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GEOLOGICAL SURVEY'S STUDIES AND POTENTIAL RESERVES OF NATURAL GAS

By

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The drilling of wells for natural gas in the United States began in 1821 and the drilling of wells for crude petroleum in 1859. Since these pioneer dates 1,150,000 wells have been drilled for oil and gas and they have produced 31.5 billion barrels of oil in 26 States and possibly 100 trillion cubic feet of gas in 30 States. The aggregate area covered by the oil and gas fields is about 26,000 square miles. In the oil fields, which cover about one-third this area, the proved reserves of oil remaining to be produced are about 20 billion barrels. The proved reserves of natural gas are placed at 140 trillion cubic feet. The potential gas reserves yet to be discovered lie in deeper zones in the producing fields, in extensions of the present fields, in new areas between the fields of the present producing regions, and in regions that are now not producing gas. About half the area of the United States appears favorable for further testing for natural gas. The reserves remaining to be discovered in the future will probably be found for the most part, as in the past, in connection with the search for petroleum. The magnitude of the undiscovered reserves, expressed in cubic feet or year's supply, will not be known in advance of their discovery by the drill but geologic conditions indicate that they will probably be large.

Development of Natural gas industry in United States

The marketing of natural gas in the United States was started in 1821 in Fredonia, N. Y., where gas supplied by a 27-foot well was conveyed through wooden tubes, replaced later by a lead pipe, to 30 light-burners in homes in the village. Earlier wells, drilled by salt manufacturers in the Appalachian region, discovered natural gas as early as 1803 in Ohio and 1815 in West Virginia, but the first use made of it was as fuel to evaporate brine in 1841 in West Virginia.

The next half century after the beginning of the sale of natural gas in Fredonia, N. Y., witnessed a growing but modest use of gas as a fuel and illuminant in New York, Pennsylvania, Ohio, and West Virginia. The gas was conveyed through pipes, some of them wooden, and one as much as 2½ miles long. In 1872, a 25-mile pine-log pipe line was built from a well near West Bloomfield, N. Y., to Rochester. In the same year a 5-mile cast-iron pipe was laid into Titusville, Pa.

The development of the natural gas industry was accelerated by the completion in 1878 of the first big gas producer in the United States, the Haymaker well at Murrysville, Pa. The completion of this well was followed by the commercial production and marketing of gas beginning in Ohio and West Virginia in 1884, Illinois in 1885, Indiana in 1886, and Kentucky in 1889.

1/ Paper delivered at a hearing of the Federal Power Commission in Washington, D. C., on June 19, 1946.

Early oil field exploration in the mid-Continent region resulted in the discovery of natural gas as early as 1860 in eastern Kansas and 1872 in Texas. Gas was first used in Kansas as an illuminant in a sanitarium at Iola in 1873, and was sold for domestic purposes at Iola in 1882, Fort Scott in 1887, Coffeyville in 1892, and Cherryvale and Independence in 1893. The first industrial use in that State was as a fuel in zinc smelters at Cherryvale in 1898. The gas industry spread into Oklahoma and Arkansas in 1902, and Louisiana in 1905. The first gas production in Texas in 1872 was followed by the discovery of new reserves and by the development of increased markets, and by 1906 the gas industry attained an important rank among the State's industries.

In the Rocky Mountain region natural gas was first produced commercially in Wyoming in 1889, Utah in 1892, Montana in 1915, and Colorado and New Mexico in 1924.

In California natural "dry" gas near Stockton and Sacramento was utilized in the early nineties. About 1903 gas was developed in the Salt Lake field and was distributed for local use. Commercial production was obtained in Buena Vista Hills in 1908, and the construction of a pipe line from this field to Los Angeles in 1913 marked the beginning of large-scale utilization of natural gas in California. The major development of numerous oil fields in that State beginning in 1908 established accessible reserves of "wet" gas in enormous quantity. Among these fields the North Dome of Kettleman Hills, discovered in 1928, more than quadrupled the proved natural gas resources of California. Another notable increment was added to the State's gas resources by the discovery in 1936 of the Rio Vista "dry" gas field.

Some of the large gas fields of the United States and the dates of their discovery are:

Monroe, La.	1916
Panhandle, Tex.	1918
Hugoton, Kans., Okla. and Tex.	1922
Pledger, Tex.	1925
North Dome, Calif.	1928
Old Ocean, Tex.	1934
Katy, Tex.	1935
Carthage, Tex.	1936
Rio Vista, Calif.	1936
Seeligson, Tex.	1937
La Gloria, Tex.	1939
Sheridan, Tex.	1940

Altogether, 30 States now produce natural gas. Texas and California have risen to top rank among the gas-producing States in the past 20 years and have passed Pennsylvania, originally the top producer, and also have passed West Virginia and Ohio.

Altogether, 33 States contain users of natural gas, which is supplied to them through 218,440 miles of trunk pipe lines and mains. The construction in the last 20 years of long-distance pipe lines from the fields to distant consumers has greatly increased the utilization of our natural gas. The longest lines radiate from the Southwest; they run from gas fields in Kansas, Oklahoma, New Mexico, Texas, Louisiana, and Arkansas to States as far away as Arizona, Colorado, South Dakota, Minnesota, Illinois, Michigan, Pennsylvania, West Virginia, Georgia, and Florida.

Geologic occurrence of natural gas

Natural gas of commerce is a mixture of hydrocarbons and gaseous impurities. The principal impurities, which vary in quantity from place to place, are carbon dioxide, nitrogen, hydrogen sulphide, and helium. Gas wells containing especially high percentages of carbon dioxide, as much as 98 per cent, have been drilled in Montana, Colorado, Utah, New Mexico, and California. The gas from wells in Utah, New Mexico, and California is being used in the manufacture of solid carbon dioxide, known generally as dry ice. Natural gas containing helium in sufficient quantities, 0.9 per cent to about 8 per cent, for its recovery on a large scale is found in gas fields in Kansas, Texas, northwestern New Mexico, Colorado, and Utah. Beginning in 1918 when the first experimental large-scale extraction plants were constructed by the Bureau of Mines, helium has been produced almost continuously by that Bureau. The maximum production was reached in World War II when helium was obtained at five extraction plants, one built many years ago at Amarillo, Tex., and the others during the war at Exell, Tex., Shiprock, N. Mex., and at Otis and Cunningham, Kans.

Natural gas is a companion to crude petroleum. The two were formed by similar geologic processes and are produced from similar and at many places common underground reservoirs. The gas and oil are under pressure and occupy pores, cracks, or openings in the reservoir rocks. The gas may occur along with oil accumulations in a reservoir or it may occur alone without oil. Because oil and gas, like water, are mobile, and have different specific gravities, their process of accumulation in the present reservoirs has involved their flowing through permeable rock strata to the tops of anticlines or other structural features which are sealed by overlying impervious rock strata. In a reservoir where both oil and gas are present, much or all of the gas may be dissolved in the oil, or a gas zone or cap may occur above the oil in the upper part of the reservoir. Thus gas is produced in gas fields that do not produce oil; it is produced from the gas cap above the oil in some fields; and it is produced with oil in some fields. The proportion of the country's natural gas production from gas wells has increased in recent years—from 51 per cent in 1938 to about 65 per cent at present.

Gas reservoirs of the condensate type have been found in increasing numbers by deeper drilling in recent years. They are widely distributed but most of them have been found in the coastal areas of Texas and Louisiana. In these reservoirs petroleum occurs in a gaseous form but a reduction in pressure in the course of its production from the wells results in the condensation of some of the gas into a liquid known as condensate.

Gas produced in oil fields may be considered to serve two useful purposes. One of these is to aid the recovery of petroleum by bringing the oil from the underground reservoir to the surface, and the other purpose is its use as fuel and as a source of raw material for liquefied petroleum products, carbon black, synthetic rubber, and chemical products.

The gas-bearing rocks in the United States are sedimentary rocks, and are of many different ages, ranging from Cambrian to Pleistocene. These rocks include both marine—those formed on the floor of an ancient sea—and nonmarine—those formed by rivers and in lakes. The kinds of gas-bearing rocks are many and includ sand, sandstone, limestone, dolomite, shale, arkose ("granite wash"), conglomerate fractured chert ("chat"), chalk, gravel, and coal.

Oil and gas have been sought for many years in anticlines but, as our knowledge of the occurrence of oil and gas has been increased by drilling, they are not sought in many other types of traps, such as lenticular sands, salt domes, traps against faults, noses on anticlines, reefs, buried hills, up-dip "wedgeouts" of the reservoir rocks, and zones of unconformities.

The search for oil and gas in the United States is a geological enterprise, and the effective and extensive application of the knowledge of geology is responsible for the discovery of most of our known resources of oil and gas. Our knowledge of the geology of the United States is very incomplete and most of the country remains to be mapped and studied in detail. As revealed at the surface, geology is observed essentially in but two dimensions. Its third dimension has been added by the oil and gas industries through the drilling of 1,150,000 wells to depths ranging up to 16,000 feet in the search for oil and gas in the United States.

Geology is also a proved and valued tool in the development and operation of oil and gas fields. It is concerned with the shape, relations, structure, and physical character of the natural gas reservoirs. The acquisition of geologic and engineering data from producing gas wells has become increasingly important in the past 30 years, because the data therefrom are necessary not only for the wise development and operation of the gas fields, but also for use in connection with the Federal tax law, and the estimation of underground gas reserves for different purposes including the financing of new pipe line projects.

Geologic studies of natural gas by Geological Survey

The Geological Survey's studies of the oil and gas resources of the United States date back to the late eighties and early nineties when reports were published on petroleum and natural gas in Ohio and Indiana. A continued and intensive program of oil and gas work was begun by the Survey about 1900. This work was started in response to the growing demand for gasoline for the ever-increasing number of American automobiles that were first introduced in 1892. Although geology was utilized to a limited extent in the selection of drilling sites for oil and gas wells prior to 1900, the drilling companies did not in general adopt the guidance of geologists until 1915. The adoption of this guidance was based on

the reports of the U. S. Geological Survey published between 1900 and 1915 and on the reports of the few geologists in company employment. The reports of the Geological Survey, as well as those of the company geologists, demonstrated clearly for many areas the relation of oil and gas accumulations to anticlinal structure. As a consequence the early part of the present century witnessed the beginning of an intensive search for anticlines as drilling sites for oil and gas wells. This search is still in progress in the United States and has spread to other petroleum regions of the world.

Also in the period 1908-25 the Geological Survey made a notable contribution to the development of the oil and gas industries through the training of petroleum geologists who resigned from the Survey to join the large geologic staffs which were then being organized by the oil companies. These geologists, who were thus Geological Survey graduates, became a significant proportion of the leaders in the intensive world-wide search for petroleum.

The oil and gas investigations of the Geological Survey have been conducted on an expanded scale during the past three years for the purpose of aiding the discovery of supplies of petroleum and natural gas which are urgently needed to meet current unprecendented requirements.

The purposes of the Survey's present investigations do not differ from those that have guided similar work by the Geological Survey for almost 50 years. On the other hand, as the methods and techniques of industry have changed during this period, the nature of the Survey's work has changed.

An important new technique, recently announced, is an airborne magnetometer which can be used for rapid geophysical surveys of potential oil and gas areas. During the past two years the Geological Survey has employed the instrument, chiefly in cooperation with the Office of Naval Petroleum Reserves, in making test surveys in areas from the northern coast of Alaska to the Gulf of Mexico. In all flights and under all conditions the airborne magnetometer has proved itself to be unsurpassed as a means of making rapid magnetic reconnaissance surveys.

The mapping of local structural features has been stressed less and less by the Geological Survey and greater emphasis has been placed on regional geologic problems, although some effort is necessarily being directed specifically to the acquisition of information essential for the administration of laws relating to the leasing of public lands for oil and gas development.

In formulating plans for the current program, the Geological Survey has sought and received the active collaboration of the oil and gas industry and of public organizations, such as State geological surveys, in order that the work may, insofar as practicable, supplement and not duplicate the work of others and may provide data of maximum and timely usefulness in the exploration for oil and gas.

The type of work that is being emphasized is regional geology involving both subsurface and surface stratigraphy in large areas, such as basins or similar geologic provinces. Studies are being devoted primarily to the accumulation of data

for the preparation of maps and stratigraphic sections showing such features as the thickness of oil-producing formations, change in facies of oil-producing formations, margins of producing or possible producing zones, and relations and extent of lenticular sands. These studies have as their objective the delimitation of broad areas that are favorable for exploration. The determination of local structural features, whether by surface, subsurface, or geophysical methods, is not being stressed.

The different parts of the United States where work has been under way during the past three years include California, Oregon, the Rocky Mountain region from New Mexico to Montana, many States in the mid-Continent region from Texas to Michigan, the Southeastern States from Mississippi to Florida, and the Appalachian region from Tennessee and Virginia to Ohio and Pennsylvania. These areas cover a considerable proportion of the parts of the country that produce natural gas or are favorable for natural gas production.

Because the current program is on an expanded scale, exceeding any oil and gas work heretofore undertaken by the Geological Survey during any year prior to 1943, the magnitude of the resultant effort is much greater than any similar effort.

Basic geologic data that are obtained by the Geological Survey in the course of its work are being made available promptly through publications to those directly concerned with the drilling of wells and the testing of new areas. The oil and gas investigations are so planned that useful and timely results are being published promptly. Most of the results are being embodied in a series of preliminary maps and charts on which are printed brief explanatory texts. These maps and charts are usually printed within a few months after the manuscript reports of the field parties are received in Washington. Their rate of release has been 3 to 4 each month.

The Geological Survey has printed 80 such maps and charts in its current series and now has 12 in press. Of such maps and charts more than 47,000 copies have been sold. Also, more than 55 articles and reports have been submitted during the past 3 years to trade and scientific journals and cooperating agencies for publication.

Geological Survey's administration of Gas Development on Public Lands

The Geological Survey's administration of oil and gas development on the public lands is performed by its Conservation Branch. Such administration includes the examination and classification of the mineral resources of the public domain, the furnishing of technical information and advice to administrative agencies, and the supervision of actual mineral-lease operations in the interests of conservation and with a view to protecting the interests of the United States, including the determination of royalty liability. By administrative arrangement, the Geological Survey maintains supervision over oil and gas operations and determines royalty liability on all restricted Indian lands, except the Osage Nation, and for certain naval petroleum reserve lands.

The field of the Conservation Branch work is coextensive with the public domain of the United States, including Alaska, and with the principal mineral-producing Indian reservations. Its duties include the classification of the public lands according to their highest use, the protection of the public interest in undeveloped mineral and water-power resources, and the promotion of economical and efficient development of mineral deposits on public and Indian land.

The Mineral Classification and the Oil and Gas Leasing Divisions of the Conservation Branch are directly concerned with oil and gas operations on the public domain.

The activities of the Mineral Classification Division, through its six field offices, are concerned with appraising the public-land holdings of the United States and are fundamental in the procedures of public-land administration. With respect to such holdings, they include the determinations of the mineral value of specific lands applied for under the various non-mineral-land laws and of the structural situation and inherent value of lands applied for under the mineral-leasing laws, particularly their oil and gas provisions, and also include the conversion of available geologic information into forms susceptible of administrative use, such as aereal classifications of mineral and nonmineral lands, definitions of the "known geologic structure" of producing oil and gas fields, and determinations of areas logically subject to unitization for purposes of oil and gas exploration and development.

In all, 13,079 cases were acted on during 1945, an increase of 20 per cent over 1944. Initial or revised definitions of the known geologic structure of 7 producing oil or gas fields were prepared and promulgated; geologic appraisal was made of 80 unit-plan submissions; and 53 special reports were rendered to the General Land Office on new discoveries of oil or gas on or adjacent to Federal lands, including 22 applications for the royalty benefits accorded by the act approved December 24, 1942 (56 Stat. 1080), for the discovery of new oil and gas fields or deposits during the national war emergency; the geologic checking and endorsement of several thousand assignments of acreage or other interests in outstanding leases, and of leases en route to issuance; and the geologic adjudication of many thousands of original applications for prospecting or development rights for oil and gas pursuant to the provisions of said laws.

For the most part the results of these investigations serve to expedite administrative action. However, many are of sufficient general interest to be made available in manuscript or map form for public inspection in the originating field offices, and a few more are published and made available for general distribution.

The Oil and Gas Leasing Division maintains 15 field offices staffed with trained technical, accounting, and clerical personnel and supervises the drilling and development operations and determines the royalty liability of lessees. It maintains records of operations in the public-land states, furnishes technical advice and statistical information to operators and the general public. It furnishes valuable analytical information to its lessees through its laboratory

facilities at Casper, Wyo., including the analyses of oil, gas, and water, the determination of permeability, porosity, oil saturation and connate water content of well cores, and the preparation of engineering reports on the possibilities of secondary recovery in active producing fields. Some idea of the magnitude of the job entrusted to the Conservation Branch is had from the total royalty value of the oil, gas, gasoline, and butane accounted for in the calendar year 1945, namely, $7,563,974 on public lands and $1,861,985 on Indian lands.

Most of the oil and gas from public-land leases is produced in California, Colorado, Montana, New Mexico, and Wyoming, and small amounts are produced in Louisiana, Michigan, North Dakota, Oklahoma, and Utah. Oklahoma, Montana, and Wyoming produce most of the oil from Indian-land leases, and all oil from naval petroleum reserve leases is produced in California at this time.

The supervision extends to 6,584 public-land leases, aggregating 4,149,000 acres in 20 States and Alaska. The public lands alone have produced from 1920 to 1945, inclusive, 844,151,958 barrels of oil, 1,340,693,294,000 cubic feet of gas, and 1,589,427,845 gallons of gasoline and butane.

Proved natural gas reserves

Our natural gas resources have been discovered in the course of the intensive search for crude petroleum and relatively little effort has been devoted to prospecting for natural gas except in California and the Appalachian area. The search for oil has resulted in discovery after discovery of new gas fields and deeper gas zones and has led to a constantly increasing volume of proved underground reserves of natural gas in spite of the mounting production. The estimates of such reserves range upward from 15 trillion cubic feet in 1919 to 140 trillion in 1945. A continued high-discovery rate of natural gas in the post war period is predicted by the Petroleum Administration for War in a recently published report (James E. Pew, "Natural Gas and its products during the War" in Petroleum in War and Peace; papers presented by the Petroleum Administration for War before the Senate special committee to investigate petroleum resources; Hon. Joseph C. O'Mahoney, Chairman, Nov. 28-30, 1945.)

Some of the increase in gas reserves is attributable to technologic advances. One of these is the drilling to greater depths in recent years and the resulting discovery with depth of a greater proportion of gas to oil. The deepest wells drilled in recent years include one in California to a depth of 16,246 feet and one in Texas to a depth of 16,655 feet. Our deepest gas as well as oil producing zone lies at a depth of 13,763-13,778 feet in Louisiana. The increase in the natural gas reserves is also due in part to the accelerated search for oil in recent years. In this search the number of geophysical crews in the field and the number of wildcat wells have reached new high levels.

The proved reserves of natural gas were discussed by E. L. DeGolyer at a hearing of the Federal Power Commission in Kansas City, Mo., in September 1945, and they are, I understand, the subject of a detailed statement to be presented

by him later at the present hearings in Washington. This subject is thus discussed briefly in this paper, by making reference to published statements, one by Mr. DeGolyer (Investigation of petroleum resources "New sources of petroleum in the United States"; Hearings before a special committee investigating petroleum resources, U. S. Senate, 79th Congress, 1st Sess. pursuant to S. Res. 36, 1946 and Oil and Gas Journal, May 4, 1946) giving an estimate of 140 trillion cubic feet as of the first of 1945, and the other by James E. Pew of the Petroleum Administration for War giving an estimate of at least 135 trillion cubic feet as of the same date. (James E. Pew "Natural gas and its products during the War" in Petroleum in War and Peace; papers presented by the Petroleum Administration for War before the Senate special committee to investigate petroleum resources. Hon. Joseph C. O'Mahoney, Chairman, Nov. 28-30, 1945.)

In arriving at the 140-trillion estimate by Mr. DeGolyer, only those fields having individual reserves of 20 billion cubic feet or more are included, except for the Appalachian area. If there be added to this estimate the 6,000 smaller fields not included therein and if allowance is made for the probable extension of present fields not yet fully explored he concludes that "we are justified in considering the present gas reserves to be something of the magnitude of 200 trillion cubic feet." The top-ranking States, each possessing 4 per cent or more of the 140-trillion reserve are:

Texas	58.2	per cent
Louisiana	12.2	" "
California	9.2	" "
Kansas	7.7	" "
Oklahoma	4.3	" "

Concerning the 135-trillion estimate Mr. Pew comments as follows:

"The figure of 135 trillion is based on estimates compiled by PAW-industry committees and is considered to be one of the most comprehensive and reliable estimates of recoverable natural gas reserves that has been made to date. It includes only the natural gas reserves now known and recoverable under present economic conditions; it does not represent the total quantity of gas that may be recovered if the fields are exhausted to lower pressures than those assumed. If all fields were calculated to a common pressure, and if allowance were made for future extensions of known fields, the estimate would be considerably higher."

The present proved reserves of natural gas, whose magnitude has thus set a new high, occupy for the first time a position, both in weight and heat value alongside the proved reserves of petroleum (G. G. Oberfell, Utilization of Natural Gas, American Gas Association Monthly, January 1946, pp. 7-13, 48). The recent developments in the utilization of natural gas--its expanding markets and importance as a source of energy and varied products--lead to the question of the size of our underground gas supply that remains to be produced. Our underground gas supply includes two categories of reserves, one, the proved reserves just discussed, and the other, the potential reserves that remain to be discovered.

Potential gas reserves awaiting discovery

The potential reserves yet to be discovered include the supplies of natural gas to be found by deeper drilling in present producing fields, to be found in extensions of the present fields, and to be found in new fields in regions now producing as well as in regions not now producing.

Sedimentary rocks that are favorable for the production of natural gas cover much of the area of the United States, as shown by the fact that productive gas fields have been developed in 30 States. These rocks underlie altogether about half the area of the United States.

There remain large areas that are not yet fully explored by the drill. In general, exploration is undertaken first in the most favorable areas as indicated by geologic evidence. These areas invite further or new drilling from time to time in response to increased knowledge of their geology. They include producing fields that warrant deeper drilling and other areas that warrant additional wells, some drilled to greater depths. Future exploration thus has two frontiers, one the extension of testing into new undrilled areas, and the other the drilling to greater depths. Although improvements in drilling technique have made possible the drilling of wells to greater and greater depths, there is a limit below which petroleum and natural gas will not be found. In many areas this limit is clearly marked by the floor or basement of crystalline rocks. In other areas the oil- and gas-bearing rocks may be less clearly limited in their downward extension by sedimentary rocks whose metamorphism and low porosity and low permeability preclude their containing oil and gas reservoirs.

The producing regions that invite the testing of deeper zones and new nearby areas include those of the Appalachians, those in the Central States from the Gulf of Mexico to the Great Lakes, and those in California and the Rocky Mountain region. In these producing regions and elsewhere there are many large areas outside the developed fields that warrant additional exploration. Some of these areas are:

California. Coastal areas near Humboldt Bay, Point Arena and Point Reyes; Salinas Basin, Sacramento Basin, San Joaquin Valley, and Imperial Valley.

Coastal region of Washington and Oregon.

Trans-Pecos region of west Texas.

Northern Llano Estacado of northwest-central Texas and northeastern New Mexico.

Anadarko Basin of western Oklahoma and of the Texas Panhandle.

McAlester Basin of southeastern Oklahoma.

Arkansas River Valley of Arkansas.

San Juan Basin of northwestern New Mexico and southwestern Colorado.

Black Mesa Basin of northeastern Arizona.

Southeastern Utah.

Uinta Basin of northeastern Utah and northwestern Colorado.

North and Middle Parks of Colorado.

Eastern Colorado.

Wyoming. The following intermontane basins: Big Horn, Wind River, Bridger and Washakie.

Powder River basin of northeastern Wyoming and southeastern Montana.

South-central and northeastern Montana.

The Dakotas.

Western Nebraska.

Salina basin of Kansas and Nebraska.

Forest City basin of northeastern Kansas, southeastern Nebraska, northwestern Missouri, and southwestern Iowa.

Warrior coal basin of Alabama.

Gulf Coastal Plain of Mississippi, Alabama, Georgia and Florida.

It is appropriate to mention also Alaska, Puerto Rico and the continental shelf along the Gulf Coast States and California whose oil possibilities are the subject of present interest.

Indications of oil are widespread in Alaska and have been known for many years. Oil production in Alaska has been small, being about 154,000 barrels which was obtained from the Katalla field from 1902 to 1933. In the past 3 years the Geological Survey and the Navy Department have made and are continuing studies of the more promising Alaskan areas for oil development. Most emphasis is being devoted to the Arctic slope. Any ensuing extensive oil exploration on the Arctic slope and elsewhere may discover commercial quantities of oil and gas.

The two coastal belts of Puerto Rico, one as much as 10 miles wide along the north coast and the other a narrower belt along the south coast are underlain by gently inclined sedimentary rocks of Tertiary age which rest unconformably on greatly deformed Cretaceous rocks that are cut by igneous intrusions. No direct

evidence of oil or gas accumulation has been found in the island but recent investigations of the oil and gas possibilities made by the Geological Survey suggest that geophysical investigations of the areas of Tertiary rocks in the two coastal areas seem justified.

The continental shelf adjacent to the United States is the slightly submerged portion of the continent extending out to about the 100-fathom line. It is 10 to 100 miles or more in width along the Atlantic coast and the Gulf of Mexico but along most of the Pacific coast it is only a few miles in width. These shelves are receiving increased attention for the further testing for their oil resources In this exploration it is probable that gas will be discovered in important quantities. The oil possibilities of the shelf area have been described by Director W. E. Wrather of the Geological Survey in the course of hearings before a Senate committee in 1945. (Investigation of petroleum resources--new sources of petroleum in the United States. Hearings before a special committee investigating petroleum resources, U. S. Senate, 79th Cong., 1st Sess. pursuant to S. Res. 36, pp. 360-380, 1946). Accordingly a very brief summary of these possibilities is pertinent in a consideration of future sources of gas.

The occurrence of numerous large and productive salt domes immediately along the open coast of the Gulf of Mexico and the gradual extension of geophysical prospecting into the marshes, bayous, lakes, and coastal bays of the Louisiana coastal strip, including the Delta of the Mississippi River, early made it evident that the oil-producing province of Louisiana and Texas extended outward beneath the waters of the Gulf. In 1927, the late Dr. David White of the Geological Survey publicly expressed the view that domes existed underneath the Gulf and pointed out that the knowledge of the topography of the bed of the Gulf furnished by charts of the United States Coast and Geodetic Survey indicated possible anticlines and domes. Dr. White suggested that the topography of the entire bottom of the submerged continental shelf be surveyed by the then newly developed methods of sonic sounding, and directed attention to the fact that even out to 35 miles from the coast, depths greater than 60 feet were rare and that in parts of the belt the water is not over 25 feet deep.

The continued extension of geophysical prospecting and drilling into the partially submerged marsh areas and adjoining lakes and coastal bays led ultimately to exploration and drilling in the Gulf of Mexico near shore and resulted in the discovery in 1938 of the Creole field, about a mile offshore from Cameron Parish, La., in the open Gulf. Subsequent development proved a productive area of about a mile square.

In 1941 the second field in the Gulf of Mexico, the Sabine Pass field, about 9,000 feet offshore from Jefferson County, Tex., was discovered. Several fields in Galveston Bay, Laguna Madre, and other coastal bays of Texas and in the bays of the Mississippi Delta have also been developed. The practicability of marine drilling and oil production in the submerged strip adjoining the coast may be accepted as established, and the existence of a large submerged area containing structural traps that are potentially productive of oil is indicated.

The submerged slopes off the California coast, in sharp contrast with the continental shelves of the Gulf of Mexico coast, are steep and the submarine topography is markedly irregular and similar in many features to the rugged mountains that adjoin or plunge toward the ocean. The strip above the 100-fathom line along most of the southern coast of California is only a few miles in width and in many places is less than a mile wide. Nevertheless, several coastal California oil fields have been extended out beneath tidelands or into submerged areas.

Oil fields of the California coastal strip in Santa Barbara, Ventura, and Los Angeles Counties are found in Tertiary sands in several sharply folded anticlines, whose axes lie obliquely to the general trend of the coast. The discovery of productive fields on these anticlines by wells close to or at the coast line, has led to production of oil from the submerged parts of the fields by directional drilling from rigs established on shore, or by drilling from piers extended for more than 2,000 feet offshore.

The possibilities of finding oil and also gas on the continental shelf area are believed by most geologists to be good. It is generally agreed also that the engineering problems involved in the discovery and production of oil and gas from the shelf can be solved. It is not yet established, however, that costs of production will be such that oil or gas can be produced far from shore in competition with other fuels.

Concluding statement

The natural gas resources of the United States are large and the present proved reserves are only a fraction of the total reserves. Geologic conditions appear to justify the conclusion that large and important gas reserves remain to be found. Whether or not the present proved reserves of 140 trillion cubic feet represent a half, more or less, of the ultimate producible reserve is not known.

Information is not available that will permit an estimation of the magnitude of our future discoveries of natural gas in exact terms, either cubic feet or year's supply. Our gas reserves yet to be discovered, whatever their magnitude, are finite in quantity. They are a wasting mineral asset--that is, they are destroyed in their use. Also, they are not replenished by geologic processes in the underground reservoirs. When one gas field is discovered, one less remains to be discovered. The problem of the discovery of oil and gas fields has become increasingly difficult and, from all available evidence, this trend will continue.

Natural gas, like numerous other abundant mineral resources of our Nation, is a rich heritage. As a geologist I am deeply concerned with the wise development and production of this convenient fuel so that posterity, like our generation, may be blessed with a full measure of this heritage.