U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

ASSESSMENT OF DEEP CONVENTIONAL AND CONTINUOUS-TYPE (UNCONVENTIONAL) NATURAL GAS PLAYS IN THE UNITED STATES

by

Thaddeus S. Dyman[1], James W. Schmoker[1], and David H. Root[2]

Open-File Report 96-529

[1]U.S. Geological Survey, P.O. Box 25046, MS 939, Denver, CO 80225

[2] U.S. Geological Survey, National Center, MS 956 Reston, VA 20192

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INTRODUCTION

Because of depressed worldwide oil prices and the highly mature state of drilling and production in many United States basins, domestic drilling activity has declined and exploration companies are looking overseas for new prospects. Concurrently, domestic oil production is declining and United States reliance on imported oil is increasing. Even if prices were to increase drastically, it would take several years for domestic exploration to reach previous levels of intensity. When the issue of economics is set aside, many domestic drilling frontiers deserve review. One such frontier is natural gas in deep sedimentary basins (Fig. 1).

The United States is rapidly exhausting its oil reserves, whereas estimates of resources of natural gas remain high. According to the National Petroleum Council (1992), the United States contains nearly 1,300 trillion cubic feet (TCF) of recoverable natural gas resources. In 1995, the U.S. Geological Survey estimated that 939 TCF of technically recoverable natural gas remained to be discovered or was part of reserve appreciation from known fields in the onshore areas and State waters of the United States (U.S. Geological Survey Oil and Gas Resource Assessment Team, 1995).

According to Petroleum Information Corporation's Well History Control System (WHCS) (Petroleum Information Corporation, 1991), more than 16,000 wells have been drilled deeper than 15,000 feet in the United States (Dyman and others, in press). These deep wells are widely distributed and are drilled into rocks of various ages and lithologies, but they represent less than one percent of the more than three million wells drilled in the United States.

Almost one fifth of the total undiscovered natural gas resources of the onshore and offshore United States are estimated to occur below 15,000 feet according to the Potential Gas Committee (1995). For example, one of the most significant exploration plays in the United States is the deep Norphlet Formation (Upper Jurassic) play of the eastern Gulf Coast Basin region (Fig. 1; Appendix A). Geologic and geochemical studies by Rice and others (1992) indicated significant potential for Norphlet and perhaps Upper Jurassic Smackover Formation natural gas reservoirs in the eastern Gulf region. In other deep basins, only a few deep wells have been drilled, and the natural gas potential of deep horizons remains poorly known.

Known deep natural gas reservoirs are distributed throughout many United States basins and occur in widely different geologic environments. However, when the Nation is taken as a whole, deep natural gas reservoirs account for only a small portion of the total natural gas production. According to Dwights Energy Data (1986), 1,998 producing reservoirs existed below 15,000 feet in the United States at the end of 1985. Of the total cumulative natural gas production in the United States (698 TCF; Mast and others, 1989), deep reservoirs accounted for seven percent (50 TCF) of which so-called significant reservoirs accounted for nearly half (22.4 TCF; Table 1; NRG Associates, 1990; Dyman and others, in press). Significant reservoirs are defined as those reservoirs with known recoverable size of at least six billion cubic feet (BCF) of gas. Two-hundred fifty-six known significant reservoirs, as identified by NRG Associates (1990), produce from depths greater than 15,000 feet, and 377 significant reservoirs produce from depths greater than 14,000 ft out of a total of more than 15,000 significant reservoirs in the United States (Table 1).

In this report, deep reservoirs are defined as those occurring at or below 15,000 feet; however, a single producing interval may extend both above and below 15,000 feet. For this reason, NRG data in Table 1 were summarized for all producing reservoirs below 14,000 feet in order to capture all reservoirs potentially occurring at or below the 15,000-ft level. Nearly three quarters of these reservoirs produce natural gas. These reservoirs occur in the Gulf Coast,

Permian, Anadarko, Williston, San Joaquin, Ventura, Cook Inlet, and Rocky Mountain basins (Figs. 1 and 2; Table 1).

One-hundred sixty two deep conventional and 11 continuous-type unconventional plays were defined for the U.S. Geological Survey 1995 National Petroleum Assessment (Gautier and others, 1995). One-hundred one of the conventional plays and six of the unconventional plays demonstrate potential for undiscovered technically-recoverable non-associated natural gas (Table 2; Appendix A).

Deep natural gas resources are described and assessed here for three primary reasons: (1) Natural gas may form in the deep central portions of basins and migrate into shallower regions where it is trapped. An understanding of deep basin processes may aid in understanding the occurrence of natural gas in shallow basin environments as well as deep ones. (2) The deeper parts of many sedimentary basins have not been adequately drilled, and opportunities for undiscovered accumulations remain good. (3) Economic conditions strongly affect the development of deep reservoirs, and an economic upturn or improved technology could produce conditions appropriate for increased exploration. Therefore, it is very important to maintain a data base of information on deep natural gas resources and reservoirs.

This report describes both conventionally-trapped and continuous-type (unconventional) plays and resources from the 1995 U. S. Geological Survey National Petroleum Assessment (U.S. Geological Survey Oil and Gas Resource Assessment Team, 1995). It contains (1) a description of deep conventional and continuous-type natural gas plays based on geologic data supplied by province geologists; (2) estimates of undiscovered technically-recoverable gas from these plays; and (3) a comparison of other recent deep natural gas assessments with the 1995 U.S. Geological Survey assessment.

Field and reservoir data were taken primarily from the Significant Field File of NRG Associates Inc. (NRG Associates, 1990). The NRG data base contains identification information, and geologic, production, and engineering data for more than 15,000 oil and gas reservoirs in the United States.

Deep plays were compiled from play descriptions supplied by province geologists and are identified in Appendix A. Many of these deep plays have a potential for both undiscovered oil and gas accumulations and are identified accordingly. For detailed discussions of plays and maps illustrating play outlines of all plays discussed in this report, refer to regional or province reports included in the 1995 U.S. Geological Survey National Petroleum Assessment CD-ROM (Gautier and others, 1995).

METHODOLOGY

Conventional Plays

The 1995 U.S. Geological Survey National Petroleum Assessment was based on the play concept, where a play is defined as a set of geologically similar discovered and undiscovered accumulations of oil and/or gas (Gautier and Dolton, 1995). A play is not a single drillable prospect but includes several prospects with similar geologic characteristics. It may have an exploration potential for conventional or unconventional accumulations and may be considered either hypothetical (no known discovery history of fields greater than 1 MMBO or 6 BCF) or confirmed (known discovered accumulations). The number of plays in equivalently-sized provinces may vary somewhat based on the manner in which each province geologist interpreted available data and on individual preferences for combining or subdividing geologic attributes. For example, 23 deep conventional plays were identified in the Western Gulf Basin while only five such plays were identified in the Permian Basin. The deep structural gas play of the Permian Basin includes several different reservoirs each of which could be defined as a separate play.

Confirmed plays were analyzed using field-size distributions, numbers of known accumulations, depths to production, and other geologic and production factors. Hypothetical plays were analyzed using geologic analogs or simulation models based on geological, geophysical, and geochemical data. Hypothetical plays were risked if some uncertainty existed as to the occurrence of at least one 1-MMBO or 6-BCFG accumulation. Play risk was expressed as a probability between 0.0 and 1.0 (see Appendix A) based on the product of estimates for

three play attributes: (1) charge, which includes the presence of source rocks, adequate time-temperature history, and migration; (2) presence of reservoir rocks; and (3) trap, including seal integrity and hydrocarbon retention (Gautier and Dolton, 1995).

In the assessment of conventional plays, a Truncated Shifted Pareto (TSP) distribution was used to model the size-frequency distribution of the population of oil and gas accumulations (Houghton and others, 1993). TSP data were combined with available geologic and production data in order to develop hypotheses about undiscovered conventional accumulations within a play and to estimate the sizes and numbers of accumulations remaining to be discovered for each play. Using play probability and other data, the numbers and sizes of undiscovered accumulations were subjected to Monte Carlo simulation to calculate a range of resources. Play-level assessments were subjected to review and compiled into province, regional, and National totals (Gautier and Dolton, 1995).

Small undiscovered accumulations (< 1 MMBO or 6 BCF) in conventional plays were treated separately for 1995 assessment based on extrapolations of numbers of field size classes greater than 1 MMBO or 6 BCF (Root and Attanasi, 1993). This estimate was made at the province level only and was not subdivided by depth interval. Data for small fields are therefore not included in this deep gas assessment.

Because of uncertainties in estimating undiscovered accumulations of oil and gas, estimates were presented as a range of values associated with different probabilities of occurrence for each play. A pessimistic case has at least a 95-percent chance of occurrence, an optimistic case has at least a 5-percent chance of occurrence, and a mean case represents the arithmetical average of all possible outcomes weighted by their probability. Appendix A includes only mean estimates for each play. The full range of estimates can be found in Gautier and others (1995). Resources attributed to reserve additions from known accumulations are not available at the play level but are substantial. Three-hundred twenty-two TCF of gas is identified in 1995 assessment as attributed to reserve appreciation from known fields for all reservoirs at all depths. Reserve additions to known deep fields are therefore not included in this deep gas assessment.

Undiscovered natural gas resources were subdivided into depth slices by using the average of two density functions. One density function is uniform between the minimum and median depth of the play, and between the median and maximum depth of the play. The other density function is linear, increasing from the minimum to the median depth and linear, decreasing from the median to the maximum depth with a discontinuity at the median. The result of this computation was a fraction of the total resource in 5,000-ft-thick depth slices. The greater-than 15,000 ft depth interval was represented as a single fraction.

Continuous-type Plays

Continuous-type plays were treated as a separate category in the 1995 National Petroleum Assessment and were assessed using a specialized methodology developed by the U.S. Geological Survey (Schmoker, 1995). These continuous-type plays are geologically diverse and fall into the following categories: coal-bed gas, some biogenic gas occurrences, fractured gas shales, and basin-centered natural gas accumulations. Only continuous-type basin-centered gas plays comprise significant future undiscovered resources in deep sedimentary basins.

Continuous-type accumulations identified in this report are not significantly affected by oil/water or gas/water contacts (Schmoker, 1995); therefore, the methodology used for assessing discrete accumulations of conventional plays is not appropriate here. Continuous-type accumulations are essentially large, potentially productive areas that cannot be defined in terms of discrete units with down-dip hydrocarbon-water contacts. The definition of continuous-type accumulations is based on geology rather than on government regulations defining tight gas.

The assessment of continuous-type plays is based on the concept that an accumulation can be regarded as a collection of hydrocarbon-bearing cells. In the play, cells represent spatial subdivisions defined by the drainage area of wells. Cells may be productive, nonproductive, or untested. Geologic risk, expressed as play probability, was assigned to each play. The number of untested cells in a play, and the fraction of untested cells expected to become productive (success ratio) were estimated, and a probability distribution was defined for estimated ultimate

recovery (EUR) for those expected to become productive cells. The combination of play probability, success ratio, number of untested cells, and EUR probability distribution yielded potential undiscovered resources for each play. Resources were assigned to 5,000-ft. depth slices in the same way as conventional plays.

DEEP UNDISCOVERED NATURAL GAS PLAYS AND RESOURCES

Appendix A contains information on deep conventional plays including province and play name, play classification as hypothetical or confirmed, depth range, fractional distribution of gas, and undiscovered conventional resources. Table 2 identifies play name, minimum, median, and maximum depth, and undiscovered resources for six continuous-type plays assessed in the U.S. Geological Survey 1995 National Petroleum Assessment. Five additional plays are identified but not assessed due to a lack of geologic information about each of them. Refer to Figure 3 for locations of regions and provinces discussed in the following sections.

The U.S. Geological Survey estimated 55.3 TCF of undiscovered technically-recoverable non-associated gas and associated gas from oil fields for 101 deep conventional plays in the lower-48 states and Alaska onshore and State waters. In addition to these gas-bearing plays, 61 conventional plays are identified in Appendix A but have do not have undiscovered gas resources attributed to them. These plays include those that (1) may contain only negligible associated gas because they are oil plays, (2) were severely risked and no gas was assessed for them, or (3) have maximum depths of 15,000 ft and have no gas resource assigned below that depth. About 83 percent of the deep undiscovered conventional resource, or 45.3 TCF of gas, was assessed from the Gulf Coast and Alaska Regions together (Fig. 4; Appendix A). Approximately half of the estimated undiscovered conventional gas (27.4 TCF) is located in the Gulf Coast region in the Western Gulf Basin and Louisiana-Mississippi Salt Basins petroleum provinces. This deep conventional resource does not include deep resources from small fields (<6 BCF of gas) or reserve appreciation from known fields.

An additional 58.4 TCF of technically-recoverable gas was assessed for six continuous-type plays in the Pacific, Colorado Plateau and Basin and Range, and Rocky Mountain and Northern Great Plains Regions (Fig. 4; Table 2). Four of these plays are in Cretaceous and Tertiary low-permeability sandstone reservoirs in the Greater Green River Basin of Wyoming and are estimated to contain 50 percent of the entire undiscovered deep gas resource estimated for the United States. The disparity in numbers and resources of conventional (101 plays--55.3 TCF) and unconventional continuous-type (six plays--58.4 TCF) plays may be due in part to a lack of data dealing with the distribution of poorly understood "basin-centered" gas accumulations. The five "unassessed" continuous-type plays in Table 5 are part of this "poorly understood" category. Not included in Table 5 are other plays that may exist but were not even defined because of a lack of geologic information. For example, deep plays may exist in basins of interior Alaska, in basins of coastal California, and in basins in the Rocky Mountain Region such as the Crazy Mountains Basin, Raton Basin, and Albuquerque Basin.

The number of deep conventional plays identified decreases with increasing depth. Of the 101 conventional gas-bearing plays, 73 plays have maximum depths ranging from 15,000 to 20,000 feet, whereas 20 have maximum depths ranging from 20,001 to 25,000 feet, and 5 have maximum depths ranging from 25,001 to 30,000+ feet. Three plays exceed 30,000 feet in depth. Seventy gas-bearing plays are confirmed (those having known production from significant reservoirs), whereas, 31 are hypothetical. Nearly 40 percent of the confirmed plays are in the Gulf Coast Region, and about 60 percent of the plays are in the Gulf Coast and Rocky Mountain Regions together. Eighty-five of 101 gas-bearing plays have a fractional distribution for non-associated gas of 0.5 or greater. Thirty-six of these plays are in the Gulf Coast Region. Fifty-nine confirmed plays have more than half of their estimated resources in the form of non-associated gas (a fractional distribution for non-associated gas accumulations of 0.5 or greater). Thirty confirmed conventional deep plays have less than half of their estimated resources in the form of non-associated gas (a fractional distribution for non-associated gas of less than 0.5). Only in the Pacific Region does the number of plays having no chance for undiscovered non-

associated gas accumulations exceed the number of plays in which half or more of their resources are non-associated gas.

REGION 1--ALASKA

The petroleum geology of Alaska is complex in part because of the accretion of exotic terranes to the ancestral North American cratonic margin (Bird, 1995). Numerous sedimentary basins evolved before, during, and after this accretion process. The Central Alaska Province contains nonmarine rocks in a series of poorly understood basins. The Northern Alaska Province includes large, deep composite basins such as the North Slope Basin, while the Southern Alaska Province includes forearc basins of the Pacific margin, primarily containing thick sequences of Tertiary marine and nonmarine rocks. Alaska provinces are frontier areas with respect to deep drilling.

Deep Conventional Plays

The three Alaska provinces include 21 deep conventional plays (Fig. 3; Appendix A). Seven of these plays, six of which are located in northern Alaska, were assessed as containing 17.7 TCF of undiscovered technically-recoverable non-associated gas. Deep undiscovered resources were not estimated to exist in the Central Alaska Province. Northern Alaska has the largest number of plays of the three provinces with 10. Only eight of the 21 plays are confirmed, indicating that Alaska petroleum provinces are relatively undrilled. For Alaska as a whole, the average maximum depth of deep conventional plays exceeds 21,000 feet. The deepest plays in the region are the hypothetical Western Thrust Belt Play (110), and Lisburne, Lisburne Unconformity and Endicott Plays (106, 107, and 108) in northern Alaska, which reach maximum depths of 35,000 and 30,000 feet respectively. Deep conventional plays in Alaska are estimated to contain 17.7 TCF of undiscovered technically-recoverable non-associated gas and 271.4 BCF of associated gas from oil fields (Appendix A; Fig. 4).

Deep Continuous-type Plays

Deep continuous-type plays were not identified or assessed in the Alaska Region.

REGION 2--PACIFIC COAST

The Pacific Coast Region includes Washington, all but the southeastern quarter of Oregon, and that part of California west of the Sierra Nevada Range (Bird and others, 1995). The geology of the region is complex because of arc-related volcanism and plutonism, subduction, crustal accretion, eruption of flood basalts, and the development of numerous small deep basins. The region is subdivided into 8 geologically distinct provinces containing deep resource potential: Western Washington and Oregon, Eastern Washington and Oregon, Northern Coastal, Sonoma-Livermore Basin, Sacramento Basin, San Joaquin Basin, Central Coastal, and Ventura Basins. Deep plays were not identified for the Los Angeles Basin in the 1995 National Petroleum Assessment. Regions 1 and 2 together have known deep ultimate recoverable gas of 0.3 TCF from deep significant reservoirs found in the NRG Associates Data File (Fig. 2; Table 1).

Deep Conventional Plays

Region 2 contains 20 deep plays (Fig. 3; Appendix A). Washington and Oregon provinces are generally gas prone, whereas most California provinces are oil prone. The Sacramento Basin is gas prone and is estimated to contain 94.7 BCF of undiscovered technically-recoverable non-associated gas from two deep plays. Although oil prone, the Ventura Basin is estimated to contain 97.8 BCF of undiscovered technically-recoverable non-associated gas from two Paleogene plays (1301 and 1311). The San Joaquin Basin Province contains the largest number of deep plays with six, although only undiscovered oil was assessed for them.

Eight of 20 plays are hypothetical indicating that the region is relatively immature with respect to deep natural gas exploration. For the region as a whole, the average maximum depth of deep plays is about 18,000 feet. The deepest play is the hypothetical Deep Overpressured Fractured Rocks of West Side Fold and Overthrust Belt Play (1011) of the San Joaquin Basin

which reaches a maximum depth of 25,000 feet. Other California basins such as the Los Angeles Basin contain deep sedimentary rocks, but no deep conventional plays were assessed for them. The Los Angeles Basin contains one deep oil play but it was not assessed because it is not expected to produce oil fields larger than 1 MMBO. In the Western Oregon and Washington Province, the Puget Lowland Deep Gas (403) and Tofino--Fuca Basin Gas (404) Plays contain 15.2 BCF of undiscovered non-associated technically-recoverable gas. Deep conventional plays in the Pacific Region contain 208.3 BCF of undiscovered technically-recoverable non-associated gas and 341.3 BCF of associated gas from oil fields (Appendix A; Fig. 4).

Deep Continuous-type Plays

Only one deep continuous-type play was assessed in the Pacific Region: the Columbia Basin-Basin-Centered Gas Play (503) in the Eastern Oregon-Washington Province (Table 2). This play underlies Tertiary Columbia River basalts in central and eastern Washington. The play is sparsely drilled. The top of an overpressured interval ranges in depth from more than 8,000 to more than 12,000 feet and may be as much as 6,400 feet thick (B.E. Law, *in* Schmoker and Oscarson, 1995). Play 503 contains 2.6 TCF of deep undiscovered technically-recoverable gas (Table 2).

Two additional continuous-type plays, the Willamette-Puget Sound Basin-Centered Gas Play (412) of the Western Oregon-Washington Province, and the Deep, Overpressured Fractured Rocks of the Central Syncline Play (1408) of the Los Angeles Basin were identified in Table 2, but not assessed, because of a lack of available geologic information.

REGION 3--COLORADO PLATEAU AND BASIN AND RANGE

The Colorado Plateau and Basin and Range Region includes nine petroleum provinces in Nevada, Idaho, Arizona, eastern California, southeastern Oregon, western and southern Utah, southwestern Colorado, and western New Mexico (Fig. 3; Peterson and Grow, 1995). The geology of the region is typified by Late Precambrian to Early Paleozoic passive continental-margin sedimentation dominated by more than 30,000 feet of shallow-water carbonate and clastic rocks. This continental margin was subjected to repeated compression and plutonism during the Late Paleozoic and Late Mesozoic culminating in Sevier-style tectonism during the Late Cretaceous. The Colorado Plateau part of the region has remained tectonically stable since the Paleozoic, but the Basin and Range was tectonically partitioned into numerous non-marine basins during the Tertiary. The entire region has a fair potential for undiscovered deep natural gas accumulations. Region 3 has no deep significant reservoirs in the NRG Associates Data File (Fig. 2; Table 1).

Deep Conventional Plays

The Colorado Plateau--Basin and Range Region contains 22 deep plays. Nine of 22 plays have potential for undiscovered technically-recoverable non-associated gas at or below 15,000 feet (Appendix A). In 11 plays, the gas fraction is 0.5 or greater. Plays are relatively equally distributed among the provinces. Only two of 22 plays, both in the Paradox Basin, are confirmed indicating that the deeper parts of most of the region are relatively undrilled. For the region as a whole, the average maximum depth of deep conventional plays is about 19,000 feet. The deepest plays, each reaching maximum depths of 25,000 feet, are in the Snake River Downwarp Province (Older Tertiary Play--1704), Western Great Basin Province (Neogene Source Rocks, Northwestern Nevada and Eastern California Play--1805, and Permian-Triassic Source Rocks Northwestern Nevada and East Central and Eastern Oregon Play--1803), and Southern Arizona--Southwestern New Mexico Province (Alamo Hueco Basin Play--2501). Deep conventional plays in the Colorado Plateau--Basin and Range Region contain 127.0 BCF of undiscovered technically-recoverable non-associated gas and 2.7 BCF of associated gas from oil fields (Appendix A; Fig. 4).

Deep Continuous-type Plays

Only one deep continuous-type gas play, the Deep Synclinal Uinta Mesaverde Play (2020) in the Uinta-Piceance Basin, was assessed in the Colorado Plateau--Basin and Range Region. This play is defined on the occurrence of gas-charged, low-permeability Late Cretaceous sandstones of the Mesaverde Group. The play is entirely below 15,000 feet and underlies conventional plays in overlying Tertiary rocks. The play contains an estimated 570 BCF of deep undiscovered technically-recoverable gas (Fig. 4).

REGION 4--ROCKY MOUNTAINS AND NORTHERN GREAT PLAINS

The Rocky Mountains and Northern Great Plains Region contains eight provinces with deep gas plays (Fig. 3). Region 4 was part of the western United States cratonic margin during much of the Paleozoic. During Mesozoic and Tertiary time, Laramide- and Sevier-style tectonism disrupted the cratonic margin. Laramide structural basins may be very deep (Hanna Basin of the Southwestern Wyoming Province extends to more than 40,000 feet) and are gas prone (Spencer, 1995). Basins in the Rocky Mountains and Northern Great Plains Region have a known recoverable resource of 2.2 TCF of gas (Fig. 2; Table 1).

Deep Conventional Plays

The Rocky Mountains and Northern Great Plains Region contains 29 deep plays in eight provinces (Appendix A). Eighteen are predominantly deep gas plays (gas fraction equals or greater than 0.5), and only four of 18 plays have no non-associated gas potential (gas fraction equals 0.0). Two of these are in the Powder River Basin Province. Deep plays are relatively equally distributed throughout the region, but the Wyoming Thrust Belt Province and Southwestern Wyoming Province each contain the most, with six plays each. Nineteen of 29 deep plays are confirmed indicating that the region is relatively mature with respect to deep drilling. The average maximum depth of all deep plays within the region is about 18,900 feet. The deepest plays (Basin Margin Anticline and Subthrust Plays of Southwestern Wyoming Province; plays 3705, 3706) extend to 30,000 feet. Other Rocky Mountain basins containing deep sedimentary rocks such as the Raton Basin are not included here because deep conventional plays were not defined for them in the U.S. Geological Survey 1995 National Petroleum Assessment. Deep conventional plays in the Rocky Mountains and Northern Great Plains Region are estimated to contain 1.9 TCF of undiscovered technically-recoverable non-associated gas and 86.9 BCF of associated gas. Nearly half of this resource is in one play, the Moxa Arch Extension Play (3601) of the Wyoming Thrust Belt Province (Appendix A; Fig. 4).

Deep Continuous-type Plays

Four deep continuous-type plays were assessed for the Rocky Mountain Region (Table 2). All four plays are in the Greater Green River Basin and occur in Cretaceous or Tertiary rocks as low-permeability basin-centered gas accumulations. Together they contain 55.2 TCF of undiscovered technically-recoverable gas, nearly one-half of the entire deep undiscovered technically-recoverable gas resource of the United States (Fig. 4). More than 90 percent of this resource (50.8 TCF) was estimated for the Cloverly-Frontier (3740) and Mesaverde (3741) Plays alone.

Two additional continuous-type plays, the Big Horn Basin Basin-Centered Gas Play (3404), and the Wind River Basin Basin-Centered Gas Play (3505) were identified in Table 2, but not assessed, because of a lack of available geologic information.

REGION 5--WEST TEXAS AND EASTERN NEW MEXICO

Provinces within Region 5 have produced hydrocarbons for many years and include plays with deep undiscovered natural gas accumulations (Fig. 3). During the Early Paleozoic, a thick shallow-water carbonate sequence was deposited in the region. Early Pennsylvanian deformation attributed to the Ouachita Orogeny trapped oil and gas in complex structural and stratigraphic traps. The Late Pennsylvanian through Permian sequence is composed of mixed clastic and carbonate rocks primarily in stratigraphic and combination traps. The region is geographically dominated by the Permian Basin (Ball and others, 1995). Forty-five percent of

the known ultimate recoverable deep natural gas resource identified for significant reservoirs (15.1 TCF) in the United States occurs in the Permian Basin (Fig. 2; Table 1).

Deep Conventional Plays

Region 5 contains six deep plays in two petroleum provinces, all but one of which contain conventional undiscovered technically-recoverable non-associated gas resources (Appendix A). All six plays contain non-associated gas potential, but the Pre-Pennsylvanian Delaware--Val Verde Basins Play (4401) and the lower Pennsylvanian (Bend) Sandstone Play (4404) have fractional distributions favoring gas accumulations. The Pre-Pennsylvanian Delaware--Val Verde Basins Play (4401) contains the most deep significant reservoirs and the largest conventional non-associated gas potential. All six plays are confirmed and together range from 15,500 to 24,000 feet in maximum depth. These deep plays are primarily structural plays and include many different stratigraphic units, whereas the many shallower plays in the region are stratigraphic, and generally are defined on the basis of known stratigraphic units. These deep conventional plays are estimated to account for 4.7 TCF of undiscovered technically-recoverable non-associated gas and 6.3 BCF of associated gas from oil fields (Appendix A; Fig. 4).

Deep Continuous-type Plays

Deep continuous-type plays were not identified or assessed for the West Texas--Eastern New Mexico Region.

REGION 6--GULF COAST

The Gulf Coast Region includes the States and State waters that border the Gulf of Mexico and extends northward to folded Paleozoic rocks of the inland fold belts (Schenk, 1995). The region represents the southern passive continental margin of North America and includes the Western Gulf Basin, East Texas Basin, Louisiana-Mississippi Salt Basins, and Florida Peninsula Provinces (Fig. 3). Since a Triassic rifting event, the region has experienced extensive sedimentation, progradation, and subsidence. The region is geologically complex because of rapid facies changes due to marine transgressions and regressions, and gravity and salt tectonism. Mesozoic strata are dominated by mixed carbonate and clastic sequences, while Cenozoic strata are dominated by clastic sequences. The Gulf Coast Region has been extensively drilled and is the foremost petroleum-producing region of the United States. Thirty-nine percent of the known ultimate recoverable natural gas resources (12.8 TCF; Table 1; Fig. 2) in deep significant reservoirs occurs in the Gulf Coast Region.

Deep Conventional Plays

The distribution of deep plays in the Gulf Coast Region is very similar to the distribution of known deep production. Nearly all of the plays have significant reservoirs; only six of 44 plays are hypothetical, indicating that the region is mature with respect to deep drilling (Appendix A). The Gulf Coast Region exceeds all other regions in numbers of deep plays, in part because of the extensive area of sediments deeper than 15,000 feet. Thirty-six plays are predominantly gas plays, and only five plays contain no potential for non-associated gas. These five oil plays are generally updip equivalents of deeper natural gas plays. The Western Gulf Province contains the most plays, and the Florida Peninsula Province contains the least. The average maximum depth of all deep plays in the region is nearly 20,000 feet. The two deepest plays, Norphlet Mobile Bay Deep Gas (4903) and Norphlet Southeast Margin Jackson Dome Flank Deep Gas (4907), extend to 24,000 feet.

The 44 plays in the Gulf Coast Region can be grouped on the basis of the stratigraphic or structural character of each play. For example, the four deep Smackover plays in the Louisiana--Mississippi Salt Basins Province are defined by their structural origin (such as Jackson Dome). Deep conventional plays in the Gulf Coast Region are estimated to account for 27.4 TCF of undiscovered technically-recoverable non-associated gas and 56.3 BCF of associated gas from oil fields (Appendix A; Fig. 4).

Deep Continuous-type Plays

Deep continuous-type plays were not identified or assessed in the Gulf Coast Region.

REGION 7--MIDCONTINENT

The Midcontinent Region includes all or parts of Oklahoma, Kansas, Nebraska, Texas, Arkansas, Missouri, Iowa, Minnesota, Wisconsin, and Colorado (Fig. 3; Charpentier, 1995). Geologically, the region represents the Paleozoic continental craton. The deepest basins, the Anadarko and Arkoma, are in the southern part of the region and formed as Early Paleozoic aulacogens. They were later altered tectonically by collisional events along the eastern and southern margin of the United States. In the northern and central parts of the region, Precambrian rifting led to the development of the Midcontinent rift. The region (excluding the Midcontinent rift) has been extensively drilled, but both confirmed and hypothetical deep natural gas plays still possess the potential for undiscovered accumulations.

All of the deep significant production from the NRG Associates Field File in the Midcontinent Region is found in the Anadarko Basin. The Anadarko Basin contains a known ultimate recoverable resource of 2.8 TCF from these deep reservoirs (Table 1; Fig. 2).

Deep Conventional Plays

The Midcontinent Region includes eight deep plays in the Superior, Anadarko Basin, Southern Oklahoma, and Arkoma Basin Provinces (Appendix A). All eight plays are classified as predominantly non-associated gas, and six of the eight plays are exclusively gas. The Anadarko and Arkoma Basins Provinces contain most of the plays with three each. Six of the eight plays are confirmed, and the average maximum depth of all deep plays in the region is about 24,000 feet. The Deep Structural Gas Play (5801) in the Anadarko Basin and the Deep Gas Play (6101) in Southern Oklahoma extend to 40,000 feet, and the two deepest wells drilled in the United States, the No. 1 Bertha Rogers and No. 1 Ernest Baden wells in the southern Anadarko Basin, are included in play 5801. Deep conventional plays in the Midcontinent Region are estimated to contain 2.3 TCF of undiscovered technically-recoverable non-associated gas (Appendix A; Fig. 4). The Deep Structural (5801) and Deep Stratigraphic Gas Plays (5812) of the Anadarko Basin contain most of the conventional undiscovered technically-recoverable non-associated gas (2.1 of 2.3 TCF).

Deep Continuous-type Plays

Deep continuous-type plays were not assessed in the Midcontinent Region. One additional continuous-type play, the Woodford/Chattanooga/Arkansas Novaculite of Midcontinent (5811) was identified in Table 2, but not assessed because of a lack of available geologic information.

REGION 8--EASTERN

Region 8 includes most of the eastern United States in the following provinces: Illinois Basin, Michigan Basin, Black Warrior Basin, Cincinnati Arch, Appalachian Basin, Blue Ridge Thrust Belt, Piedmont, Atlantic Coastal Plain, Adirondack Uplift, and New England (Fig. 3; Ryder, 1995). The Illinois and Michigan Basins are cratonic basins filled with Paleozoic sedimentary rocks and are underlain by Precambrian rift systems. The Appalachian and Black Warrior Basins are foreland basins recording complex histories of continental rifting, passive margin subsidence, continental collision, and basin subsidence. Up to 40,000 feet of sedimentary rocks are preserved in the eastern Pennsylvania part of the Appalachian Basin. The region has been extensively drilled for petroleum, but deep natural gas plays still possess the potential for undiscovered accumulations. No deep significant fields or reservoirs were identified in the NRG Associates Data File for the Eastern Region.

Deep Conventional Plays

Region 8 includes 12 deep plays in five provinces: Michigan, Illinois, Black Warrior, and Appalachian Basins, and Blue Ridge Thrust Belt Province (Appendix A). All 12 plays are predominantly non-associated gas plays, and eight of the 12 plays are entirely gas. The

Appalachian Basin Province contains the most plays with five. The Michigan and Illinois Basins and Blue Ridge Thrust Belt Provinces each contain one play. Six of the 12 plays are confirmed indicating that the region is moderately explored with respect to deep drilling. The Precambrian Rift Play (6315) of the Michigan Basin is the deepest play in the region and extends to 30,000 feet. Deep conventional plays in the Eastern Region account for 293.8 BCF of undiscovered technically-recoverable non-associated gas (Appendix A; Fig. 4). About 44 percent of this resource, or 129 BCF, was assigned to the Appalachian Basin.

Deep Continuous-type Plays

Deep continuous-type plays were not identified or assessed in the Eastern Region.

COMPARISON WITH OTHER RECENT NATIONAL ASSESSMENTS

The U.S. Geological Survey estimates that about 113.7 TCF of technically-recoverable undiscovered gas remains to be discovered from the deeper portions (depths of 15,000 ft and greater) of deep sedimentary basins in the United States . About one-half of this estimated resource (58.4 TCF; Table 3) is attributed to six continuous-type unconventional plays in the Greater Green River Basin of Wyoming, the Columbia Plateau of Washington, and the Uinta--Piceance Basin of Utah. About one-half of the remaining resource (27.4 TCF) occurs in conventional plays of the Gulf Coast Basin, and an additional one-third (17.9 TCF) in Alaska. Only 14 of 101 deep gas-bearing conventional plays are estimated to each contain more than 1 TCF of technically-recoverable undiscovered gas (Appendix A).

Table 3 lists undiscovered natural gas resources by region for four recent National petroleum assessments for which data are available at the regional level (refer also to Fig. 5). Totals include technically-recoverable conventional and unconventional resources and both non-associated and associated gas from oil fields below 15,000 feet. Bear in mind that each estimating group used different assessment methodologies and procedures including: geographic areas of coverage, entities assessed, definition of conventional versus unconventional resources, affiliation of province and regional experts, quantitative probability distributions and aggregations, assessment review process, method of subdividing resources by depth interval, and sources of data. For example, the Gas Research Institute (GRI) estimates include reserve growth for existing fields in their totals which have not been subdivided in their published reports. Other estimators reported totals for reserve growth separately. Refer to Dyman and Schmoker (in press) for a detailed discussion of the many areas in which these National petroleum assessments are different.

The GRI and National Petroleum Council (NPC) assessments were based on the GRI Hydrocarbon Supply Model, whereas the U.S. Geological Survey and Potential Gas Committee (PGC) assessments were based on a probabilistic analysis of geologically-based plays. The GRI total does not include Alaska deep gas because GRI did not subdivide Alaska data by depth. The GRI estimate, therefore, should be considered a minimum one. The NPC did not assess Alaska, and the PGC estimated only negligible gas in Alaska basins. Even if Alaska is excluded, the GRI estimate is still the largest (184 TCF; Fig. 5; Table 3).

Regional comparisons indicate significant differences in results. Even though the GRI estimate was the highest of the four groups, regional estimates, with the exception of the Gulf Coast Basin, are relatively low when compared to those of the other groups (Fig. 5). The U.S. Geological Survey Midcontinent Region estimate is noticeably low when compared to the others. Conversely, the U.S. Geological Survey Rocky Mountain Region estimate is noticeably high because of the inclusion of unconventional continuous-type plays (55.2 TCF). Variations in regional totals are partly due to differences in the way in which regions were defined geographically.

POTENTIAL ADDITIONAL RESOURCES AND AREAS OF FUTURE STUDY

An analysis of the U.S. Geological Survey 1995 National Oil and Gas Resource Assessment reveals many areas for future study, some of which could result in greater estimates of undiscovered deep gas resources. One such area involves re-evaluating and assessing existing conventional and continuous-type plays that were too poorly understood to assess in 1995. For

the 1995 assessment, five deep continuous-type plays were identified but not assessed because of a lack of basic geologic and petroleum-related information (Table 2). These basin-centered gas plays could contain significant undiscovered technically-recoverable resources. In addition to these plays, others may exist that were not previously identified. Rocky Mountain basins such as the Raton, Albuquerque, Wind River, and Crazy Mountains Basins, California basins, and the Midcontinent rift are possible areas to investigate.

An additional 61 deep conventional plays are listed in Appendix A, but have no undiscovered non-associated gas resources attributed to them. We feel that it is important to recognize these plays, and have included them in our Appendix. These plays include those that: (1) are oil plays, (2) were severely risked in that no gas was ultimately estimated for them, or (3) have a maximum depth of 15,000 ft and have no gas resource assigned to them below that depth. Fifteen deep conventional oil plays were identified in Appendix A, and gas resources other than associated gas were not estimated for them (gas fraction = 0). An example play in this category is the Cook Inlet Late Mesozoic Oil Play (305). An additional fourteen deep conventional gas plays (gas fraction greater than zero) were highly risked (probability 0.1 or less; Appendix A) and were not assessed. An example play in this category is the hypothetical Older Tertiary Play (1704) of the Idaho Snake River Downwarp Province. Risking hypothetical plays is a subjective process, and assigning even a slightly lower risk (higher probability of resources) based on geologic information could result in additional estimated undiscovered gas resources. Twenty-three deep conventional plays in Appendix A were assigned a maximum play depth of 15,000 feet. Many of these plays are hypothetical gas plays, and depth information for them is poorly known. An example in this category is the Southwest Oregon Eocene Gas Play (410), which is also highly risked (0.1).

Recommendations for future investigations based on results of the U.S. Geological Survey 1995 National Petroleum Assessment include:

1. Re-evaluate the geologic characteristics and drilling histories of existing and potential deep hypothetical plays as more data becomes available. These plays could contribute to estimates of additional deep gas resources as more data becomes available.
2. Conduct geologic studies to determine the spatial relationships between deep conventional and continuous-type plays in some deep basins. Conventionally-trapped deep gas plays may grade into basin-centered, continuous-type gas plays down-dip in the Appalachian, Anadarko, Wind River, and other basins of the United States.
3. Economic analysis of deep gas accumulations, leading to the resource category of economic, technically-recoverable, undiscovered gas. In this way the assessment will be further enhanced by the information necessary to subdivide resources into short, intermediate, and long-term categories based on economics.
4. Determine the existence and extent of continuous-type plays in basins for which they were not assessed previously. Continuous-type accumulations have been hypothesized for the Appalachian, Anadarko, and other basins (see Table 3).

Even though comparisons are difficult to make due to the many differences in procedures and methods by the different groups, the four estimates provide a range of values that can be used to develop National energy policy decisions.

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Table 1. Summary of significant reservoirs equal to or greater than 14,000 feet in depth in major deep basin areas of U.S. Based on data from NRG Associates Significant Field File (NRG Associates, 1990) and compiled in Dyman (1995). Significant reservoirs contain ultimate recoverable resources greater than 6 BCF of gas (equals 1 MMBO). Rec.= recoverable; res.= reservoirs; total of of 377 reservoirs used for U.S. Cumulative production and known recoverable natural gas in trillions of cubic feet (TCF). Cumulative gas= cumulative natural gas production through 1988; known rec.= known recoverable natural gas (cumulative production and reserves); strat= stratigraphically trapped reservoirs; carb= carbonate reservoirs. Percentages do not always add up to 100 percent due to rounding.

Location	Number of reservoirs and (percent of total number) (377)	Cumulative gas production and (percent of total gas) (21.4 TCF)	Known rec. gas and (percent of total gas) (33.2 TCF)	Stratigraphic and lithologic information	Comments
Rocky Mts	22 (6)%	0.4 (2)%	2.2 (7)%	Jurassic and Cretaceous clastic reservoirs and Paleozoic mixed carb/clastic reservoirs	Deep gas mostly from Utah-Wyoming thrust belt. Potential from Hanna and Wind River basins
Anadarko Basin	84 (22)%	2.4 (11)%	2.8 (8)%	Mostly a clastic basin. Some Cambrian-Silurian carbonate production	65% of reservoirs produce from Pennsylvanian strata
Permian Basin	89 (24)%	12.4 (58)%	15.1 (45)%	Middle Paleozoic mixed clastic/carb. reservoirs and Lower Paleozoic mostly carbonate res.	67 out of 89 reservoirs occur in Devonian or older rocks. Permian reservoirs are strat-igraphically-trapped
Gulf Coast Basin	174 (46)%	6.2 (29)%	12.8 (39)%	Tertiary reservoirs mostly clastic; Jurassic and Cretaceous reservoirs mixed carbonate/clastic	37% of deep reservoirs are Tertiary
Williston Basin	5 (1)%	0.1 (<1)%	<0.1 (<1)%	Ordovician Red River dolomitic reservoirs	Structurally trapped
California/ Alaska	3 (<1)%	<0.1 (<1)%	0.3 (1)%	Tertiary clastic reservoirs	Structural and stratigratigraphic traps

Table 2. Deep continuous-type gas plays of the U.S. Geological Survey 1995 National Petroleum Assessment. Includes both assessed and unassessed plays with maximum depths of 15,000 feet or greater. Mean value of undiscovered gas resources only for that portion of play at or below 15,000 feet; in billions of cubic feet (BCF). Minimum (min), median (med), and maximum (max) depth for assessed plays in feet. Refer to Schmoker and Oscarson (1995) for geologic description of each play.

Province number--name	Play name (number)	Depth min	Depth med	Depth max	Undiscovered gas (BCF)
04--Western Oregon-Wash.	Willamette-Puget Sound Basin-Centered Gas (412)		not assessed		
05--Eastern Oregon-Wash.	Columbia Basin-Basin--Centered Gas (503)	9,500	13,000	17,500	2,636
14--Los Angeles Basin	Deep, Overpressured Fractured Rocks of the Central Syncline (1408)		not assessed		
20--Uinta-Piceance Basin	Deep Synclinal Uinta Mesaverde (2020)	15,000	18,000	24,000	570
34--Big Horn Basin	Basin-Center Gas (3404)		not assessed		
35--Wind River Basin	Basin-Center Gas (3505)		not assessed		
37--Southwestern Woming	Green River Basin-Cloverly-Frontier (3740)	11,500	17,000	22,000	25,004
	Green River Basin-Mesaverde (3741)	8,500	15,000	21,000	25,848
	Green River Basin-Lewis (3742)	10,500	12,000	19,000	4,265
	Green River Basin-Fort Union (3744)	9,500	10,200	17,000	95
58--Anadarko Basin	Woodford/Chattanooga/Arkansas Novaculite of Midcontinent (5811)		not assessed		
Total				58,418	

Table 3. Estimates of undiscovered natural gas by region for depths of 15,000 feet or greater from recent National Petroleum Council (NPC), Potential Gas Committee (PGC), U.S. Geological Survey (USGS), and Gas Research Institute (GRI) assessments. Data are mean estimates, except for PGC column where they represent most likely values. Regional boundaries vary for each assessment. Gas in billions of cubic feet (BCF). Data include associated gas from oil accumulations and non-associated gas. Onshore regions and state waters only. Only total column available for GRI and PGC assessments. Unconventional gas here primarily includes gas in low-permeability (tight) sandstones. Undiscovered volumes of gas under different categories may vary due to the way in which a category is defined. For example, the U.S. Geological Survey estimate includes continuous-type sandstones based on geologic criteria, whereas the PGC, GRI, and NPC identifies tight sandstones based on Federal Energy Regulatory Commission-designated criteria. Resource estimates based on current technology case only. Plus sign (+) indicates that GRI data for Alaska not broken out by depth and not included (total GRI Alaska resource is 121,453 BCF). Letter t indicates that resource estimates identified for designated region tabulated elsewhere. Asterisk (*) indicates that GRI total includes natural gas attributed to reserve growth in existing fields. Gas volumes rounded to nearest BCF. Individual estimates may or may not include State offshore waters. USGS estimates do not include undiscovered gas from small fields (less than 6 BCFG).

Region	National Petroleum Council (NPC) 1992[1]			Potential Gas Committee (PGC) 1995[1]	U.S. Geological Survey (USGS) 1995[1]			Gas Research Institute (GRI)* 1995[1]
	Conventional	Unconventional	Total	Total	Conventional	Unconventional	Total	Total
Alaska	not assessed			0	17,936	0	17,935	+
Pacific	4,258	0	4,258	1,450	550	2,636	3,186	4,916
Rocky Mts.	11,728	8,992	20,721	36,234	1,946	55,212	55,158	44,303
Colorado Plateau	t	t	t	t	130	570	700	t
W. Texas-E. New Mex.	12,328	0	12,328	t	4,705	0	4,426	32,734
Gulf Coast	25,124	917	26,041	44,600	27,439	0	27,404	66,034
Midcontinent	16,414	5,471	21,885	35,204	2,264	0	2,264	34,133
Eastern	2,159	0	2,159	12,800[2]	294	0	294	2,133
Total	72,011	15,381	87,392	130,288	55,264	58,418	113,681	184,253

[1] Refer to National Petroleum Council (1992), Potential Gas Committee (1995), Gautier and others (1995), Woods (1993), Vidas and others (1993), and Gas Research Institute (1995) for detailed explanations of assessments.

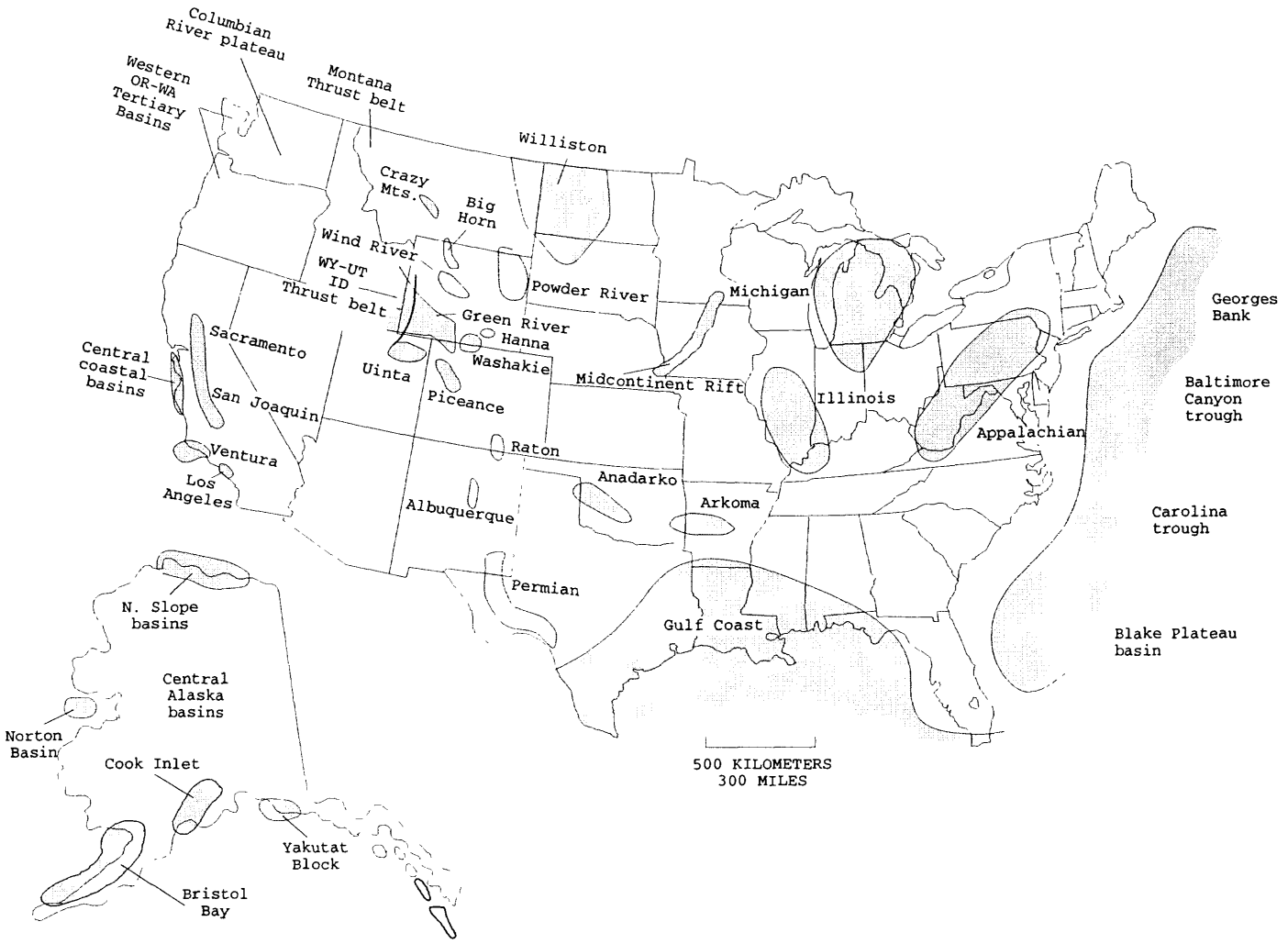

Figure 1. Generalized map of conterminous United States and Alaska showing basins containing rocks greater than 15,000 feet (about 4,600 m) deep. Shaded areas represent entire basins. WY-UT-ID = Wyoming- Utah-Idaho. Federal offshore areas identified but not discussed in report. Some small areas and basins listed in Appendix A are not identified on the map.

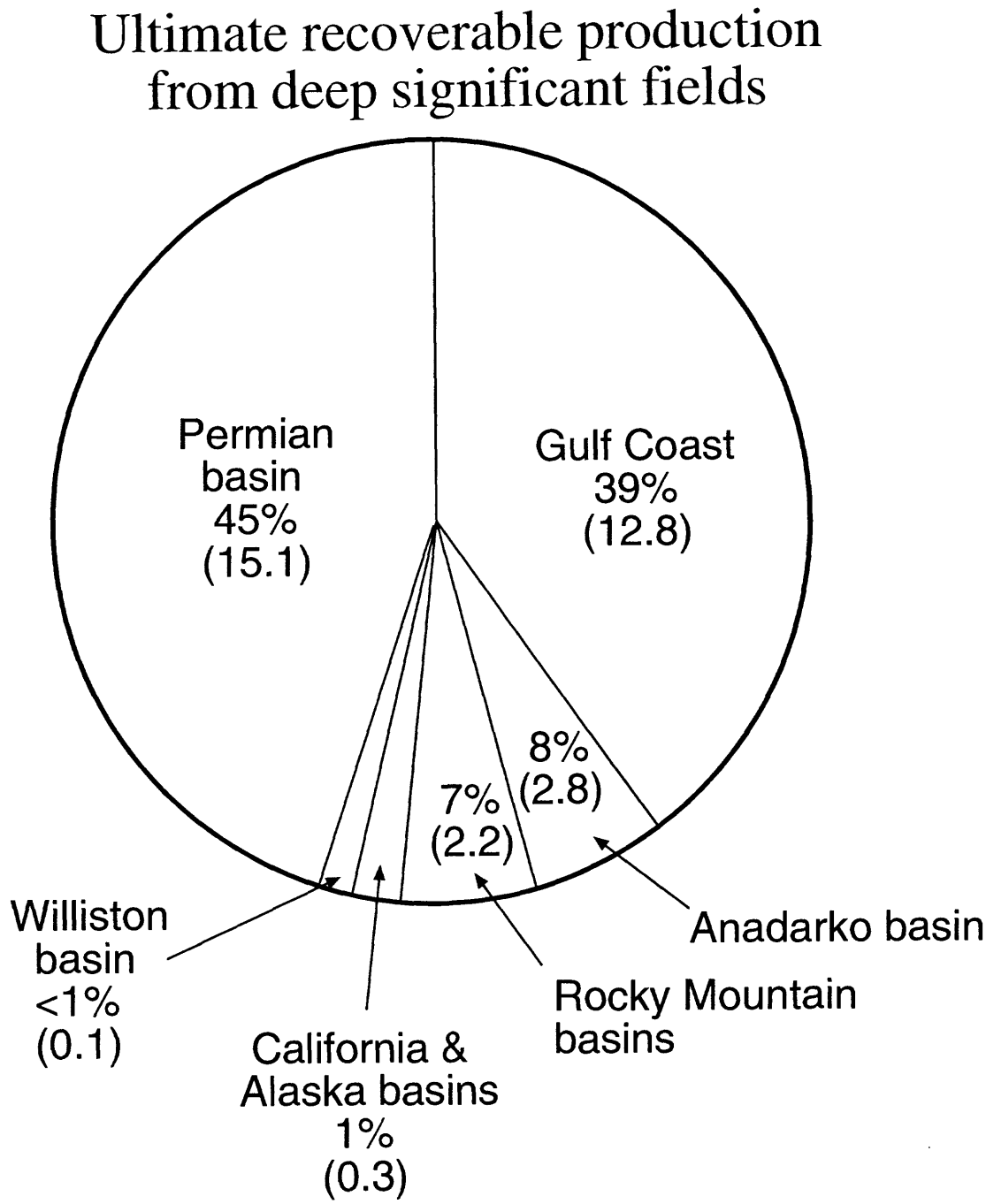

Figure 2. Pie chart illustrating the distribution of known ultimate recoverable gas from deep significant fields by region in the U.S. Numbers in parentheses represent estimates in trillions of cubic feet of natural gas (TCFG) taken from NRG Associates file for reservoirs below 14,000 feet in the U.S. (NRG Associates, 1990). Percent for each region based solely on NRG Associates data. Small fields not included. Refer to Table 1 for data summary.

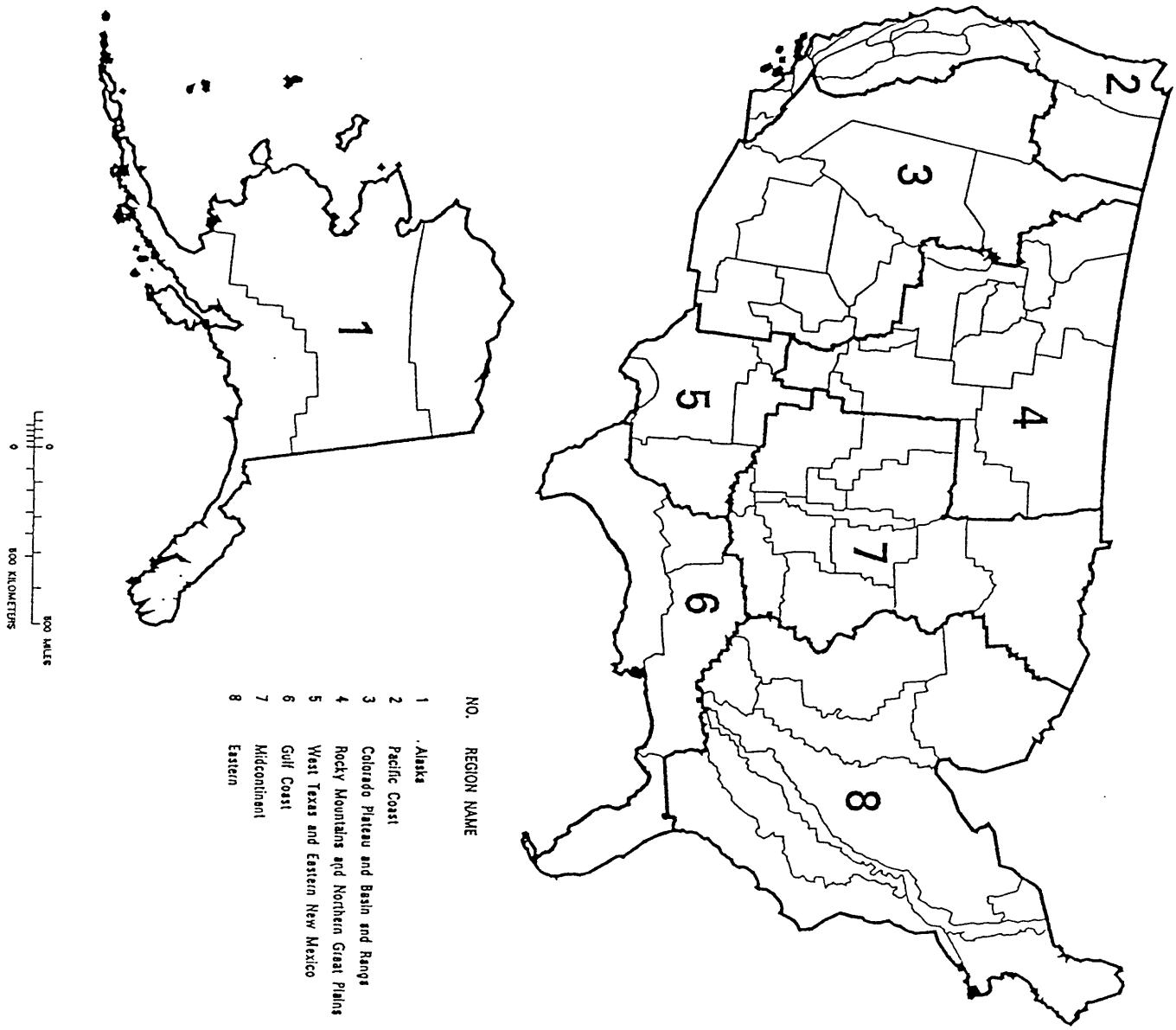

Figure 3. Map of United States showing province and region boundaries for U.S. Geological Survey 1995 National petroleum assessment (from U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995).

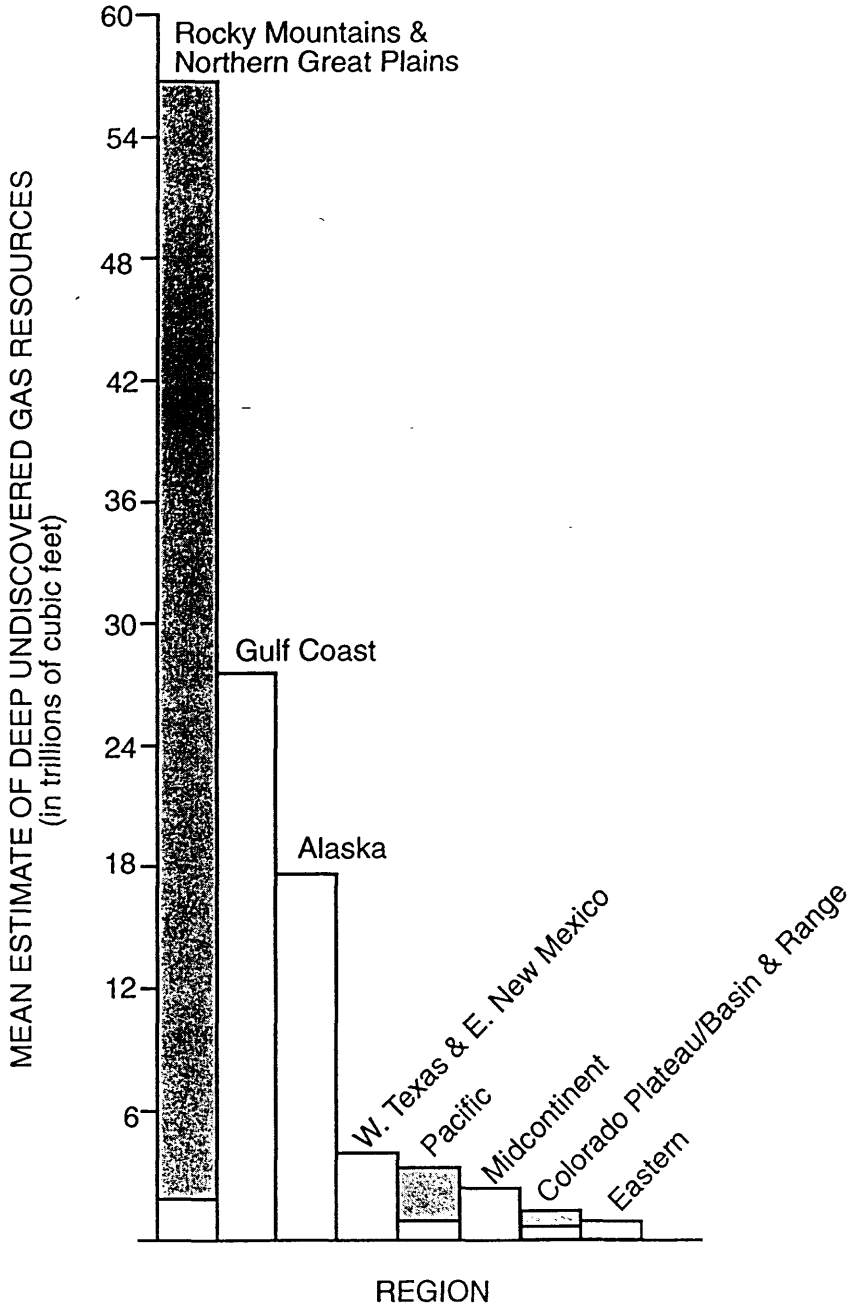

Figure 4. Histogram illustrating distribution of estimates of deep undiscovered technically-recoverable gas by region in the United States for the 1995 U.S. Geological Survey National assessment of oil and gas resources. Shaded portion included resources attributed to continuous-type plays for each region. Resources include both non-associated gas and associated gas from oil fields. Mean estimate shown. Refer to Table 2 for data summary.

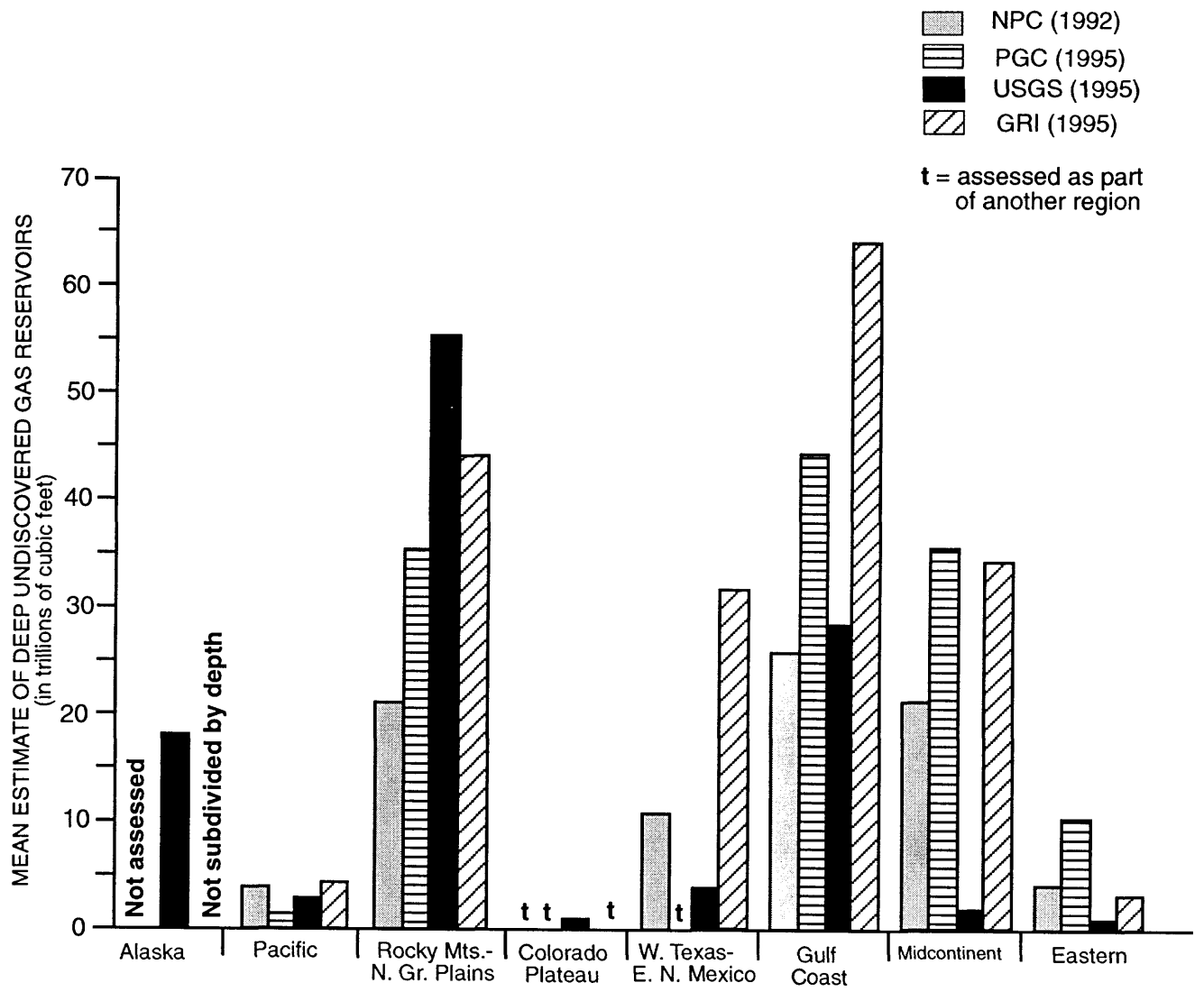

Figure 5. Histogram illustrating distribution of estimated deep undiscovered technically-recoverable gas by region in the United States for recent National petroleum assessments including the National Petroleum Council (1992), Potential Gas Committee (1995), U.S. Geological Survey (1995), and Gas Research Institute (1995). Resources include both non-associated gas and associated gas from oil fields. Refer to Table 3 for data summary and explanation of differences.

Appendix A. Undiscovered technically-recoverable deep gas resources for conventional petroleum plays extending to depths equal to or greater than 15,000 feet in the U.S. Only a part of some plays occurs below 15,000 feet. Play definitions compiled from data by province geologists (Gautier and others, 1995). C, confirmed play with known production; H, hypothetical play; min, minimum depth of play; med, median depth of play; max, maximum depth of play; Prob, the probability of undiscovered accumulations of at least 6 BCF of gas or 1 MMBO in play where play is hypothetical; Gas fraction, fractional distribution of undiscovered non-associated gas accumulations expected in this play where 0.0 indicates an oil play and 1.0 indicates a non-associated gas play. Blank indicates no data available. Refer to Table 2 for undiscovered resources in unconventional continuous-type plays. Question mark indicates highly interpretive or speculative data. Play numbers correspond to play numbers in Gautier and others (1995). Non-associated gas only listed for portion of play below 15,000 feet and in billions of cubic feet. Where non-associated gas volumes are zero, play may be entirely an oil play, play may be highly risked (resources unlikely), or maximum depth of play is 15,000 feet and undiscovered resources were allocated to shallower depths. Numbers in parentheses after region and province names represent total undiscovered technically-recoverable conventional gas volumes where first number is non-associated gas, second number is associated gas from oil fields, and third number after equal sign (only for region) is total gas (BCFG).

Region and Province	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas vol.
Region 1-Alaska (17,664.4; 271.4=17,935.8)								
Northern Alaska (17,588.4; 127.8)	102 Turbidite	C	1.0	500	8000	25000	0.2	433.5
	103 Barrow Arch Beaufortian	C	1.0	1500	7000	15000	0.3	0.0
	104 Barrow Arch Ellesmerian	C	1.0	2200	10000	15300	0.0	0.0
	105 Ellesmereian-Beaufortian Clastics	C	1.0	2000	10000	26000	1.0	1,631.8
	106 Lisburne	H	0.5	9000	25000	30000	1.0	3,435.3
	107 Lisburne Unconformity	H	0.6	8500	25000	30000	gas	0.0
	108 Endicott	H	1.0	9500	25000	30000	gas	0.0
	109 Fold Belt	C	1.0	100	4000	25000	0.8	2,340.2
	110 Western Thrust Belt	H	0.2	1000	10000	35000	0.6	679.2
	111 Eastern Thrust Belt	C	1.0	2000	13000	25000	0.7	9,068.4
Central Alaska (0.0; 0.0)	201 Central Alaska Cenozoic Gas	H	0.1			15000?	gas	0.0
	203 Central Alaska Paleozoic Oil	H	0.1			15000+	oil	0.0
	204 Kandik Pre-Mid Cretaceous Strata	H	0.1			15000+	gas?	0.0
Southern Alaska (76.0; 143.6)	301 Alaska Peninsula Mesozoic	H	<0.1	2000		20000	gas	0.0
	302 Alaska Peninsula Tertiary	H	<0.1	5000		15000+	gas	0.0
	303 Cook Inlet-Beluga-Sterling Gas	C	1.0	2000	4000	20000	1.0	76.0
	304 Cook Inlet Hemlock-Tyonek Oil	C	1.0	5000	10000	18000	0.0	0.0
	305 Cook Inlet Late Mesozoic Oil	H	<0.1			15000	oil	0.0
	307 Copper River Mesozoic Oil	H	<0.1			15000	oil	0.0
	308 Gulf of Alaska Yakataga Fold Belt	H	0.7	0		28000+	oil	0.0
	309 Gulf of Alaska Yakutat Foreland	H	0.4	1600		28000+	oil	0.0

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas volume
Region 2-Pacific (208.3; 341.3= 549.6)								
Western Oregon and Washington (15.2; 3.0)	403 Puget Lowland Deep Gas	H	0.1	10000	15000	20000	1.0	13.4
	404 Tofino-Fuca Basin Gas	H	0.2	500	6000	20000	1.0	1.8
	405 Western Washington Melange	H	0.5	100	9000	18000	0.0	0.0
	410 Southwest Oregon Eocene Gas	H	0.1	500	3000	15000	1.0	0.0
Eastern Washington-Oregon (0.0; 0.0)	501 Northwestern Columbia Plateau Gas	H	0.6	500	8000	15000	1.0	0.0
Northern California Coastal (0.0; 0.0)	703 Sargent/Hollister Oil and Gas	C	1.0	1000	2000	15000	0.5	0.0
Sonoma-Livermore Basin (0.6; 0.1)	801 Sonoma-Livermore	C	1.0	1000	6000	16000	0.5	0.6
Sacramento Basin (94.7; 0.0)	902 Southern Forbes-Kione	H	0.4	4000	8000	20000	1.0	57.2
	903 Western Winters through Domingene	C	1.0	2000	7000	16000	1.0	37.5
San Joaquin Basin (0.0; 270.9)	1003 Lower Bakersfield Arch	C	1.0	5600	8500	18000	0.0	0.0
	1004 West Side Fold Belt Sourced by Post-Lower Miocene Rocks	C	1.0	800	9000	18000	0.0	0.0
	1005 West Side Fold Belt Sourced by Pre-Middle Miocene Rocks	C	1.0	300	9000	22000	0.0	0.0
	1008 Tejon Platform	C	1.0	500	6000	15000	0.0	0.0
	1009 Southern End Thrust Salient	C	1.0	2000	9000	16000	0.0	0.0
	1011 Deep Overpressured Fractured Rocks of West Side Fold and Overthrust Belt	H	<0.1	18000		25000	gas	0.0
Central Coastal Basins (0.0; 0.0)	1104 La Honda Oil	C	1.0	0	1800	15000	0.0	0.0
Ventura Basin (97.8; 67.3)	1301 Paleogene - Onshore	C	1.0	1000	7000	20000	0.4	25.6
	1302 Neogene - Onshore	C	1.0	500	8000	20000	0.0	0.0
	1304 Cretaceous	H				15000+	gas?	0.0
	1311 Paleogene-Offshore State Waters	C				15000+	gas	72.2
Region 3-Colorado Plateau and Basin and Range (127.0; 2.7= 129.7)								
Idaho Snake River Downwarp (2.1; 0.0)	1701 Miocene Lacustrine (Lake Bruneau)	H	0.2	5000	7000	15000	0.6	2.1
	1703 Pre-Miocene	H	0.1	4000	6000	15000	0.6	0.0
	1704 Older Tertiary	H	0.1	10000	15000	25000	0.9	0.0

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non assoc. gas volume
Western Great Basin (1.2; 0.0)	1801 Hornbrook Basin--Modoc Plateau	H	0.1	4500	9000	15000	0.9	0.0
	1803 Permian-Triassic Source Rocks Northwestern Nevada and East Central and Eastern Oregon	H	0.2	5000	10000	25000	0.5	1.2
	1804 Cretaceous Source Rocks, Northwestern Nevada	H	0.1	4500	9000	15000	0.1	0.0
	1805 Neogene Source Rocks, Northwestern Nevada and Eastern California	H	0.1	4500	12000	25000	gas?	0.0
Eastern Great Basin (41.8; 1.7)	1902 Late Paleozoic	H	0.2	3000	8000	20000	0.2	3.0
	1905 Younger Tertiary Basins							4.1
	1906 Late Paleozoic-Mesozoic (Central Nevada) Thrust Belt	H	0.2	3000	12000	20000	0.0	0.0
	1907 Sevier Frontal Zone	H	0.4	6500	12000	20000	gas	34.7
Uinta-Piceance Basin (7.9; 1.0)	2014 Basin Margin Subthrusts	H	0.1	6000	14000	20000	0.6	7.9
Paradox Basin (6.5; 0.0)	2101 Buried Fault Blocks, Older Paleozoic	C	1.0	6000	9000	15000	0.4	0.0
	2104 Permian-Pennsylvanian Marginal Clastic	H	0.4	3000	7000	20000	0.8	6.5
	2105 Salt Anticline Flank	C	1.0	3000	5000	15000	0.7	0.0
Albuquerque Basin--Sante Fe Rift (50.2; 0.0)	2301 Albuquerque Basin	H	0.5	8000	12000	20000	0.8	50.2
	2305 San Juan Sag	H	0.6	3000	7000	15000	0.0	0.0
Northern Arizona (17.3; 0.0)	2403 Late Proterozoic (Chuar-Sourced) and Lower Paleozoic	H	0.3	6000	9000	20000	0.5	17.3
Southern Arizona--SW New Mexico (0.0; 0.0)	2501 Alamo Hueco Basin	H	0.1	1500	12000	25000	0.4	0.0
	2502 Pedregosa Basin	H	0.1	5000	10000	17000	0.4	0.0
South-Central New Mexico (0.0; 0.0)	2602 Orogrande Basin	H	<0.1	2000	10000	24000	0.5	0.0
	2603 Mesilla--Mimbres Basins	H	<0.1	5000	14000	24000	0.4	0.0
Region 4-Rocky Mountains (1,859.2; 86.9= 1,946.1)								
Montana Thrust Belt (263.7; 0.1)	2701 Imbricate Thrust Gas	C	0.3	3000	12000	19000	0.95	256.3
	2704 Helena Salient Gas	H	0.5	500	9000	20000	1.0	6.9
	2706 Tertiary Basins Oil and Gas	H	0.3	2000	8000	16000	0.8	0.5

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas volume
Southwest Montana (30.2; 0.0)	2901 Crazy Mountains and Lake Basins Cretaceous Gas	C	1.0	1000	5000	20000	1.0	26.0
	2904 Beartooth Frontal Oil and Gas	H	0.4	4000	12000	20000	0.4	2.7
	2907 Tertiary Basins Oil and Gas	H	0.2	200	12000	18000	0.8	1.5
Williston Basin (13.4; 0.0)	3102 Red River (Ordovician)	C	1.0	7000	13000	16000	0.5	0.0
	3106 Post Madison through Triassic Clastic	C	1.0	10000	13000	16000	1.0	0.0
	3107 Pre-Red River Gas	C	1.0	12000		16000+	1.0	13.4
Powder River Basin (0.0; 0.4)	3301 Basin Margin Subthrust	H	0.4	5000	12000	15000	0.0	0.0
	3304 Upper Minnelusa Sandstone	C	1.0	5000	85000	15000	0.0	0.0
Big Horn Basin (58.4; 0.0)	3401 Basin Margin Subthrust	H	0.5	5000	12000	20000	0.3	10.1
	3403 Deep Basin Structure	C	1.0	8000	14000	20000	1.0	48.3
Wind River Basin (131.3; 2.8)	3501 Basin Margin Subthrust	C	1.0	5000	12000	20000	0.3	32.7
	3503 Deep Basin Structure	C	1.0	1300	85000	24000	0.9	86.8
	3504 Muddy Sandstone Stratigraphic	C	1.0	5000	12000	16000	0.3	11.8
	3506 Phosphoria Stratigraphic	H	0.8	2000	11000	20000	0.0	0.0
Wyoming Thrust Belt (1161.3; 61.0)	3601 Moxa Arch Extension	C	1.0	10000	14000	18000	1.0	953.0
	3602 Crawford--Meade Thrusts	H	1.0	4500	11000	17500	1.0	48.7
	3603 Northern Thrusts	H	1.0	4500	10000	15000	0.7	0.0
	3604 Absaroka Thrust	C	1.0	5000	10000	18000	0.8	118.7
	3606 Hogsback Thrust	C	1.0	6000	10000	17000	0.6	40.8
	3607 Cretaceous Stratigraphic	C	1.0	1000	8000	17000	0.0	0.0
Southwestern Wyoming (153.2; 22.6)	3701 Rock Springs Uplift	C	1.0	1500	6000	18000	0.8	18.4
	3702 Cherokee Arch	C	1.0	1500	5000	20000	0.3	18.4
	3703 Axial Uplift	C	1.0	2000	6000	15000	0.3	0.0
	3704 Moxa Arch--LaBarge	C	1.0	1200	10000	18000	0.7	45.5
	3705 Basin Margin Anticline	C	1.0	4000	14000	30000	0.6	44.3
	3706 Subthrust	H	0.8	5000	12000	30000	0.4	26.6

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas volume
Region 5-West Texas and Eastern New Mexico (4,698.2; 6.3= 4,704.5)								
Permian Basin (4,408.5; 6.3)	4401 Pre-Pennsylvanian, Delaware-Val Verde Basins	C	1.0	8400	16000	24000	1.0	2,337.8
	4402 Pre-Pennsylvanian, Central Basin Platform	C	1.0	4000	10000	15500	0.2	0.0
	4404 Lower Pennsylvanian (Bend) Sandstone	C	1.0	8000	11000	16500	0.8	278.7
	4406 Upper Pennsylvanian, Northwestern and Eastern Shelves, Northern Delaware and Midland Basins and Northern Central Basin Platform	C	1.0	5000	11000	16000	0.2	23.8
	4412 Delaware Sandstones	C	1.0	5000	11000	16000	0.3	33.7
Marathon Thrust Belt (11.0; 0.0)	4601 Frontal Zone Oil and Gas	C	1.0	3500	9000	18000	0.4	11.0
Region 6-Gulf Coast (27,382.2; 56.3= 27,438.5)								
Western Gulf Basin (19,108.1; 6.4)	4701 Houston Salt Dome Flank Oil and Gas	C	1.0	250		16000	0.6	34.2
	4702 Norphlet South Texas Deep Gas	H	0.8	14000	18000	22000	1.0	505.6
	4703 Smackover South Texas Gas	C	1.0	10000	16000	22000	1.0	635.9
	4704 Cotton Valley Western Gulf Gas and Oil	C	1.0	3000	12000	20000	0.7	83.0
	4705 Lower Cretaceous Carbonate Shelf/ Shelf Edge Gas and Oil	C	1.0	6000	14000	20000	0.7	881.5
	4709 Tuscaloosa Deep Sandstone Gas	C	1.0	12000	17000	22000	1.0	4,800.0
	4710 Woodbine South Angelina Flexure Oil and Gas	C	1.0	7000	14000	20000	0.3	299.3
	4720 Lower Wilcox Downdip Over-pressured Gas	C	1.0	8000	16000	20000	1.0	1,820.4
	4723 Upper Wilcox Downdip Over-pressured Gas	C	1.0	8000	16000	22000	1.0	3,368.8
	4724 Middle Eocene Sandstones Downdip Gas	C	1.0	8000	12000	18000	0.9	211.6
	4727 Yegua Downdip Gas	C	1.0	8000	14000	22000	1.0	2,117.3
	4729 Jackson Downdip Gas	H	0.5	6000	14000	22000	1.0	1,252.0
	4731 Vicksburg Downdip Gas	C	1.0	7000	14000	22000	1.0	639.4
	4732 Frio South Texas Downdip Oil and Gas	C	1.0	6000	12000	18000	1.0	154.3

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas volume
	4735 Frio SE Texas/S. Louisiana Mid-dip Gas and Oil	C	1.0	6000	12000	16000	0.6	62.0
	4736 Frio SE Texas/S. Louisiana Downdip Gas	C	1.0	8000	14000	20000	1.0	558.8
	4738 Anahuac Sandstone Gas and Oil	C	1.0	8000	15000	20000	0.7	236.6
	4740 Lower Miocene Deltaic Sandstone Gas and Oil	C	1.0	3000	10000	16000	0.7	44.1
	4741 Lower Miocene Slope and Fan Sandstone Gas	C	1.0	8000	14000	20000	1.0	1,123.2
	4742 Middle Miocene Fluvial Sandstone Gas and Oil	C	1.0	1000	10000	17000	0.8	68.5
	4743 Middle Miocene Deltaic Sandstone Gas and Oil	C	1.0	8000	14000	20000	0.8	131.9
	4744 Upper Miocene Fluvial Sandstone Gas and Oil	C	1.0	1000	8000	16000	0.4	3.5
Western Gulf Basin continued	4745 Upper Miocene Deltaic Sandstone Gas and Oil	C	1.0	4000	14000	20000	0.6	96.8
Louisiana--Miss. Salt Basins (8,239.0; 49.9)	4901 Piercement Salt Dome Flanks Oil and Gas	C	1.0	4000	10000	16000	0.7	31.9
	4903 Norphlet Mobile Bay Deep Gas	C	1.0	17000	20000	24000	1.0	5,259.6
	4904 Norphlet Wiggins - Hancock Arch Gas	H	0.6	13000	17000	21000	1.0	233.3
	4905 Norphlet Salt Basin Oil and Gas	C	1.0	8000	12000	17000	0.0	213.4
	4906 Norphlet Alabama Updip Oil	H	0.5	8000	12000	16000	0.0	0.0
	4907 Norphlet SE Margin Jackson Dome Flank Deep Gas	H	0.5	20000	22000	24000	1.0	111.1
	4909 Smackover Wiggins - Baldwin Flanks Gas	C	1.0	12000	16000	20000	1.0	356.5
	4910 Smackover Alabama/Florida Peripheral Fault Zone Oil and Gas	C	1.0	10000	15000	20000	0.3	319.9
	4912 Smackover Salt Basins Gas and Oil	C	1.0	8000	12000	18000	0.6	180.5
	4913 Smackover Jackson Dome Deep Gas	C	1.0	20000	21000	23000	1.0	259.8
	4918 Haynesville Salt Basins Gas and Oil	C	1.0	6000	14000	20000	0.9	379.9
	4920 Gilmer Limestone Gas	C	1.0	10000	14000	18000	1.0	367.0
	4921 Cotton Valley Updip Oil	C	1.0	2000	10000	18000	0.0	0.0
	4922 Cotton Valley Salt Basins Gas	C	1.0	8000	14000	20000	1.0	155.8
	4925 Hosston Updip Oil	C	1.0	4000	9000	16000	0.0	0.0

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas volume
	4926 Hosston/Travis Peak Salt Basins Gas	C	1.0	4000	12000	18000	1.0	240.8
	4929 Sligo/Pettet Salt Basins Gas	C	1.0	5000	11000	16000	1.0	16.2
	4931 James Limestone Gas	C	1.0	8000	11000	16000	gas?	61.0
	4933 Glen Rose/Rodessa Salt Basins Gas	C	1.0	3000	10000	16000	1.0	52.3
	4935 Paluxy Downdip Gas	C	1.0	4000	10000	16000	1.0	0.0
Florida Peninsula (0.0; 0.0)	5006 Wood River Dolomite Deep Gas	H	0.1	14000	16000	19000	oil?	0.0
Region 7-Midcontinent (2,264.1; 0.0= 2,264.1)								
Superior (85.5; 0.0)	5101 Precambrian Midcontinent Rift System	H	0.4	5000	10000	25000	0.6	85.5
Anadarko Basin (2067.3; 0.0)	5801 Deep Structural Gas	C	1.0	13000	17000	40000	1.0	770.0
	5812 Deep Stratigraphic Gas	C	1.0	13000	15000	30000	1.0	1,297.3
	5827 Washes	C	1.0	500	9400	15000+	0.8	0.0
Southern Oklahoma (107.8; 0.0)	6101 Deep Gas	C	1.0	13000	15000	40000	1.0	107.8
Arkoma Basin (3.5; 0.0)	6205 Arbuckle through Misener Basement Fault and Shelf Gas	C	1.0	4000	8000	15000	1.0	0.0
	6206 Cromwell-Spiro-Wapanucka Sub-Choctaw Thrust Gas	C	1.0	7000	12000	15000	1.0	0.0
	6207 Carboniferous Turbidite Thrust Belt Gas	H	0.2	6000	13000	20000	1.0	3.5
Region 8-Eastern (293.8; 0.0= 293.8)								
Michigan Basin (0.0; 0.0)	6315 Precambrian Rift	H	0.1	10000	20000	30000	1.0	0.0
Illinois Basin (102.7; 0.0)	6405 Illinois Basin - Rough Creek Graben	H	1.0	4500	12000	19000	1.0	102.7
Black Warrior Basin (61.5, 0.0)	6501 Cambrian and Ordovician Carbonate	H	1.0	1000	10000	25000	0.8	42.3
	6502 Upper Mississippian Sandstone	C	1.0	2500	8000	16000	0.8	14.1
	6503 Pennsylvanian Sandstone	C	1.0	1500	7000	15000	1.0	0.0
	6505 Devonian Chert and Carbonate	H	0.8	2000	8000	18000	1.0	5.1

Province name	Play number and name	Status	Prob	Depth (feet) min	Depth (feet) med	Depth (feet) max	Gas fraction	Non-assoc. gas volume
Appalachian Basin (129.6; 0.0)	6701 Rome Trough	H	0.8	6000	10000	25000	1.0	26.7
	6702 Upper Cambrian, Ordovician, and Lower/Middle Sulurian Thrust Belt	C	1.0	1000	10000	20000	1.0	40.1
	6703 Beekmantown/Knox Carbonate Oil/Gas	C	1.0	2500	10000	18000	0.5	26.9
	6704 Rose Run/Gatesburg/Theresa Sandstone Gas	C	1.0	5000	9000	20000	1.0	35.9
	6706 Trenton/Black River Carbonate Oil and Gas	C	1.0	1000	8000	15000	0.5	0.0
Blue Ridge Thrust Belt (0.0; 0.0)	6801 Southern Appalachians Sub-Thrust Sheet	H	<0.1			>15000	1.0	0.0