offshore proved reserves, and subtracted).

[4] Offshore proved reserves, 760,000 MBBL (Energy in California, January 1973), have been subtracted.

[5] Includes onshore inferred + indicated reserves only (offshore inferred + indicated reserves, 3,197,549 MBBL were estimated from the Gulf of Mexico inferred + indicated reserves in the same ratio as offshore Louisiana (south) proved reserves to Gulf of Mexico proved reserves, and subtracted).

[6] Offshore proved reserves, 2,395,784 MBBL have been subtracted. Estimated Louisiana offshore portion of Gulf of Mexico total.

[7] Includes onshore inferred + indicated reserves only. (offshore inferred + indicated reserves, 150,817 MBBL, were estimated from the Gulf of Mexico proved reserves, and subtracted).

[8] Offshore proved reserves, 113,000 MBBL, have been subtracted. Estimated Texas RR#3 offshore portion of Gulf of Mexico total.

[9] Includes onshore inferred + indicated reserves only. (offshore inferred + indicated reserves, 76,180 MBBL, were estimated from the Gulf of Mexico inferred + indicated reserves in the same ratio as offshore Texas RR#4 proved reserves to Gulf of Mexico proved reserves, and subtracted).

[10] Offshore proved reserves, 57,000 MBBL, have been subtracted. Estimated Texas RR#4 offshore portion of Gulf of Mexico total.

[11] Estimates of cumulative production and proved reserves are those reported by API as of December 31, 1972.

TABLE 8.—*Estimated Inferred + Indicated Reserves of natural gas for the United States through December 31, 1972*

[In millions of cubic feet; derived by application of Hubbert's Correction Factors to AGA Ultimate Recovery for each State; *includes offshore]

State	Estimated ultimate production from known fields[8]	AGA cumulative production[8]	AGA proved reserves	Estimated inferred + indicated reserves	Inferred+indicated/ proved reserves
Alabama----------------	711,575	32,450	245,714	433,411	1.76
Arkansas---------------	6,828,805	2,648,096	2,455,877	1,724,832	0.70
California					
Coastal-------------	6,003,609 *	4,582,833 *	761,580 *	659,196 *	0.87 *
Los Angeles basin---	7,779,581 *	6,763,260 *	493,340 *	522,981 *	1.06 *
San Joaquin basin---	22,153,206	14,688,996	4,073,942	3,390,268	0.83
Colorado---------------	5,232,405	2,232,981	1,655,200	1,344,224	0.81
Florida----------------	535,276	18,637	180,629	336,010	1.86
Illinois---------------	1,362,354	1,449,540	545,361	0	0.0
Indiana----------------	203,166	169,129	87,324	0	0.0
Kansas-----------------	34,656,662	19,989,737	11,938,716	2,728,209	0.23
Kentucky---------------	4,615,028	3,016,192	938,082	660,754	0.70
Louisiana					
North--------------	27,641,650	20,541,151	3,320,328	3,780,171	1.14
South--------------	208,363,462 *	79,933,750 *	52,258,173 [2]	41,478,706 [1]	0.79
Michigan---------------	2,404,169	435,268	1,296,815	672,086	0.57
Mississippi------------	7,490,832	4,732,872	1,104,336	1,653,624	1.50
Montana----------------	3,012,174	1,371,489	1,064,036	576,649	0.54
Nebraska---------------	393,240	282,452	50,260	60,528	1.20
New Mexico					
Northwest----------	18,258,544	8,002,925	8,160,874	2,094,745	0.26
Southeast----------	23,574,328	15,130,778	4,174,773	4,268,777	1.02
New York---------------	625,744	517,541	139,184	0	0.0
North Dakota-----------	1,467,298	657,972	441,625	367,701	0.83
Ohio-------------------	6,780,545	4,923,164	1,146,677	710,704	0.62
Oklahoma---------------	67,867,548	39,101,016	14,492,030	14,274,502	0.98
Pennsylvania-----------	10,690,352	8,677,438	1,406,948	605,966	0.43
Texas Districts					
RR1----------------	5,028,395	2,174,549	1,620,405	1,233,441	0.76
RR2----------------	31,168,539	16,531,304	9,496,136	5,141,099	0.54
RR3----------------	64,345,153 *	31,243,379 *	11,000,458 [4]	5,830,303 [3]	0.53
RR4----------------	67,502,443 *	29,444,933 *	14,637,694 [4]	8,371,274 [5]	0.57
RR5----------------	4,620,996	2,068,519	1,171,395	1,381,082	1.18
RR6----------------	24,841,388	15,702,124	5,710,441	3,428,823	0.60
RR7B---------------	5,844,960	4,220,331	663,560	961,069	1.45
RR7C---------------	9,493,641	4,330,537	2,581,980	2,581,124	1.00
RR8----------------	51,013,171	20,372,613	15,481,337	15,159,221	0.98

RR8A----------------	7,722,983	4,314,806	2,366,951	1,041,226	0.44
RR9-----------------	6,547,247	3,571,066	1,559,594	1,416,587	0.91
RR10----------------	54,500,086	40,844,936	9,359,260	4,295,890	0.46
Utah-------------------	2,876,527	978,864	1,022,110	875,553	0.85
Virginia---------------	139,064	57,449	35,921	45,694	1.27
West Virginia----------	17,898,003	14,140,583	2,345,957	1,411,463	0.60
Wyoming----------------	13,796,520	6,296,109	4,088,728	3,411,683	0.83
Miscellaneous----------	116,163	78,423	269,987	0	0.0
Total U.S. (onshore 48)·			195,843,738	138,929,576	0.71
Alaska *---------------	68,476,312	629,864	31,455,443	36,391,005	1.16
Gulf of Mexico---------			38,785,667 [7]	27,226,723 [6]	0.70

[1] Includes onshore inferred + indicated reserves only (offshore inferred + indicated reserves, 15,300,000 MMCF were estimated from onshore + offshore inferred + indicated reserves in the same proportion as offshore proved reserves to onshore + offshore proved reserves, and subtracted).

[2] Offshore proved reserves, 19,392,833 MMCF, were estimated as 50 percent of the Gulf of Mexico proved reserves, and subtracted.

[3] Includes onshore inferred + indicated reserves only (offshore inferred + indicated reserves, 6,574,597 MCCF, were estimated from onshore + offshore inferred + indicated reserves in the same proportion as offshore proved reserves to onshore + offshore proved reserves, and subtracted).

[4] Offshore proved reserves, 9,696,416 MMCF were estimated as 25 percent of the Gulf of Mexico proved reserves, and subtracted.

[5] Includes onshore inferred + indicated reserves only (offshore inferred + indicated reserves, 5,352,126 MMCF were estimated from onshore + offshore inferred + indicated reserves in the same proportion as offshore proved reserves to onshore + offshore proved reserves, and subtracted.

[6] Sum of estimated Louisiana (south), Texas RR3 and RR4 offshore inferred + indicated reserves.

[7] AGA, API, CPA (1973), p. 114.

[8] Estimates of cumulative production and proved reserves are those reported by AGA as of December 31, 1972.

2. New drilling finds new reservoirs within the field limits; and
3. Recovery of oil and gas is found to be greater than anticipated and/or new recovery processes are applied to reservoirs to recover quantities of oil and gas that were previously considered nonrecoverable.

Many authors have discussed the growth of API–AGA ultimate recovery with time from known fields; Hubbert (1967, 1974) has presented a method for making estimates of the future growth of API–AGA ultimate recovery. His method is based on average growth curves derived from past changes in estimates of API–AGA ultimate oil and gas recovery with time since the fields were discovered.

As shown in figure 39, Hubbert's (1967, 1974) future recovery growth in known fields is correlated with the indicated + inferred reserves in this report. Indicated and inferred reserves are limited to areas immediately adjacent to or within the limits of known oil and gas fields. Estimates of these reserves assume a future economic climate including the economic impact of future technological advancement, which must be at least equivalent to the historical economic climate including the historical economic impact of technological developments.

Indicated + inferred reserves for the United States were estimated by applying the α correction factor (Hubbert, 1974) to the December 31, 1972 ultimate recovery data for each State published by AGA, API, CPA (1973). Tables III and XVII of AGA, API, CPA (1973) list crude oil and natural gas ultimate recovery data respectively by State, and within States, according to the year in which the fields were discovered. Hubbert's (1974) equations for these growth curves are expressed as:

$$Y_\infty = Y_\tau \alpha$$

where Y_∞ is the estimated oil (or gas) ultimate production (see fig. 39), $\alpha = 1/[1-e^{-0.076(\tau+1.503)}]$ for oil, $\alpha = 1/[1-e^{-0.063(\tau+4.343)}]$ for gas, τ is the elapsed time from the beginning of the year of discovery of the fields, and Y_τ is the past production plus the current estimate of proved reserves for those fields. Hubbert's ultimate production refers to the sum of cumulative past production, current estimates of proved reserves, and the amount of recoverable oil or gas in known fields to be added by future developments and additions to reserves.

Using the AGA, API, CPA (1973) data from their table III, the estimated ultimate production of oil, Y_∞, from fields discovered in each year back to 1920, was calculated for each State, and API–AGA district, where $\tau = 1973 - $year of discovery. This procedure assumes that Hubbert's curves, which were derived from data for the entire United States, could be used to approximate ultimate production in individual States or districts. For all fields discovered prior to 1920 $\alpha = 1.0$ was used. The same procedures were used to estimate ultimate production for natural gas (associated + dissolved) using the December 31, 1972, ultimate recovery data from table XVII of AGA, API, CPA (1973).

Inferred + indicated reserves as of December 31, 1972, for each State were then calculated as:

Inferred + Indicated Reserves = Estimated Ultimate Production − Cumulative Production − Proved Reserves.

The State cumulative production and proved reserves data for oil were obtained from table III (AGA, API, CPA, 1973), columns 2 and 3. The State proved reserves data and cumulative production for natural gas were obtained from tables XIII and XVIII (AGA, API, CPA, 1973), respectively.

The AGA, API, CPA data, and consequently, the calculated inferred + indicated reserves figures, contain both onshore and offshore data for Alaska, California (coastal and Los Angeles Basin), Louisiana (south), and Texas Railroad Districts 3 and 4. All other States have onshore data only.

The inferred reserves + indicated reserves and the data used for the calculations for each State are given here in tables 7 and 8. Adjustment to the data to account for offshore areas are specified in footnotes to those tables. The calculated ratios of inferred + indicated to proved reserves are also given in the tables.

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