Chapter AO

ASSESSMENT OVERVIEW

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ABSTRACT

To fulfill its mission of providing timely earth-science information needed for policy decisions, and in the absence of recent petroleum assessments, the U.S. Geological Survey (USGS) has completed a re-assessment of the petroleum potential of the 1002 area of the Arctic National Wildlife Refuge (ANWR) as well as the adjacent Native and State offshore lands.

This re-assessment is a comprehensive three-year study by a large team of USGS scientists. Geologic studies were done in collaboration with scientists from other agencies and universities, but the estimation of oil and gas resources was conducted entirely by USGS staff and contractors. The previous USGS assessment of this area was completed in 1987. Since then, numerous wells have been drilled and oil accumulations have been discovered near the 1002 area, new geologic and geophysical data have become available, seismic processing and interpretation capabilities have improved, and the economics of North Slope oil development have changed significantly. This study incorporates all available public data, and includes new field and analytic work as well as the re-evaluation of all previous work.

Using a method similar to that employed in previous USGS assessments in the ANWR and in the National Petroleum Reserve-Alaska (NPRA), this study estimated in-place, technically recoverable, and economically recoverable oil and gas resources in ten petroleum plays.

The total quantity of in-place oil in the 1002 area is estimated to range from a high-side (F_5) of 31.5 BBO to a low side (F_{95}) of 11.6 BBO with a mean (expected value) of 20.7 BBO. The total quantity of technically recoverable oil in the 1002 area is estimated to range from a high-side (F_5) of 11.8 BBO to a low side (F_{95}) of 4.3 BBO with a mean (expected value) of 7.7 BBO. Quantities of economically recoverable oil are reported as a set of curves (incremental cost functions) associated with the 95th and 5th fractiles and mean estimate. The curves show increasing amounts of economically recoverable oil with increasing price. The mean estimate shows that at a market price of 15 dollars per barrel no economic oil exists in the 1002 area. At 16 dollars per barrel, about 1 BBO are economically recoverable, and at 20 dollars per barrel, about 3 BBO are economically recoverable. Natural gas is considered to be non-economic for at least two decades.

Numerous prior assessments of the oil and gas resources of the Arctic National Wildlife Refuge have been made by the USGS as well as other

state, federal, and private agencies. Except for previous USGS assessments which used similar methods, direct comparison of estimated resources from this assessment with those of most previous assessments is precluded because of different methods and assumptions. With those limitations in mind, the amount of oil estimated for the 1002 area in this assessment is generally larger than that of most previous estimates. The increase results in large part from improved resolution of reprocessed seismic data and geologic information provided by recent nearby wells drilled outside the 1002 area, some of which have discovered producible quantities of oil.

INTRODUCTION

The USGS is commonly asked to provide the Federal Government with timely scientific input in support of decisions regarding land management, environmental quality, and economic and strategic policies. To do so, the USGS must anticipate issues most likely to be the focus of policy makers in the future. In anticipation of the need for such scientific information and because no recent assessment existed, the USGS has conducted new geologic studies of the Arctic National Wildlife Refuge 1002 area and prepared a new petroleum resource assessment.

The 1002 area, which constitutes about 8-percent (1.5-million acres) of the total area of the Arctic National Wildlife Refuge, is currently off-limits to petroleum exploration and without known petroleum accumulations (Fig. AO1). By all accounts, it is the only part of the Refuge with significant petroleum potential. Situated along the Arctic coast north of the Brooks Range, the 1002 area lies between the major oil fields at Prudhoe Bay that provide nearly one-quarter of daily United States oil production and the Mackenzie delta where nearly 50 petroleum discoveries have been made. The 1002 area is rich in wildlife resources, and because of this the area has been the focus of debate arising from a perceived conflict between oil development and preservation of wildlife and habitat.

In 1980, the Alaska National Interest Lands Conservation Act, Section 1002, provided for a detailed and comprehensive evaluation of the fish and wildlife and petroleum resources in the coastal plain ("1002 area") of the Arctic National Wildlife Refuge. A report to the Congress on those resources was also stipulated. In 1987, the Department of the Interior submitted that report (Clough and others, 1987), an effort jointly authored by the Fish and Wildlife Service, the Bureau of Land Management (BLM), and the USGS. The geologic summary and the in-place petroleum assessment of that report were provided by the USGS and the economic petroleum assessment was provided by the BLM. Later that same year, technical details of the USGS and BLM petroleum evaluation were published in USGS Bulletin 1778 (Bird and Magoon, 1987).

Since completion of that assessment, numerous wells have been drilled and oil accumulations have been discovered near the 1002 area (Fig. AO2). In addition, new geologic and geophysical data have become available, seismic processing and interpretation capabilities have improved, and the economics of North Slope oil development have changed significantly. The current study, the first comprehensive re-evaluation since 1987, incorporates these recent findings and developments.

In keeping with the USGS responsibility for assessing the petroleum potential of all onshore and state-water areas of the U.S., the total assessment area was extended offshore to the 3-mile boundary between State and Federal jurisdiction. Thus, in addition to the Federal lands of the 1002 area, the assessment includes resources associated with adjacent State waters and Native lands (Fig. AO2). Petroleum commodities assessed include crude oil, natural gas, and natural gas liquids.

This publication sets out the petroleum geology data and interpretations used in assessing the oil and gas resources of the study area; it describes the assessment techniques, presents the assessment results, and provides a comparison with previous assessments. Data from this study add to a foundation of geologic studies in this area, conducted in large part by the USGS, now spanning about nine decades. This chapter is intended to provide both background information and an overview of the current study.

ASSESSMENT PROJECT

The new USGS assessment involved nearly three years of study by USGS scientists and contractors, who coordinated their work with colleagues in other Federal agencies, Alaska State agencies, and several universities (Table AO1). A total of 46 USGS scientists worked on the project at some time during its 3-year life. Some were involved for as little as one week of field work, several retired part way through the project, others were transferred to other assignments, and some joined the project after its start. The overall level of involvement was about one-third time.

Project members and collaborators were widely disbursed geographically and coordination of effort presented a challenge. To meet the challenge, workshops were held periodically and at other times, small working groups

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met. Over the course of the project, new field studies were conducted, new well and sample data were analyzed, existing seismic data were reprocessed and analyzed, new aeromagnetic data were acquired, and the assessment method was reviewed and modified. Findings from previous studies were also reviewed and incorporated.

New field studies were conducted during the summers of 1995, 1996, and 1997. Typically, two 6-person crews, each crew working for about five days, were supported by helicopter operating out of a field camp at the Kavik airstrip, located about 15 miles southwest of the 1002 area (Fig.AO2). Field teams were organized and staffed to accomplish specific objectives as defined in the analysis of data needs. A summary of this work can be found in Schenk and others (Chap. FS). Panoramic photomontages by Takahashi provide views of the 1002 area and adjacent countryside (Chap. IG). An invaluable collection of well-organized notes, sketches, and maps of USGS field work for the years 1980, and 1982–1985 conducted by the late C.M. Molenaar and field parties, is included here as scanned images (Appendix CM). These notes record much of the field work that was conducted in preparation for the 1987 assessment, and they were a useful guide for more recent studies. Studies of basement rocks—their age, composition, reservoir potential, and distribution—were conducted by Dumoulin (Chap. CC) and Kelley (Chap. BR). A special study was conducted of surface water quality, particularly that of streams draining areas underlain by petroleum source rocks that are naturally rich in heavy metals (Wang, Chap. SA).

Wells adjacent to the 1002 area provide critical points of control for the evaluation of the area's petroleum resources. At this time, approximately 60 wells lie within 30 miles of the 1002 area (Fig. AO3). Of this total, more than one-third were either drilled or released to the public domain since completion of the 1987 assessment (Fig. AO2). Information is public on all but ten wells. Those ten, including the well drilled within the 1002 area on Native lands, the KIC Jago River No. 1, are confidential and, therefore, were not available for this study (Fig. AO2). In this study, we produced a comprehensive data inventory for 41 wells and made large-format data displays for 39 (Nelson and others, Chap. WL). Plots include formation boundaries, ages, lithologies, logs, oil and gas indications, test results, engineering-, thermal maturity-, and source rock-data. From this compilation and from published reports, the geological and physical properties of eighteen formations were characterized (Nelson and Bird, Chap. FP) so that these properties may be inferred within the 1002 area. Procedures used to extract petrophysical properties from well logs are described by Nelson (Chap. PP). Included are determinations of net-to-gross reservoir ratios, a statistical model relating porosity and vitrinite reflectance, capillary pressure data used to compute water saturation, and velocity and density data determinations from log and core data in support of seismic and gravity interpretations. A critical element in the framework geology is the age of the rocks. Poag (Chap. BI) provides a biostratigraphic framework for Cretaceous and Tertiary rocks synthesized from a variety of contractor paleontology reports on the wells. Wells also played an important part in describing the geologic setting of the assessment area (Bird, Chap. GG).

Reflection seismic surveys within and adjacent to the 1002 area constitute the single most important set of data in the evaluation of the area's petroleum potential (Fig. AO4). All 1,451 miles of proprietary seismic data collected by a petroleum-industry consortium in 1984 and 1985 were reprocessed and reinterpreted. This survey provides a grid of approximately 3 by 6 miles. Seismic surveys within the Refuge require an act of Congress and these represent the only seismic control within the 1002 area. Seismic reprocessing and velocity analysis are described in the report by Lee and others (Chap. SP). All data were stacked, migrated, and depth-converted. Previously, only about one-quarter of the data were reprocessed by the USGS and none was depth converted.

The onshore seismic data were tied to the offshore USGS regional seismic grid (Grantz and others, 1982), to offshore wells, and to published seismic sections and wells in adjacent areas of offshore Canada (Dietrich and others, 1989; Dietrich and Lane, 1992; Dixon, 1996). Permission to show additional 1002 area seismic sections beyond that published in 1987 (in various papers in Bird and Magoon, 1987; Clough and others, 1987) or to show the sections at enhanced resolution and as depth-converted displays was denied by the petroleum-industry consortium. Accordingly, all seismic figures in this publication are at the same scale and resolution as previously published. Unfortunately, these seismic sections, as displayed, show only a small fraction of the detail revealed by the reprocessing. This detail was a key element in the new interpretations that grew out of the current study. Interpreted seismic sections provided critical information on sizes and numbers of potential petroleum accumulations (traps) for this assessment. These sections also constitute the basic information on structural style and timing of deformation (Potter and others, Chap. BD), seismic mapping (Grow and others, Chap. NA), structural modeling (Cole and others, Chap. SM) and sequence stratigraphic analysis (Houseknecht and Schenk, Chap. BS).

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Other geophysical methods were also used in the assessment. A commercial aeromagnetic survey was purchased, and analysis of it and gravity data by filtering techniques provided useful information on location, size, continuity, and faulting of structures, both shallow and deep (Phillips, Chap. AM and Saltus and others, Chap. GR). In combination with seismic data, these surveys constrained interpretations of rock units at depth—a critical part of the assessment in attempting to determine the areal distribution of potential reservoir rocks.

The petroleum system concept was employed to systematize and unify the evaluation of petroleum source rocks and the processes of petroleum generation, migration, and entrapment. By this approach, three petroleum systems have been identified and described with the 1002 area (Magoon and others, Chap. PS). Building on the foundation of earlier work, all previous and several new surface occurrences of oil were collected and analyzed, as were oils from several wells. A catalog of chromatograms is provided in a special directory accessed from chapter OA. Hydrous pyrolysis was used to simulate oil generation from potential source rocks to perform oil-to-source correlations (Lillis and others, Chap. OA). Study of fluid inclusions (Burruss, Chap. FI) extended the analysis of petroleum occurrences into the microscopic realm. Source rock richness (total organic carbon) and thickness were calculated from well logs and were found to compare favorably to laboratory measurements (Keller and others, Chap. SR). The thermal maturity of rocks at the surface and variations of maturity with depth are described by Bird and others (Chap. VR). Modeling of burial history and hydrocarbon generation (Rowan, Chap. BE; Houseknecht and Hayba, Chap. HG; Hayba and others, Chap. FF) shows variations in timing and location of petroleum generation, probable migration directions, and potential trapping areas.

Numerous geologic reports on the ANWR and nearby areas have become available since 1987. These include summary reports of the offshore (Grantz and others, 1990), onshore (Banet, 1990a, 1990b; Moore and others, 1994), the Mackenzie Delta region (Dixon, 1996), and detailed studies of the Aurora well, the only well with public information near the eastern part of the 1002 area (Banet, 1992, 1993, 1994; Paul and others, 1994). A large collection of reports on various geologic topics related to northern Alaska, including several oil fields in the Prudhoe Bay area, was published in Tailleur and Weimer (1987). Application of apatite fission-track analysis to provide details of the thermal history of a region and, indirectly, to date the time of structural trap formation (e.g., O'Sullivan and others, 1993; O'Sullivan, 1996) is also a new development since 1987. A significant body of work constituting more than 70 reports and maps, largely focused on the ANWR, has been produced by faculty and students of the University of Alaska and personnel at the Alaska Division of Geological and Geophysical Surveys.

Highlights of the technical studies conducted in support of this assessment are summarized in Table AO2.

PROJECT SCHEDULE

Over the course of the project at intervals of six to nine months, workshops were held in Denver or Menlo Park where geologic data and interpretations were presented. These were open meetings designed to foster scientific exchange. Attending these meetings were representatives of collaborating groups, such as the University of Alaska and the Alaska Division of Geological and Geophysical Surveys. Between workshops, smaller, working group meetings were held to develop assessment methodology, structural interpretations, prospect mapping, etc.

In late April 1997, a preliminary assessment was conducted. The purpose was to evaluate the completeness of the methodology, to assure that all project personnel understood the methodology and the geologic inputs that were required, to identify any information 'gaps' that had to be filled before the final assessment could be conducted, and to establish a set of task deadlines to assure timely completion of the assessment. No numerical results of this preliminary assessment were distributed outside the project methodology team.

The final assessment was conducted in January 1998. All assessment input was arrived at by group consensus. For each play, a designated scientist would lead the discussion and usually offered a set of assessment input values. These values were discussed and oftentimes modified. During the course of the assessment meeting, checks were conducted on the reasonableness of the input values and consistency in treatment, particularly where similar rocks occurred in more than one play.

Following the final assessment meeting, several reviews were held to examine the reasonableness and internal consistency of the input values and assessment results. Participation in the preliminary and final assessment meetings and the review sessions was restricted to USGS personnel and contractors. During this time, the economic analysis was proceeding. In May 1998, final assessment results were released at the annual meeting of the

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American Association of Petroleum Geologists in Salt Lake City, Utah in an oral presentation (Bird, 1998) and in hard copy fact-sheet format (USGS, 1998; and also included in this publication). Additional geologic details were also given in an oral presentation at that meeting by Houseknecht and Schenk (1998).

TECHNICAL REVIEW

Prior to the final assessment, a series of technical review meetings were held with State and Federal agencies and industry consortium members. The purpose of the meetings was to provide an opportunity for review and comment on the technical aspects of the petroleum geology, the identified plays, and the assessment methodology. In October 1997, three separate review meetings were held in Anchorage with Federal agencies (Bureau of Land Management, Minerals Management Service, Fish and Wildlife Service), with State agencies (Alaska Oil and Gas Conservation Commission, Division of Geological and Geophysical Surveys, University of Alaska), and with petroleum-industry consortium members. Later that same month, a similar meeting was held in Houston, Texas with industry consortium members. Because the technical review meetings necessarily involved the display of proprietary seismic data, these meetings were restricted to those private companies that are members of the consortium and to government agencies that have legitimate 'need to know' status. Confidentiality statements were signed by participants to assure the proprietary nature of the data.

In early 1998, following the final assessment, a technical review similar to those reviews of the previous October was presented to the American Association of Petroleum Geologists Committee on Resource Evaluation (AAPG-CORE) in Denver, Colorado. Following that, a separate review of assessment methodology was provided to a subcommittee of AAPG-CORE. Reviewers did not review the assessment itself. To preserve the integrity and objectivity of the results, no assessment inputs, results, or estimates were shown or discussed in these meetings.

ASSESSMENT METHODOLOGY

The Method. This assessment used a play-analysis method. The play, being the basic unit of assessment, is defined as a volume of rock with common geologic attributes, such as source rock, reservoir rock, trapping mechanism, and timing. Ten plays were defined and assessed in this study using the play-analysis method. For each play, the method requires input which describes the number of prospects (potential oil or gas accumulations) as well as their geologic and fluid characteristics. A range of values for numbers of prospects and their geologic characteristics is recorded to indicate the uncertainty in the process. Monte Carlo simulation combines the characteristics and numbers of prospects with the uncertainty into a range of possible (simulated) oil and gas accumulations. Because of this, the method has also been described as a deposit simulation method.

The play analysis method is well suited for assessing frontier areas such as the 1002 area where few or no petroleum accumulations have been identified and where limited amounts of data exist. The method provides a direct assessment of the geologic characteristics and the uncertainties associated with estimation of those characteristics. The output provides estimates of sizes, numbers, and depths of oil and gas accumulations—those details that are required for economic analysis.

The origins of this play-analysis method can be traced to a resource-appraisal method developed by the Geological Survey of Canada (Roy and others, 1975). As described in Bugg and others (1988), the Canadian method was modified and incorporated as one component of a more comprehensive analysis of the National Petroleum Reserve in Alaska (NPRA) involving exploration, development, production, transportation, and distribution of petroleum resources (U.S. Department of the Interior, 1979). Its initial application in the 1979-1980 assessments of the NPRA is described in the reports by White (1981), Bird (1988), and Miller (1988). Descriptions of later application in the 1980 and 1987 assessments of the ANWR are found in reports by Mast and others (1980) and Dolton and others (1987).

In the current assessment, we made several modifications to the method. These include (1) a rearrangement of the assessment data-input form to more closely reflect the order in which information was requested from the geologist/assessor; (2) application of a minimum size cut-off-value of 50-million barrels oil-equivalent in-place, the likelihood of which was assessed in the risk parameters; (3) clarification of risking options; (4) development of more detailed models for oil and gas characteristics, pressures, and formation volume factors based, in large part, on North Slope and Mackenzie delta data (e.g., Quinn, Chap. PA); (5) generation of field-size distributions not only at the mean but also at the 5th and 95th fractiles; (6) modification and application of aggregation procedures developed for the 1995 National oil and gas assessment (Gautier and others, 1995); and (7) application of Monte Carlo simulation rather than probability theory to generate the estimates. A more detailed description of the method is provided in the report by Schuenemeyer (Chap. ME) and definitions of assessment terms are provided by Charpentier (Chap. DF). The computer code used to produce the assessment is described in Schuenemeyer (Chap. ME).

Play Definition. The initial step of the assessment was the definition of plays. The stratigraphic column (Fig. AO5) shows the rocks that make up the ten plays assessed as well as the rock interval in which nearby oil and gas deposits occur and the three petroleum systems identified in the 1002 area. Figures AO6 through AO15 provide a one-page synopsis of each play. More detailed descriptions of the plays are provided in the chapters by Houseknecht and Schenk (Chaps. P1, P2, P3), Schenk and Houseknecht (Chaps. P4, P5), Kelley (Chap. P6), Perry and others (Chap. P8), and Grow and others (Chaps. P7, P9, P10). Each play in this assessment generally represents a part of a more regionally extensive play identified in the offshore (Sherwood and others, 1996), in adjacent parts of Canada (Dixon and others, 1994), or the onshore North Slope (Bird, 1995).

The Process. A flow chart showing the assessment process is provided in Figure AO16. For each play, a distribution of the number and size of potential petroleum accumulations was estimated based on a distribution of probable values for geologic characteristics such as reservoir thickness and porosity. These distributions were restricted to potential accumulations larger than 50 million barrels of oil (MMBO) in-place, so that the assessment would not be influenced by smaller accumulations that generally are non-economic on the North Slope. Currently on the North Slope, pools as small as 5 million barrels are being exploited when found within or adjacent to existing infrastructure. These types of accumulations in this assessment would not be distinguishable from the prospects or accumulations that we are modeling--that is, they are too small to resolve with the available 3-mile by 6-mile seismic grid. We expect that these resources are captured in the modeled accumulations assessed because of the necessarily broad range of input values. The input parameters for each play can be found in Schuenemeyer (Chap. RS).

The resulting distributions were then subjected to a risking procedure designed to weigh the likelihood that geologic conditions were favorable to generate a 50 MMBO in-place accumulation. Risk was applied at both the play and prospect levels, as described by Schuenemeyer (Chap. ME). The geologic distributions and the risks were then combined to produce an estimate of in-place petroleum resources for each play. Following that step, a recovery factor appropriate to each play was applied to the in-place petroleum estimates to calculate technically recoverable petroleum resources.

Estimates for each play were aggregated to calculate total petroleum resources for the entire assessment area (which includes State, Federal and Native land), the ANWR 1002 area (excluding Native lands), and the 1002 area's two natural geologic subunits—the deformed and undeformed areas (Fig. AO2). The aggregate distributions are somewhat sensitive to the degree of geologic dependency between plays. We evaluated play dependency in a manner similar to that of the 1995 national oil and gas assessment (Gautier and Dolton, 1996). That procedure involved evaluating the play attributes of charge, reservoir, and trap for each pair of plays (Fig. AO16 and Schuenemeyer, Chap. ME).

The assessment methodology yields results that express a range of uncertainty, illustrated by the probability curves in Fig. AO17 and listed in Table AO3. To stress the importance of this uncertainty, results reported here include 95th and 5th percentiles, which are considered reasonable minimum and maximum values. The mean expresses the average or expected value.

ASSESSMENT RESULTS

This assessment estimated the total quantity of in-place oil resources within the entire assessment area to be between 15.6 and 42.3 billion barrels (95th and 5th percentile), with a mean of 27.8 billion barrels (BBO). Non-associated gas resources are estimated to be between 0 and 14.5 trillion cubic feet (TCF), with a mean of 5.1 TCF. Within just the 1002 area (excluding Native lands), the total quantity of in-place oil resources is estimated to be between 11.6 and 31.5 BBO (95th and 5th percentile), with a mean of 20.7 BBO. Non-associated gas resources are estimated to be between 0 and 13.4 TCF, with a mean of 4.6 TCF (Table AO3, Fig. AO17).

The total quantity of technically recoverable oil resources within the entire assessment area is estimated to be between 5.7 and 16.0 BBO (95th and 5th percentile), with a mean of 10.4 BBO; non-associated gas resources are estimated to be between 0 and 10.9 TCF, with a mean of 3.8 TCF. Within just the 1002 area (excluding Native lands), the total quantity of technically recoverable oil resources is estimated to be between 4.3 and 11.8 BBO (95th and 5th percentile), with a mean of 7.7 BBO; non-associated gas resources are estimated to be between 0 and 10.0 TCF, with a mean of 3.5 TCF. (Table AO3, Fig. AO17). Estimates of oil and gas resources for each play are presented in the report by Schuenemeyer (Chap. RS) along with aggregated resource totals for the entire assessment area, the 1002 area, and 1002 sub areas.

Quantities of technically recoverable oil are not expected to be uniformly distributed throughout the 1002 area. The undeformed part of the 1002 area (Fig. AO2) is estimated to contain between 3.4 and 10.2 BBO (95^{th} and 5^{th} percentile), with a mean of 6.4 BBO. The deformed part of the 1002 area is estimated to contain between 0 and 3.2 BBO (95^{th} and 5^{th} percentile), with a mean of 1.3 BBO. The relative contribution of each play to the resources in these sub areas is shown in Figure AO18. This figure shows that most resources are expected to occur in just a few plays. About two-thirds of the expected (mean) amount of oil in the undeformed area is estimated to occur in the Topset play, whereas about 5/6ths of the oil in the deformed area is estimated to occur in the Thin-Skinned Thrust-Belt play.

The average (mean) sizes and numbers of oil accumulations estimated (simulated) in this assessment are provided in Figure AO19. The unusual-appearing size classes in the figure are based on powers of two, the common classification scheme used in field-size analysis. The figure shows, in part A, that a total of about 35 accumulations are expected to occur in size classes ranging from 8 to 8,192 MMBO. The most numerous oil accumulations are expected to occur in the 64-128 MMBO size category, and the largest field size category with significant amounts of oil is 1024–2048 MMBO. Part B of the figure shows the volume of oil in each size class. Because more of the oil occurs in large fields, the histograms are shifted to the right relative to the histograms in part A. The cumulative (gray) curve shows that slightly less than half (42 percent) of the technically recoverable oil is expected to occur in accumulations of 512 MMBO or larger. From this analysis we conclude that there are no Prudhoe Bay-sized accumulations (12 BBO+) in the 1002 area, but there is a possibility of a field, the size of which approaches that of the Kuparuk River oil field (2 BBO+). Additional details on sizes and numbers of simulated oil fields is presented in the economic analysis chapter (Attanasi, Chap. EA).

The significance of the estimated of sizes and numbers of oil accumulations in the 1002 area becomes apparent when viewed from a national perspective. In the U.S., there are about 26,000 oil accumulations (EIA, 1998). Slightly more than one percent (298) are larger than 100 MMBO, and a large proportion (usually 40 to 50-percent) of the total amount of oil occurs in those few large accumulations (PennWell, 1998). In the 1002 area, we estimate (at the mean) about 16 oil accumulations larger than 128 MMBO which account for about 83 percent of the technically recoverable oil. Three or four of those accumulations are estimated to be larger than 512 million barrels and to contain about 42-percent of the total estimated oil. Oil accumulations in the 500 million to 2 billion barrel size range are small only in comparison to the 13 billion barrel Prudhoe Bay oilfield. They are significant when considering that the largest onshore discovery in the U.S. during the last eighteen years was 350 million barrels and the last discovery larger than a billion barrels (Kuparuk River) was made almost 30 years ago.

ECONOMIC ANALYSIS

The cost of transforming the undiscovered, technically recoverable resources into producible reserves and the volumes of those reserves were estimated in the economic analysis (Attanasi, Chap. EA). The analysis was confined just to oil resources within the 1002 area; non-associated gas accumulations were considered non-economic for at least two decades in the future and, therefore, were not part of the analysis.

The costs considered were those related to finding, developing, producing, and transporting the oil, as well as a 12-percent after-tax rate of return to capital. All calculations were in constant dollars, and costs were as of 1996, the latest information available to us. The necessity of using two-year out-of-date costs, means that our assessment of economically recoverable oil resources in the 1002 area is a conservative analysis, that is, one that understates the quantity of oil that could potentially be found and developed at a given price.

In the economic analysis, oil accumulations from the simulation analysis were classified into size categories as shown, for example, in Figure AO19. Accumulations were further classified into depth categories in 5,000 ft intervals. Representative accumulations of each particular size and depth category were evaluated to determine if, at a given price, they were commercially developable. Finding rate functions were applied to predict numbers and sizes of discoveries for sequential increments of wildcat wells in a particular depth interval. Given a particular market price, exploration will continue until the aggregate after-tax net present value of the resources found can no longer cover exploration costs. As market price rises, so does the value of exploration targets. This results in more wildcat well increments, effectively extending exploration.

The overall result of this analysis is a set of curves (incremental cost functions) associated with the 95th, 5th, and mean estimates (Figure AO20).

The curves show increasing amounts of economically recoverable oil with increasing market price. For example, the mean estimate shows no economic oil in the 1002 area at a market price of 15 dollars per barrel. At 16 dollars per barrel, about 1 billion barrels of oil are economically recoverable, and at 20 dollars per barrel, about 3 billion barrels are economically recoverable. The range of economically recoverable resources at 15-, 20-, and 25-dollars-per-barrel increments are shown in Figure AO21 for comparison to previous estimates.

To the extent that our analysis is conservative, the three curves should be shifted downward to lower prices. The amount of downward shift and whether each curve should be shifted an equal amount is unknown. From a policy perspective, one should view these numbers as indicating that at least this amount and probably more resource is present. It seems to us that this is preferable to a non-conservative estimate that would overstate the amount of resources. As new technology and cost information becomes available, a new economic analysis can be obtained from the underlying geologic assessment of technically recoverable resources.

PREVIOUS ASSESSMENTS

Assessments of the northern part of the Arctic National Wildlife Refuge are numerous and date from the early 1970s. Early assessments were mostly qualitative or provided quantitative estimates of only selected parts of the Refuge. The absence of subsurface data and limited information from surface exposures were a major hindrance to quantitative assessments. Beginning in 1980, all assessments of the Arctic National Wildlife Refuge have been quantitative. These are generally of two types. Those that involve a thorough review and analysis of data and those that are derived from the former by simply changing various assumptions or factors. All previous assessments known to us are described below in chronological order. The first three are qualitative assessments. Those following are quantitative assessments; their estimated oil resources are summarized in Table AO4 and shown in Figure AO21.

State of Alaska, 1972. Hartman (1972) concluded that the Marsh Creek anticline, the largest and most readily observable structure in the area, had potential for reserves of 14 BBO, given certain favorable assumptions.

USGS, 1976. Mull and Kososki in an administrative report to the U.S. Fish and Wildlife Service in 1976 concluded that only the northern two-thirds of the Arctic coastal plain is prospective for petroleum. They considered the area southeast of Barter Island (Fig. AO2) to have the highest potential, with multi-billion-barrel oil accumulations possible. The area west of Barter Island was considered moderately prospective, with petroleum accumulations possible but probably smaller than in the area of highest potential.

USGS, 1978. The analysis of Grantz and Mull (1978) was based on new geologic mapping and gravity surveys in the Refuge, geologic mapping in the adjacent parts of Canada, compilations of well data west of the Refuge, and seismic profiles in the Beaufort Sea adjacent to the Refuge and offshore Canada. They concluded that the potential for large, multi-billion-barrel oil fields in Ellesmerian rocks in the Refuge is low but that Brookian rocks in this area have good potential for a number of moderate, and perhaps large, gas and oil deposits in both Tertiary and Cretaceous strata.

USGS, 1980. This was the first quantitative assessment of the area and used an early version of the play-analysis method (Mast and others, 1980). It was conducted just prior to the establishment of the 1002 area and included the entire area north of the Brooks Range between the Canning River and the Canadian border. Assembly and review of the data and the assessment itself were accomplished by a group of scientists within a few months time. No seismic data were available and only a few wells to the west had been drilled and the data released. It was estimated that in-place volumes of oil ranged from 0.2 BBO (F_{95}) to 17 BBO (F_5), with a mean of 4.9 BBO.

State of Alaska, 1986. In 1986, the State of Alaska (Hansen and Kornbrath, 1986) used the same methodology as the 1980 USGS assessment, although the plays identified and assessed were different than those evaluated by the USGS. The assessment area included all lands north of the Brooks Range between the Canning River and the Canadian border but excluded native lands. Volumes of estimated in-place oil resources ranged from 0.1 BBO (F_{95}) to 26.5 BBO (F_5), with a mean of 7.2 BBO.

USGS, 1987. In 1987, the USGS (Dolton and others, 1987), again using the play analysis method, reported estimates for the 1002 area that were nearly triple those of their 1980 assessment based on comparison of the means. In-place resources ranged from 4.8 BBO (F_{95}) to 29.4 BBO (F_5), with a mean of 13.8 BBO. The main basis for the increase in the estimated resources was the availability of seismic data, which had been collected in 1984 and 1985, and additional nearby well control. These data had the effect of changing previous estimates of number and size of prospects, the depth range of oil generation, and the conditional deposit probability.

BLM, 1987. The Bureau of Land Management (BLM) in 1987 (Callahan and others, 1987) estimated economically recoverable oil resources in the 1002 area using the PRESTO II computer simulation model developed and used by the Minerals Management Service. A number of geologic, economic, and engineering assumptions were made, including a 0.44 BBO minimum economic field size (MEFS) and an oil price of $33/barrel (1984 dollars in the year 2000). This assessment was limited to 26-seismically mapped structures (prospects). As noted in their report, additional recoverable resources may be present in stratigraphic traps and structures that cannot be adequately mapped with the available seismic data set. They reported conditional, economically recoverable oil resources that ranged from 0.6 BBO (F_{95}) to 9.2 BBO (F_5), with a mean of 3.2 BBO and a marginal probability of 19 percent.

EIA, 1987. In reviewing the DOI (USGS/BLM) assessment in 1987, the Energy Information Agency (EIA) considered the economically recoverable oil estimates too conservative. It provided its own estimate by applying an area-wide 25-percent recovery factor to the USGS in-place estimates. They report unconditional (fully risked) estimates of economically recoverable oil ‘cases’ ranging from a low case of 1.20 BBO to a high case of 7.35 BBO, with a base case of 3.45 BBO. Their report notes that these cases are compared to but are not strictly the same as the F_{95}, F_5, and mean values of the BLM results presented in 1987 (EIA, 1987, p. 18).

BLM 1991. In 1991 the BLM updated their 1987 estimate on the basis of new cost data and additional geologic data, including 800 miles of reprocessed seismic data and four additional wells drilled adjacent to the 1002 area. The updated estimates of conditional, economically recoverable oil resources ranged from 0.6 BBO (F_{95}) to 8.8 BBO (F_5), with a mean of 3.6 BBO with a marginal probability of 46 percent and an overall MEFS of about 400 MMBO.

AAPG 1991. Writing a position paper for the American Association of Petroleum Geologists, Gunn (1991) reviewed the estimates of BLM 1987 and 1991 and argued that they were too low; he suggested that reservoir thickness, porosity, recovery efficiency, and trap-fill values used were too conservative and should have been higher; furthermore, source rocks judged to be mostly gas-prone should be regarded as more oil-prone; the stand-alone assumption was overly conservative, the minimum economic field size (MEFS) too large, and drilling cost estimates were too high. With different, less conservative assumptions, Gunn predicted an unconditional mean value of 7 BBO with an upside (F_5) volume of 14.8 BBO. In his report, these volumes are referred to as recoverable. They are interpreted here to mean unconditional, economically recoverable amounts of oil. Estimates for in-place and conditional, economically recoverable oil resources are also provided (Table AO4).

GAO 1993— In reviewing the 1991 BLM update, the General Accounting Office (GAO) in 1993 observed that the 1991 assessment did not fully consider the uncertainty associated with oil prices and discount rates. GAO reran the BLM's Presto model using lower prices and assumed leasing would begin 2-years later than did BLM. This analysis indicated that changes in the MEFS from lower oil prices reduced the probability that the 1002 area contained at least one economically viable oil field to a 27-percent probability from BLM's 46-percent. GAO calculated that conditional, economically recoverable resources ranged from 1.5 BBO (F_{95}) to 9.4 BBO (F_5) with a mean of 4.0 BBO and that fully risked economically recoverable resources ranged from 0 BBO (F_{95}) to 5.9 BBO (F_{05}) with a mean of 1.1 BBO.

USGS 1995—At the request of the Office of Policy, Budget and Analysis of the U.S. Department of the Interior, the USGS estimated approximate amounts of oil and gas resources in the 1002 area by allocation of technically recoverable resources. Allocation was from five regional North Slope plays assessed during the 1995 National Assessment that significantly impinge upon the 1002 area. Because of the great uncertainty in allocating resources from broad, regional plays to small specific areas, only ranges (F_5 and F_{95}) were reported. Results of that allocation were estimates ranging from 0.1 BBO to 5.2 BBO (F_{95} and F_5, respectively). Applying the same allocation percentages to plays assessed during the 1989 National Assessment (Mast and others, 1989) resulted in estimates that ranged from 0.7 to 11.7 BBO (F_{95} and F_5, respectively). Additionally, estimates of the volume of economically recoverable oil were made by applying the 1991 BLM minimum economic field size of 0.4 BBO to the allocation. That application resulted in estimates of 0 at F_{95}, 0 at F_{50}, and 4.1 BBO at F_5, with an expected (mean) value of 0.9 BBO.

COMPARISON WITH PREVIOUS ASSESSMENTS

Meaningful comparisons require that similar resource categories be compared and that differences in methodology or economic assumptions be considered. Figure AO21 and Table AO4 show assessment results grouped by resource category. Descriptions of each assessment in the previous section indicate differences in methodology and assumptions.

The most comparable assessments are those of in-place resources because all were made using the same method. The size of the area analyzed varied from one assessment to another. Also, each successive assessment has been based on more and better data. The current assessment shows significantly more oil at the 95th fractile and the mean than previously, but only a modest increase at the 5th fractile over the 1987 USGS assessment.

In the technically recoverable resource category, USGS estimates based on allocations are compared to estimates based on the current assessment. Methodological differences suggest little comparability. In spite of this, the current estimates show a significant increase at the 95th fractile and a somewhat lesser increase at the 5th fractile.

Comparison of economically recoverable oil estimates is virtually meaningless because of different conditions and assumptions. At the outset, one observes that there are two categories of economically recoverable resources: *conditional* and *fully risked* (Table AO4 and Fig. AO21). Conditional estimates are those in which some prior condition is assumed. In this case, the assumed prior condition is the existence of at least one petroleum accumulation greater than the minimum economic field size (MEFS). There is a risk associated with this assumption. That risk is known as the marginal probability. Conditional estimates multiplied by the marginal probability give ‘fully risked’ estimates. In other words, conditional estimates include only part of the risk. Fully risked estimates, as the name implies, incorporate all risk. The current USGS assessment reports only fully risked estimates.

Further difficulty in comparing economically recoverable oil estimates is introduced because each estimate is based on a different set of assumed costs and future oil prices. Over time, from one assessment to another, costs and prices of North Slope oil have changed, often significantly. There is no way to recompute or adjust prior estimates to a common set of costs and prices that would be required to make a meaningful comparison. Earlier estimates were generally based on higher costs, the anticipation of significantly higher oil prices, and different methods of analysis. At a market price of 20 dollars per barrel, our estimates are similar to or slightly greater than all but the highest previous estimates.

As a generalization (and oversimplification), the results of this assessment show an overall increase in all petroleum categories assessed compared to most previous assessments of the 1002 area. The increase stems in large part from improved resolution of reprocessed seismic data, which allowed the identification of many more potential petroleum accumulations in parts of the area, and geologic information provided by recent nearby oil discoveries. An additional factor, related to our economic estimates, is technological improvements leading to reduced costs for discovery and production of North Slope oil.

The geographic distribution of resources reflects a significant change from the 1987 Federal assessment. In that assessment, about 75 percent of the mean estimated in-place oil was in the southeastern or deformed area and only 25 percent in the northwest or undeformed area (Fig. AO2). In the current assessment nearly 85 percent of the in-place oil is in the undeformed area and only about 15-percent within the deformed area. Estimated in-place oil resources for the deformed area in the current assessment are about 30 percent of the 1987 estimates. That area, with only a single well offshore and complex geology onshore, carries great uncertainty. Further, part of that area considered oil prospective in 1987 is now considered prospective only for gas because of new understanding of the thermal history of the rocks. Estimated in-place oil resources for the undeformed area in the current assessment are five times greater than 1987 estimates. The difference is related to improved resolution of seismic records which allowed the identification of numerous potential petroleum accumulations (traps) in combination with geologic information from recent petroleum discoveries adjacent to this area.

SUMMARY

In anticipation of the need for scientific information to support Federal decision making and in light of the dated perspective of previous assessments, the USGS has completed a re-assessment of the petroleum potential of the 1002 area of the Arctic Refuge as well as nearby Native and State offshore lands. This was a comprehensive three-year study by a team of USGS scientists. Geologic studies were done in collaboration with scientists from other agencies and universities, but the estimation of oil and gas resources was conducted entirely by USGS staff and contractors. Since the previous USGS assessment of this area, completed in 1987, numerous wells have been drilled and oil fields have been discovered near the 1002 area, new geologic and geophysical data have become available, seismic processing and interpretation capabilities have improved, and the economics of North Slope oil development have changed significantly. This study incorporates all available public data, and includes new field and analytic work as well as the re-evaluation of all previous work.

Using a methodology similar to that used in previous USGS assessments in the ANWR and the NPRA, this study estimates that the total quantity of technically recoverable oil in the 1002 area is 7.7 BBO (mean value), which is distributed among ten plays. Results of our economic analysis are reported as a set of curves (incremental cost functions) associated with the 95th and 5th fractiles, and mean estimates. The curves show increasing amounts of economically recoverable oil with increasing price. The mean estimate shows no economic oil exists in the 1002 area at a market price of 15 dollars per barrel. At 16 dollars per barrel, about 1 BBO are economically recoverable, and at 20 dollars per barrel, about 3 BBO are economically recoverable. Natural gas is considered to be non-economic for at least two decades.

Comparison of estimated resources from this assessment with those of previous assessments is difficult because methods and assumptions varied from one assessment to another. As a generalization (and oversimplification), the results of this assessment show an overall increase in all petroleum categories assessed compared to most previous assessments of the 1002 area. The increase stems in large part from improved resolution of reprocessed seismic data, which allowed the identification of many more potential petroleum accumulations in parts of the area, and geologic information provided by recent nearby oil discoveries.

The geographic distribution of resources reflects a significant change from the 1987 Federal assessment. In that assessment, about 75 percent of the mean estimated in-place oil was in the southeastern or deformed area and only 25 percent in the northwest or undeformed area. In the current assessment nearly 85 percent of the in-place oil is in the undeformed area and only about 15-percent within the deformed area.

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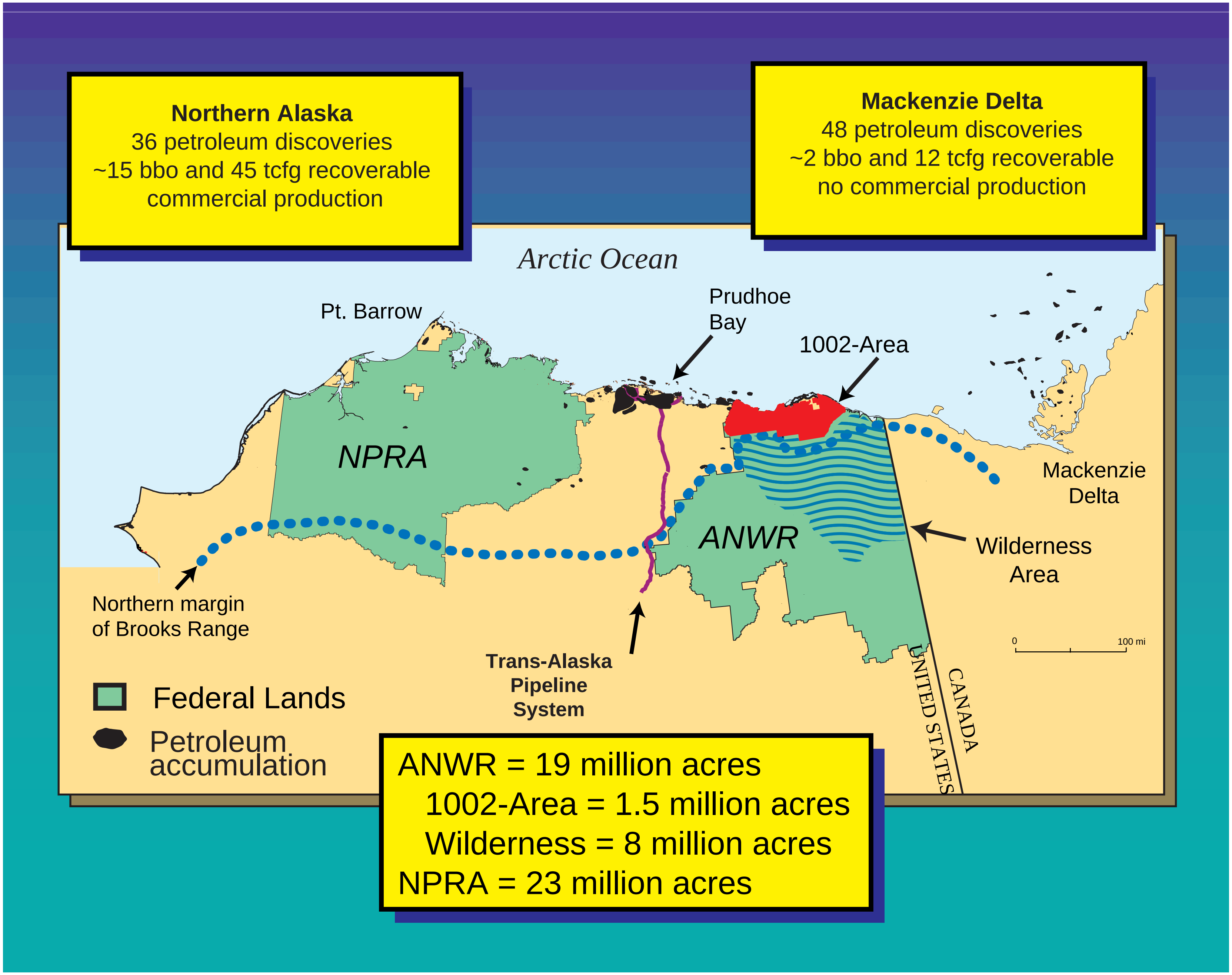

Figure AO1. Map of northern Alaska and nearby parts of Canada showing locations of the Arctic National Wildlife Refuge (ANWR), the 1002 assessment area, and the National Petroleum Reserve - Alaska (NPRA). Locations of known petroleum accumulations and the Trans Alaska Pipeline System (TAPS) are shown, as well as summaries of known petroleum volumes in northern Alaska and the Mackenzie delta of Canada. bbo = billion barrels of oil, includes cumulative production plus recoverable resources; tcfg = trillion cubic feet of gas recoverable resources.

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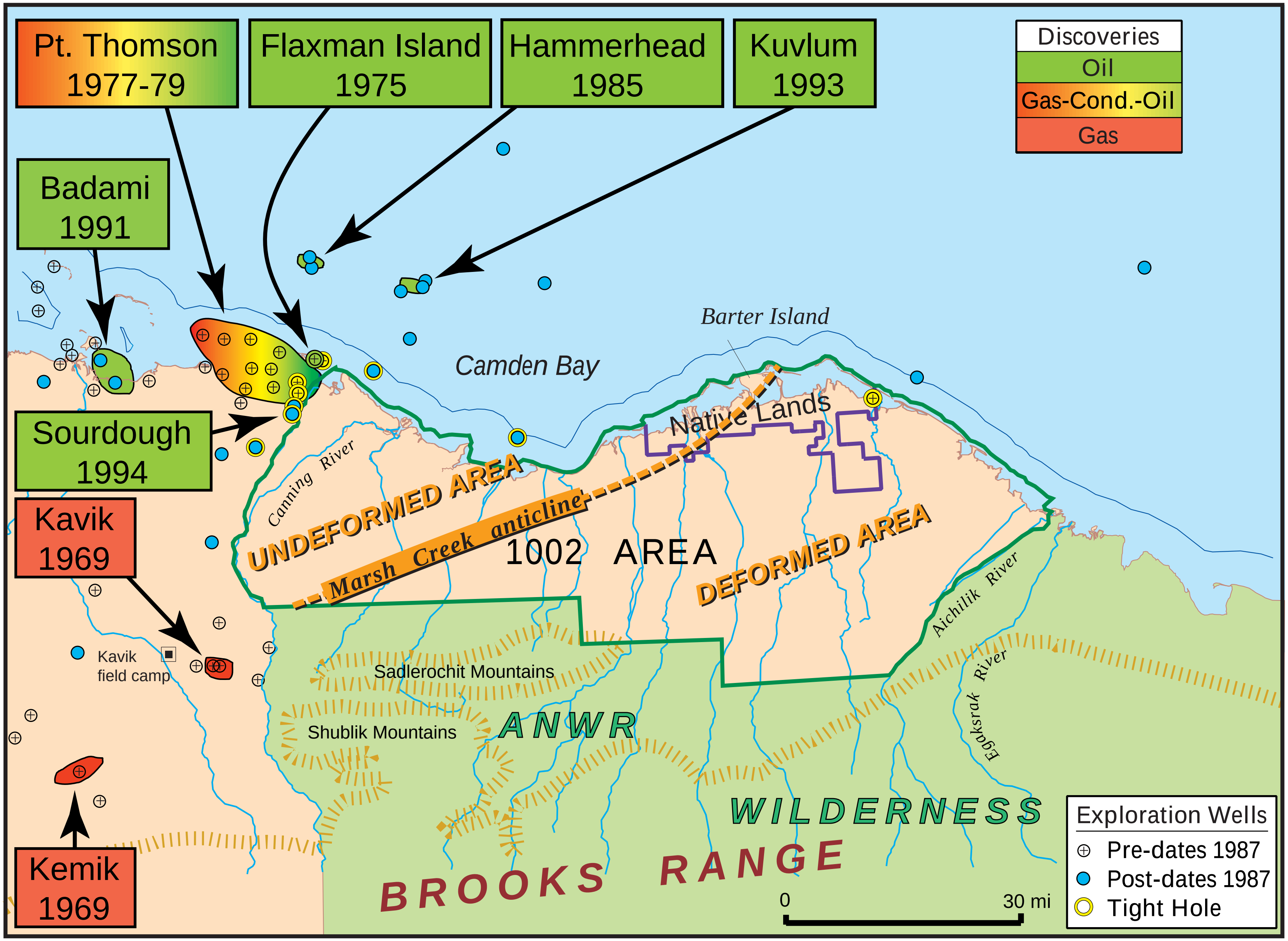

Figure AO2. Map of the ANWR 1002 and adjacent areas showingpetroleum discoveries and status of exploratory wells relative to 1987 USGS assessment. Orange dashed line marks approximate boundary between undeformed area, where rocks are generally horizontal, and deformed area, where rocks are folded and faulted.

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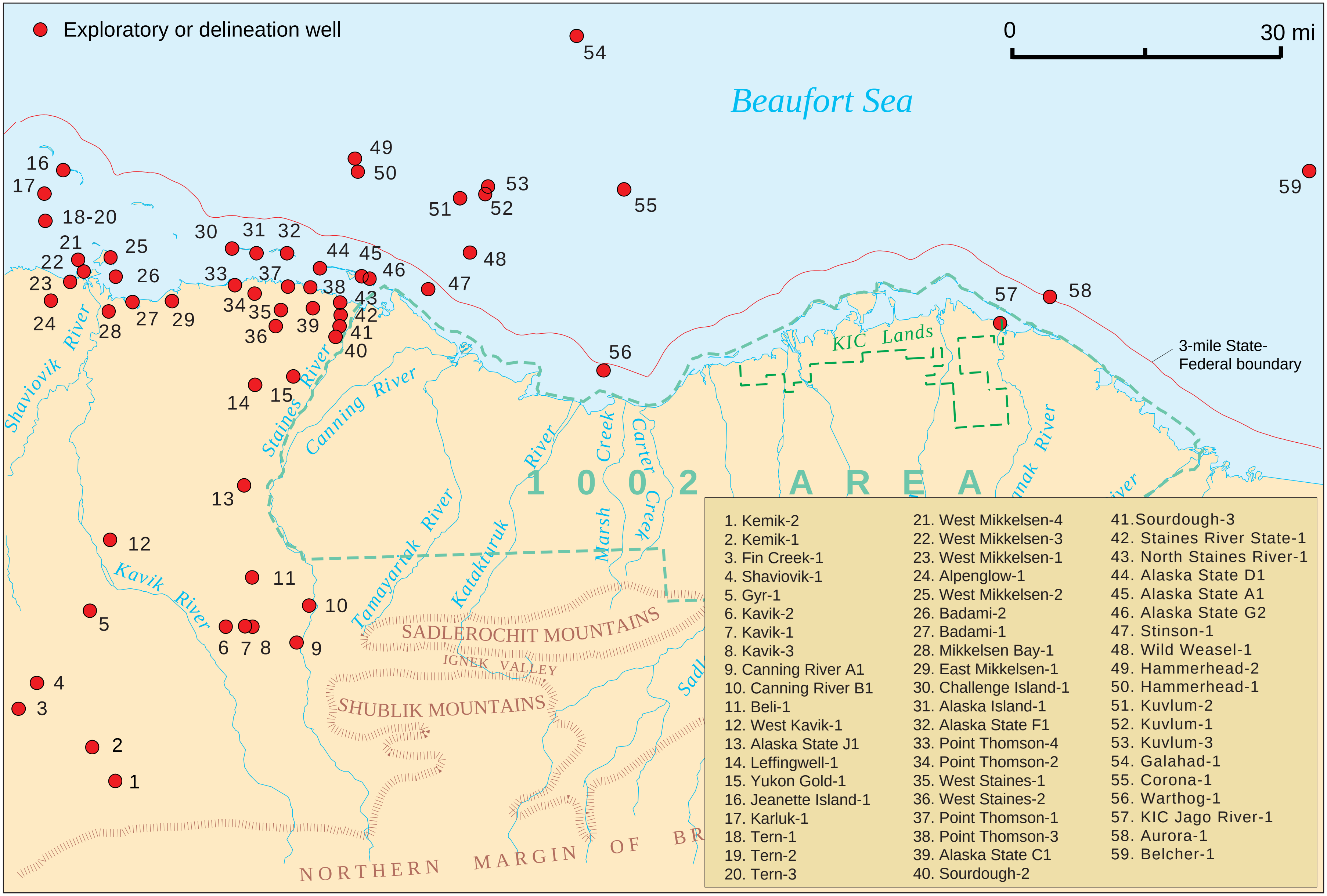

Figure AO3. Location map of wells near the ANWR 1002-area.

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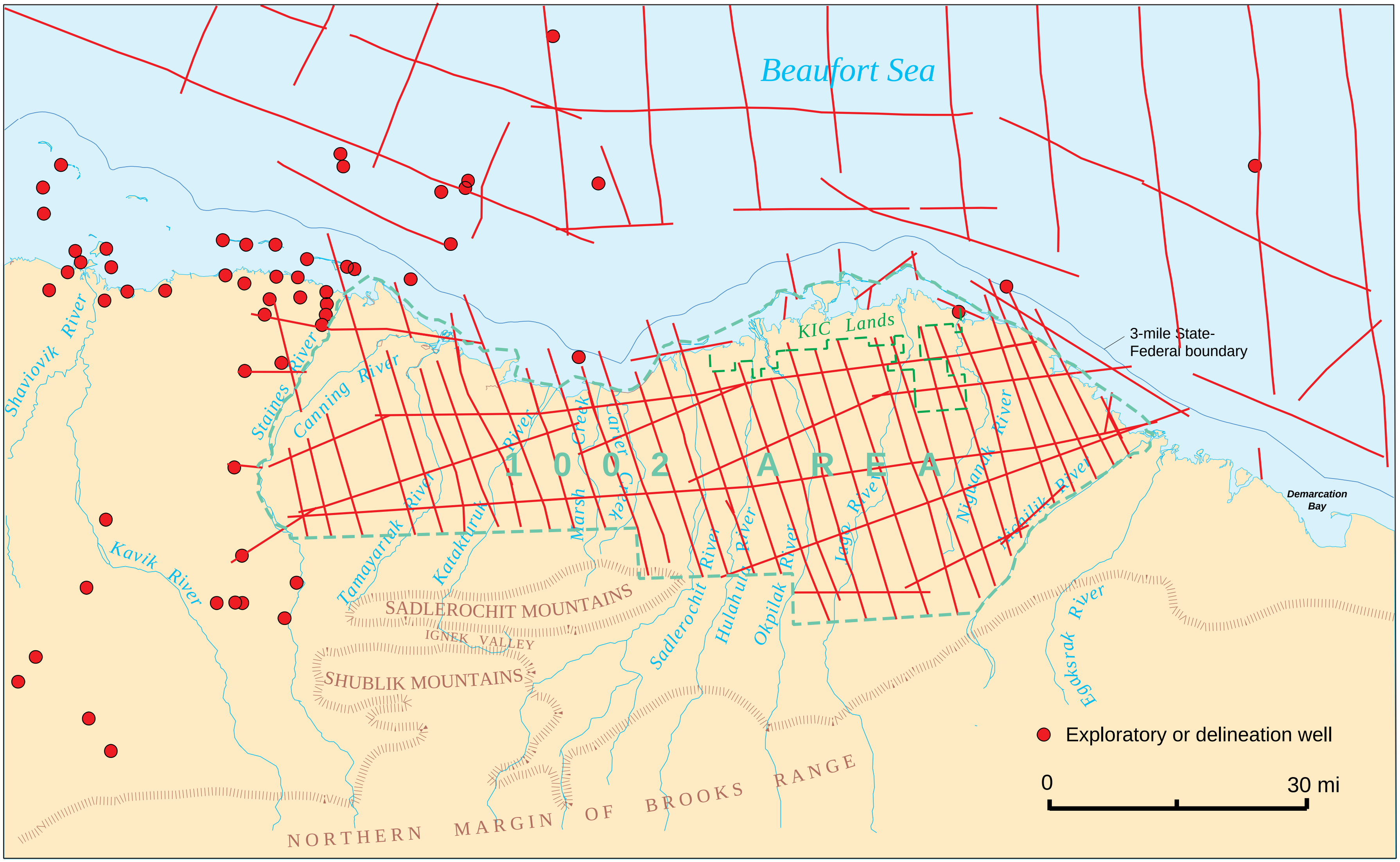

Figure AO4. Seismic coverage (red lines) in and adjacent to the ANWR 1002-area used in this assessment.

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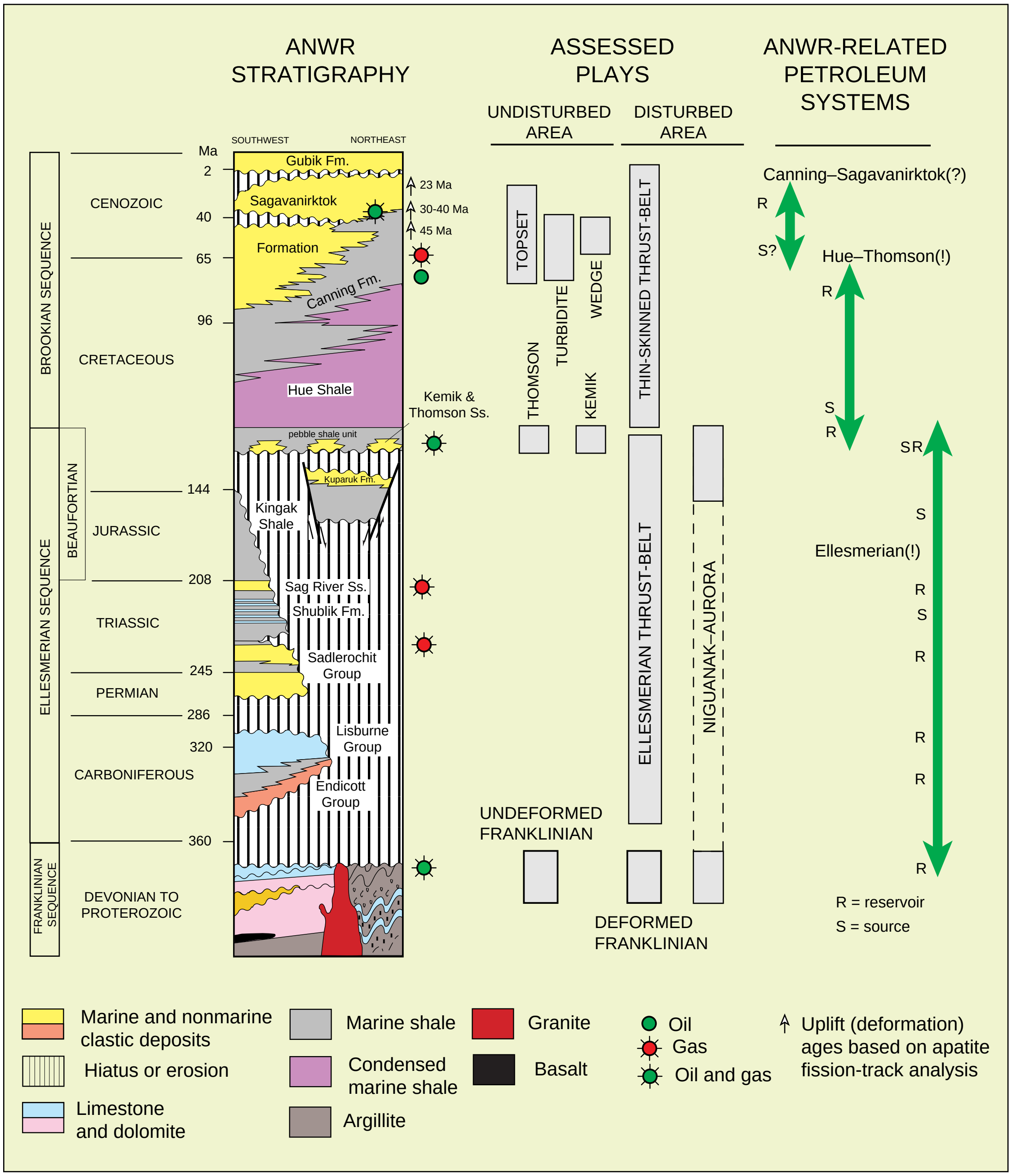
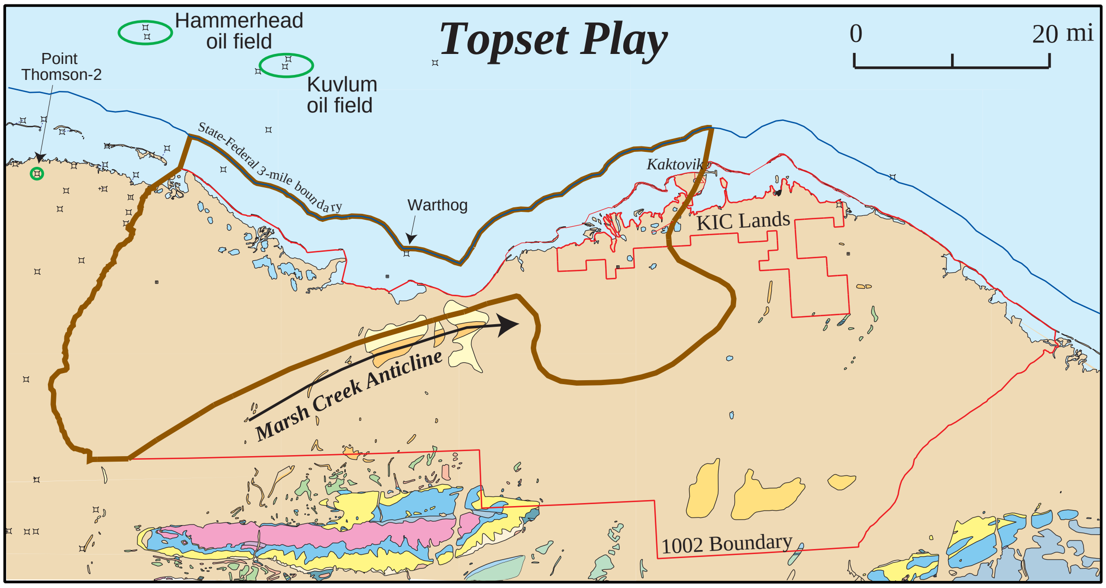


Figure AO5. Summary of ages, names, and rock types present in the ANWR 1002 area. The occurrence of recoverable petroleum in these rock formations outside the ANWR 1002 area is indicated by green and red circles. Grey bars at right indicate the ten petroleum plays evaluated in this assessment and their corresponding rock formations (to the left). Note the grouping of plays according to deformed and undeformed areas as shown in Figure AO2. The names and stratigraphic extent of petroleum systems in the 1002 area are also shown.

Figure AO6. Summary of Topset Play.



The **Topset Play** includes hydrocarbon potential within Brookian shallow marine through non-marine facies (i.e., Sagavanirktok Formation), which collectively display topset seismic character. Modified from Topset play in previous ANWR assessment. Related to Topset Play of 1995 USGS National Assessment and the Brookian Unstructured Eastern Topset Play of the 1995 MMS National Assessment.

Area: Gross play area totals 735,764 acres of which 555,487 acres lie within the 1002 area, 30,306 acres lie beneath KIC lands, and 149,971 acres lie beneath State waters.

Traps: Broad, unfaulted anticlines; anticlines related to rotational growth faulting; shelf-edge erosional truncations and growth faults; and lenticular sandstone bodies encased in mudstone.

Reservoir: Marine shelf, deltaic, and fluvial sandstones of Paleocene to Miocene age.

Source: Mainly Hue Shale and Canning Formation; potential Shublik Formation contribution.

Timing: Favorable because of syndepositional folding and faulting, shelf-edge growth faulting, and stratigraphic trap development coupled with hydrocarbon generation spanning most of Tertiary time.

Hydrocarbons: Oil and gas are present in the offshore extension of this play in the Hammerhead and Kuvlum accumulations. Oil is present in the play interval in Point Thomson-2 well. Oil is present in surface exposures along Marsh Creek anticline and Canning River.

Analog fields: Hammerhead, Kuvlum, West Sak, and Ugnu.

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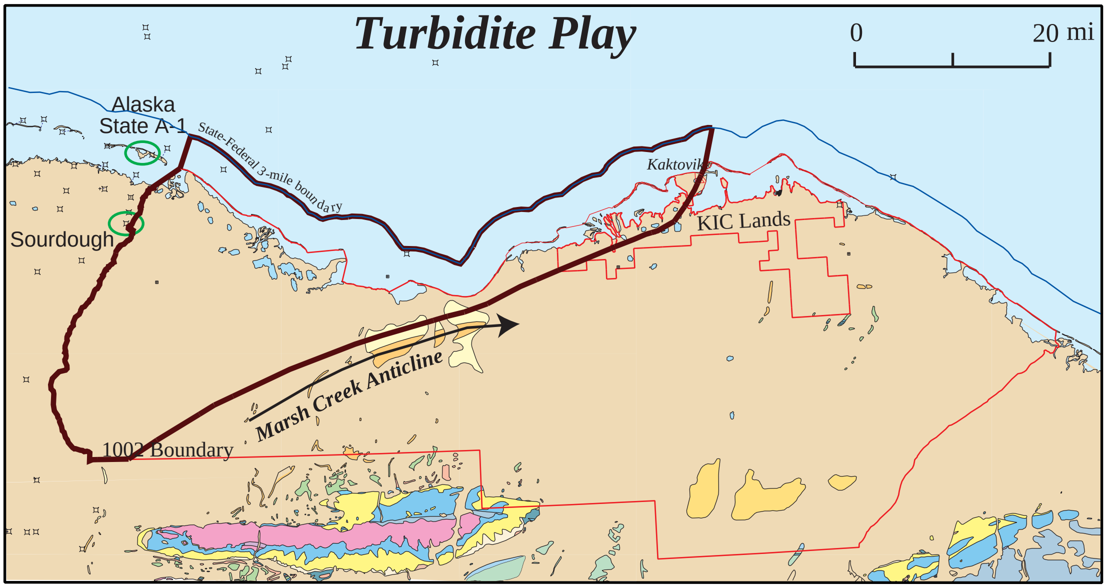
Figure AO7. Summary of Turbidite Play.



The **Turbidite Play** includes hydrocarbon potential within Brookian slope and deep marine facies (i.e., Canning Formation), which display clinoform and bottomset seismic character. Essentially same as Turbidite play of previous ANWR assessment and the 1995 USGS National Assessment, and the Brookian Unstructured Eastern Turbidite Play of the 1995 MMS National Assessment.

Area: Gross play area totals 599,694 acres of which 430,138 acres lie within the 1002 area, 19,584 acres lie beneath KIC lands, and 149,971 acres lie beneath State waters.

Traps: Turbidite channel and lobe sandstones encased in marine slope and deep basin mudstone.

Reservoir: Turbidite channel and lobe sandstones of Paleocene to Eocene age incised into slope muds and within bi-directional closures interpreted as turbidite mounds on seismic lines.

Source: Primarily Hue Shale and Canning Formation; potential Shublik Formation contribution.

Timing: Favorable because stratigraphic trap development occurred shortly after deposition of inferred source rocks located beneath or lateral to traps.

Hydrocarbons: Oil and gas are present in the onshore, westward extension of this play in the Badami, Flaxman Island, Tarn, and possibly the Sourdough accumulations. Oil has been tested in turbidite sandstones in many of the wells in the Point Thomson area. Oil is present in surface exposures along Marsh Creek anticline, Jago River, and Canning River.

Analog fields: Flaxman Island, Badami, Tarn, Sourdough(?).

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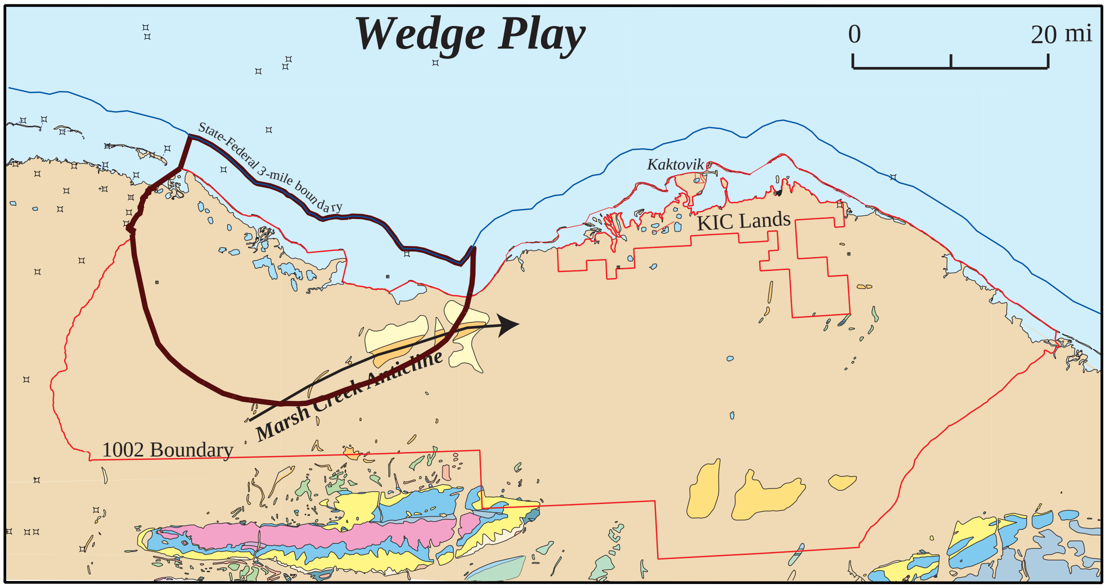
Figure AO8. Summary of Wedge Play.



The **Wedge Play** includes hydrocarbon potential within a wedge of Brookian strata that may contain facies ranging from deep marine to shoreline. This play was included as part of the Turbidite Play of the previous ANWR assessment and the 1995 USGS National Assessement, and as part of the Brookian Unstructured Eastern Turbidite Play of the 1995 MMS National Assessment.

Area: Gross play area totals 384,669 acres of which 301,238 acres lie within the 1002 area, and 83,431 acres lie beneath State waters.

Traps: Updip pinchouts of inferred sandstone facies and lenticular sandstone bodies encased in mudstone.

Reservoir: Shingled turbidite sandstones, incised turbidite channel sandstones, and/or shoreface sandstones.

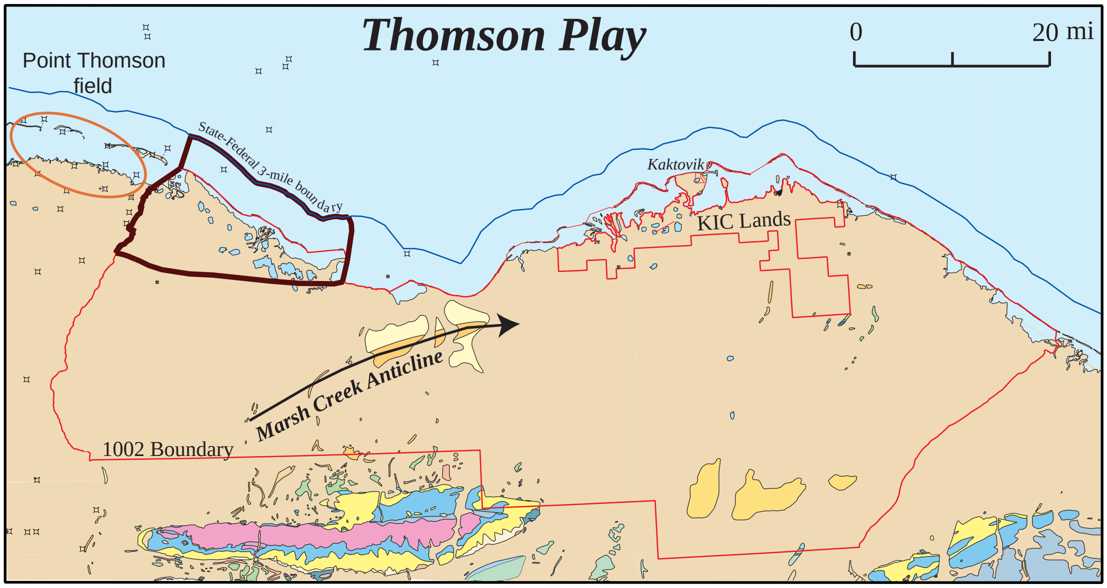
Source: Predominantly Hue Shale and Canning Formation; potential Shublik Formation contribution.

Timing: Favorable because stratigraphic trap development occurred shortly after deposition of inferred source rocks located beneath or lateral to traps.

Hydrocarbons: None known.

Analog fields: None known.

Figure AO9. Summary of Thomson Play.



The **Thomson Play** includes hydrocarbon potential in stratigraphically trapped Thomson sand reservoirs on the flanks and crest of the Mikkelsen High. This play is part of the Thomson/Kemik play previously assessed in ANWR. It is related to the Barrow Arch Beaufortian Play of 1995 USGS National Asses sment and the Rift Play of the 1995 MMS National Assessment.

Area: Gross play area totals 138,107 acres of which 94,380 acres lie within the 1002 area, and 43,727 acres lie beneath State waters.

Trap: Potential traps for the Thomson are postulated to be strati graphic pinch-outs, valley-fill, and block-fault traps.

Reservoir: Potential Thomson reservoirs range from non-marine to shall ow marine sandstones, with a predominant detrital source from carbonate rocks in the basement complex.

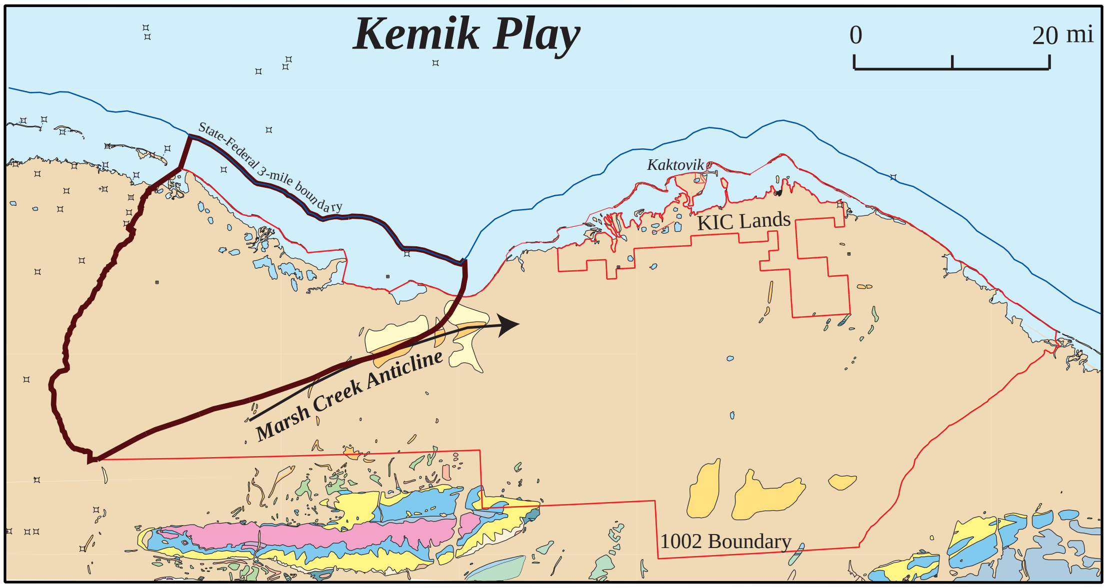
Source: The main hydrocarbon sources are postulated to be the Hue S hale and the lower part of the Canning Formation, with the Shublik Fo rmation a potential secondary source.

Timing: The early development of stratigraphic and structural traps leads to favorable timing considerations in the Thomson Play.

Hydrocarbons: Considerations of thermal maturation, burial history and de pths to potential reservoirs predict a hydrocarbon split of 90% o il and 10% gas in undiscovered reservoirs.

Analog fields: The Thomson sandstone contains significant quantities of hydrocarbons in the Point Thomson area (undeveloped) immediately adjacent to the 1002 area.

Figure AO10. Summary of Kemik Play.



The **Kemik Play** includes hydrocarbon potential in Kemik Sandstone reservoirs developed on the regional Early Cretaceous unconformity. This play is part of the Thomson/Kemik play previously assessed in ANWR. It is related to Barrow Arch Beaufortian Play of 1995 USGS National Assessment and the Rift Play of the 1995 MMS National Assessment.

Area: Gross play area totals 476,730 acres of which 395,746 acres lie within the 1002 area, and 80,984 acres lie beneath State waters.

Trap: Postulated to be stratigraphic (updip pinchouts of nearshore marine sandstones) and structural (within down-dropped normal fault blocks observed on seismic).

Reservoir: Reservoirs may range from non-marine valley fill reservoirs to shallow marine transgressive sandstones to nearshore marine sandstones. In contrast to Thomson reservoirs, the Kemik was sourced from a quartz- and chert-rich provenance.

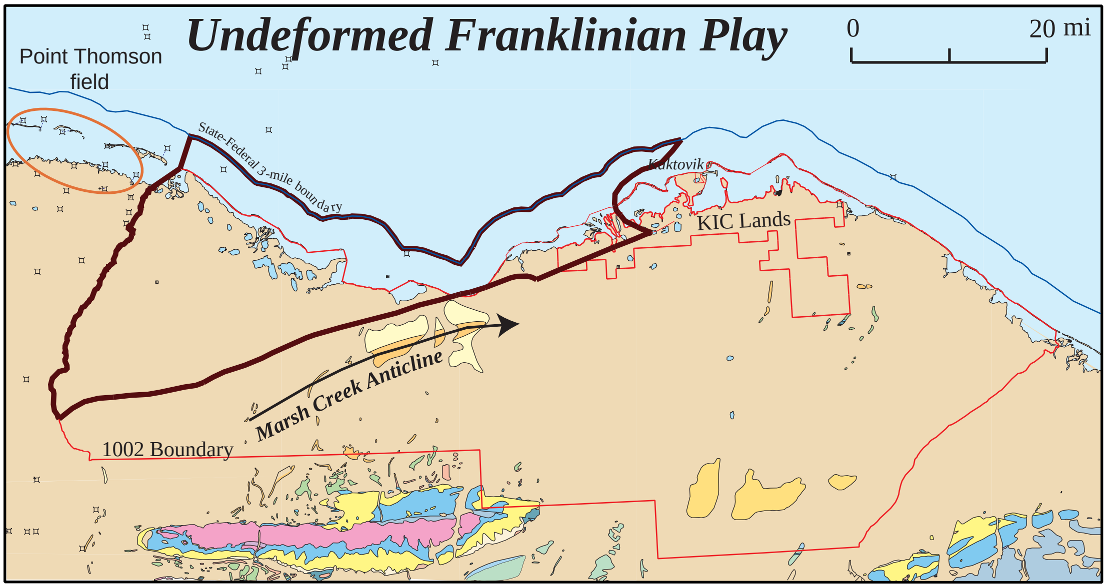
Source: The main hydrocarbon source is postulated to be the Hue Shale, with the lower part of the Canning and the Shublik forming a secondary source.

Timing: The early development of both stratigraphic and structural traps leads to favorable timing considerations in the Kemik Play.

Hydrocarbons: Considerations of thermal maturation, burial history and depths to potential reservoirs predict a hydrocarbon split of 90% oil and 10% gas in undiscovered Kemik reservoirs.

Analog fields: Possible analogs for Kemik reservoirs include the “C” Zone in the Kuparuk River field and coeval reservoirs at Walakpa.

Figure AO11. Summary of Undeformed Franklinian Play.



The **Undeformed Franklinian Play** includes hydrocarbon potential in basement carbonate rocks. This is the same play previously assessed in ANWR (called Undeformed Pre-Mississippian). Related to Barrow Arch Ellesmerian, Barrow Arch Beaufortian, and Endicott Plays of 1995 USGS National Assessment and to the Undeformed Early Cretaceous Basement Play of the 1995 MMS National Assessment.

Area: Gross play area totals 463,410 acres of which 317,560 acres lie within the 1002 area, 12,442 acres lie beneath KIC lands, and 133,408 acres lie beneath State waters.

Trap: Unconformity traps in reservoirs below, with main source rocks and seal above, the regional Early Cretaceous unconformity.

Reservoir: Pre-Mississippian carbonate rocks with combinations of intercrystalline, vuggy, and fracture porosity.

Source: Mainly Hue Shale and Canning Formation with possible Shublik contribution.

Timing: Favorable because of trap development shortly after deposition of seal and source rocks.

Hydrocarbons: Oil and or gas are present in the westward extension of the Undeformed Franklinian Play in the Point Thomson field.

Analog Fields: Point Thomson.

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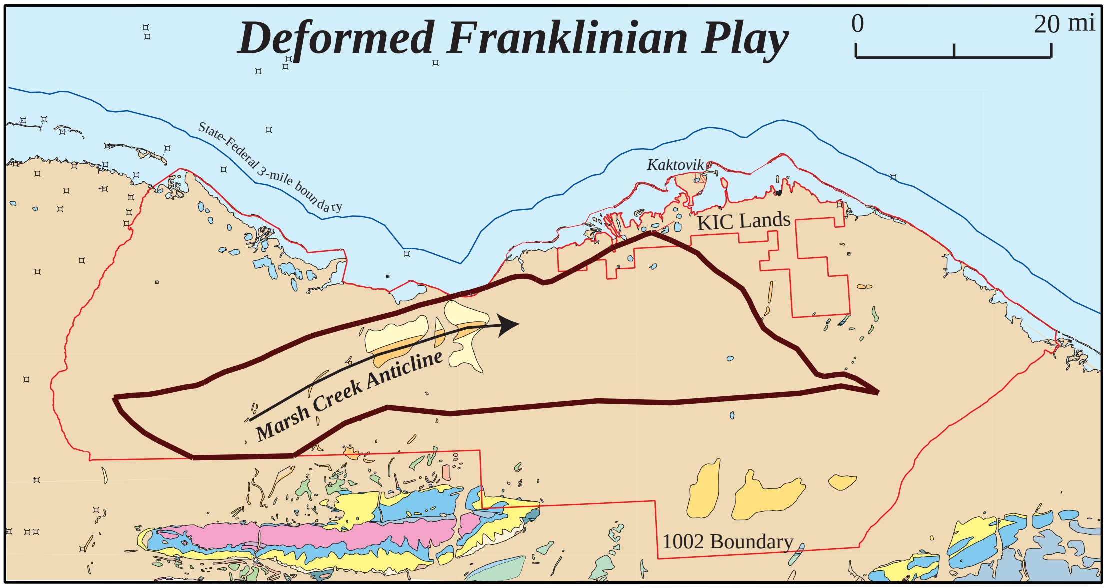
Figure AO12. Summary of Deformed Franklinian Play.



The **Deformed Franklinian Play** includes hydrocarbon potential in basement carbonate rocks involved in thrust-faulted anticlines. This play is part of the Folded Ellesmerian/Pre-Mississippian Play previously assessed in ANWR. It is also part of the Eastern Thrust-Belt Play of the 1995 USGS National Assessment.

Area: Gross play area totals 498,995 acres of which 489,894 acres lie within the 1002 area, 8,669 acres lie beneath KIC lands, and 532 acres lie beneath State waters.

Trap: Anticlinal and fault traps in reservoirs below, with main source rock and seal above, the regional Early Cretaceous unconformity.

Reservoir: Pre-Mississippian carbonate rocks with combinations of intercrystalline, vuggy, and fracture porosity.

Source: Mainly Hue Shale with possible Shublik Formation and minor Canning Formation contribution.

Timing: Deep burial and late stage deformation and trap formation suggests that parts of the play may be more favorable for gas than for oil.

Hydrocarbons: Rare dead oil indications are present in pre-Mississippian carbonate rocks in Sadlerochit and Shublik Mountains.

Analog Fields: None known.

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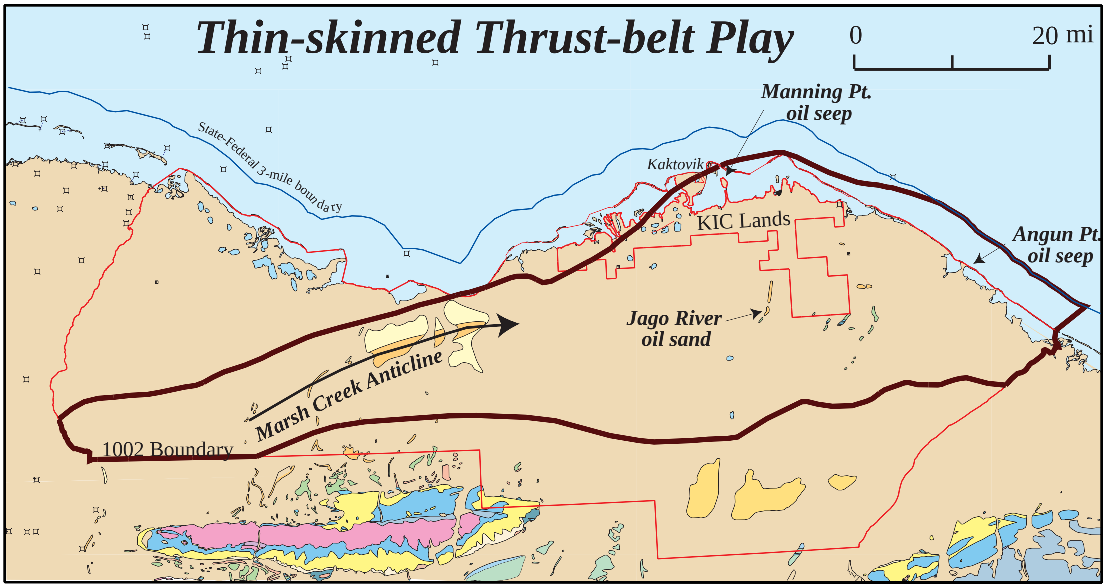
Figure AO13. Summary of Thin-skinned Thrust-Belt Play.



The **Thin-skinned Thrust-Belt Play** includes hydrocarbon potential in folded and faulted Brookian reservoirs. This is the same play as previously assessed in ANWR called Imbricate Fold Belt Play. Part of Fold Belt Play of 1995 USGS National Assessment and related to the Brookian Fold Belt Play of the 1995 MMS National Assessment.

Area: Gross play area totals 1,005,494 acres of which 858,220 acres lie within the 1002 area, 83,582 lie beneath KIC lands, and 63,691 acres lie beneath State waters.

Traps: Complex anticlinal and fault-controlled traps.

Reservoirs: Mostly turbidite sandstone with a limited amount of topset marine and deltaic sandstone.

Source: Mainly Hue Shale and Canning Formation; possible minor Shublik Formation contribution.

Timing: Complex relations with northward migrating deformation during early and mid-Tertiary followed by later Tertiary deformation andbasement uplift.

Hydrocarbons: Oil seeps at Manning Point and Angun Point, oil-stained sandstone in several locations along and south of the Marsh Creek anticline, oil-bearing sands along Jago River on the Niguanak high.

Analog fields: Adlartok (westernmost Mackenzie Delta field), Umiat, East Umiat, Gubik; and frontal thrust belt fields in the Canadian Rockies and Wyoming salient of the Cordilleran thrust belt.

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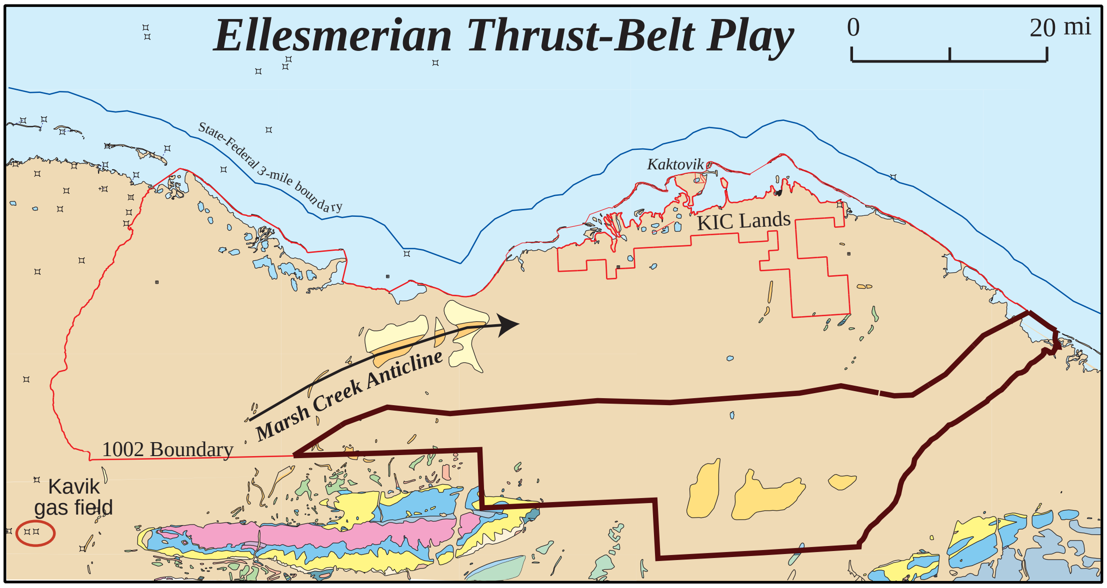
Figure AO14. Summary of Ellesmerian Thrust-Belt Play.



The **Ellesmerian Thrust-Belt Play** includes hydrocarbon potential in thrust-faulted structures involving Ellesmerian clastic and carbonate rocks. This play is the Ellesmerian part of the play previously assessed in ANWR called Folded Ellesmerian/Pre-Mississippian Play. Part of Eastern Thrust Belt Play of 1995 USGS National Assessment.

Area: Gross play area totals 471,773 acres of which 471,773 acres lie within the 1002 area.

Traps: Anticlinal and combination truncation and anticlinal traps

Reservoirs: Ledge Sandstone Member of the Ivishak Formation, Sag River Sandstone, Kekiktuk Conglomerate, and Lisburne Group carbonate rocks.

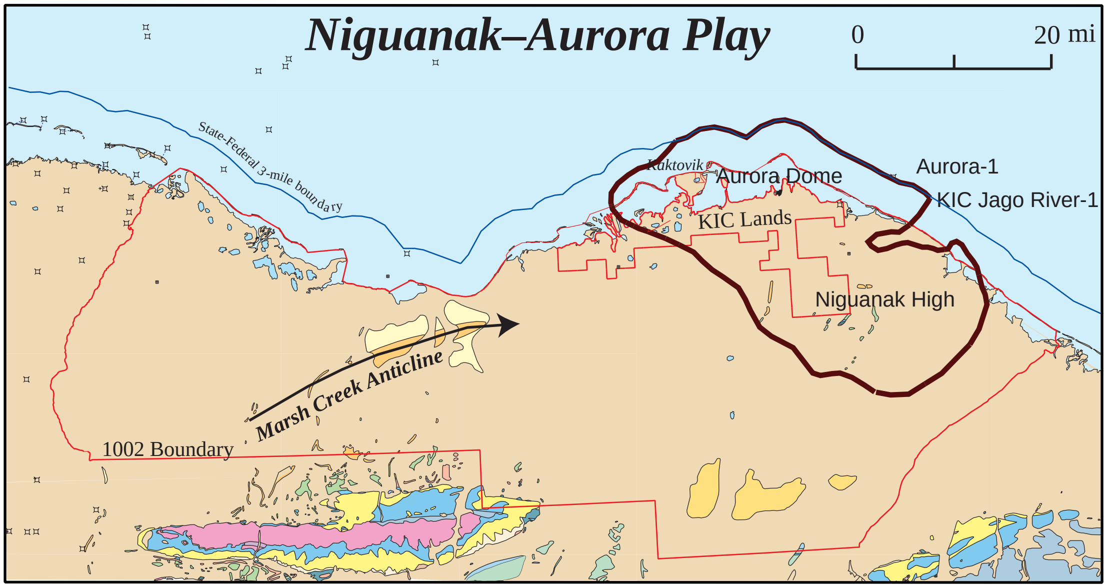
Source: Shublik Formation, Hue Shale and Canning Formation.

Timing: High thermal maturity and late Tertiary trap development suggest that play is primarily gas.

Hydrocarbons: Gas in Kemik and Kavik fields, a westward extension of this play, with dead oil in outcrop and core samples.

Analog fields: Kavik and Kemik gas fields

Figure AO15. Summary of Niguanak–Aurora Play.



The **Niguanak–Aurora Play** includes hydrocarbon potential in basement carbonate and Early Cretaceous sandstone reservoirs involved in thrust-faulted structures. This play is that part of the previously assesse d ANWR play called Folded Ellesmerian/Pre-Mississippian Play consisting of two large structures identified as prospects #18 and #19. Related to Eastern Thru st Belt Play of 1995 USGS National Assessment and to the Rift Play 1995 MMS National Assessment.

Area: Gross play area totals 389,586 acres of which 238,791 acres lie within the 1002 area, 76,061 lie beneath KIC lands, and 74,734 acres beneath State waters.

Traps: Roll-over anticlines and possible stratigraphic traps withi n north-verging thrust stacks of Franklinian and younger rocks.

Reservoirs: Primarily basement carbonates with the possibility of Kemik or Thomson-type sands as well as Kuparuk-type sandstone as seen in the Aurora well.

Source: Canning Formation and Hue Shale.

Timing: Deep burial and late stage (Eocene-Oligocene) deformation suggests that parts of the play may be more favorable for gas than for oil.

Hydrocarbons: None known.

Analog fields: None known.

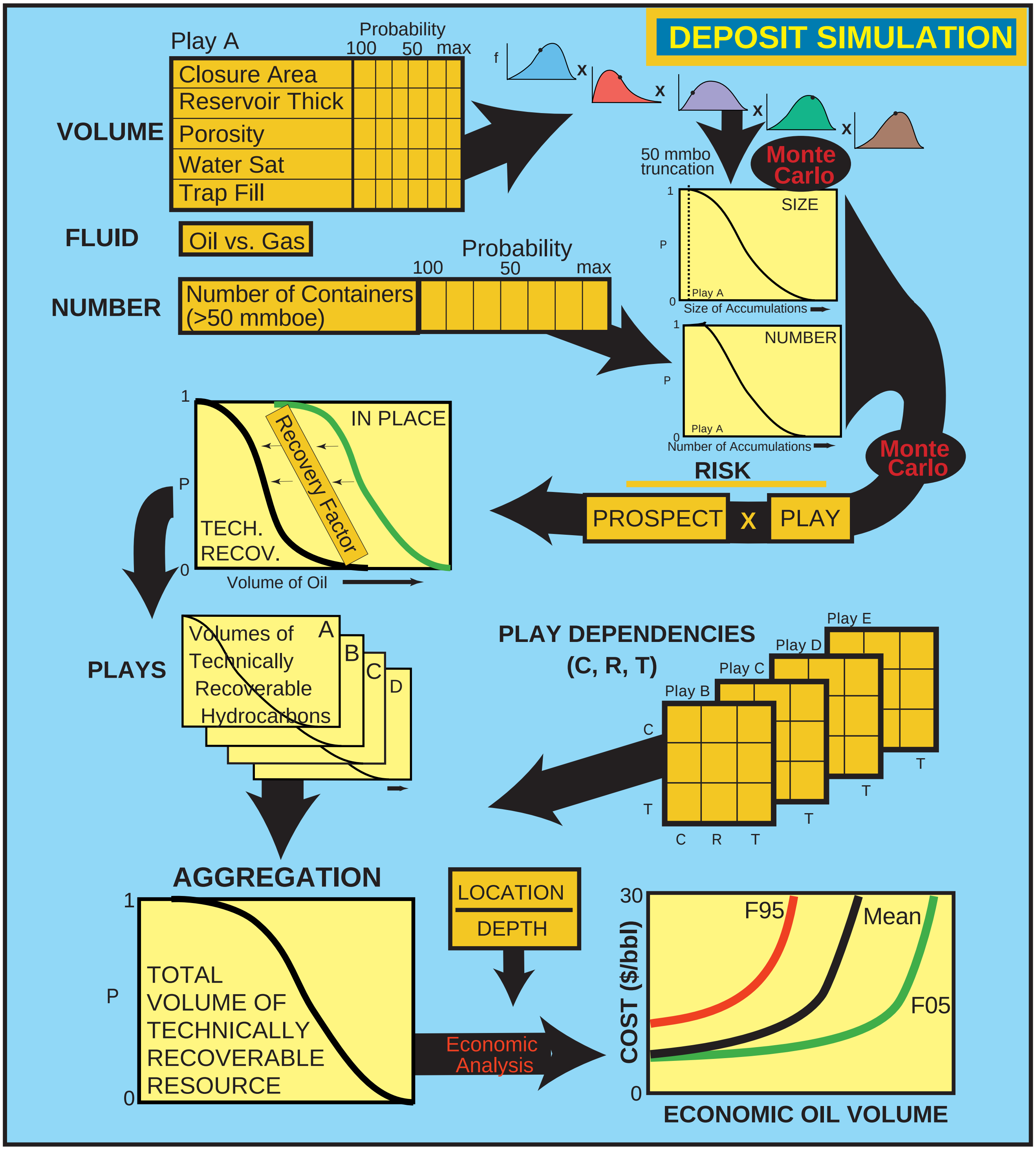


Figure AO16. Flow chart illustrating the steps followed in the assessment process. Orange boxes show required input, yellow boxes show output.

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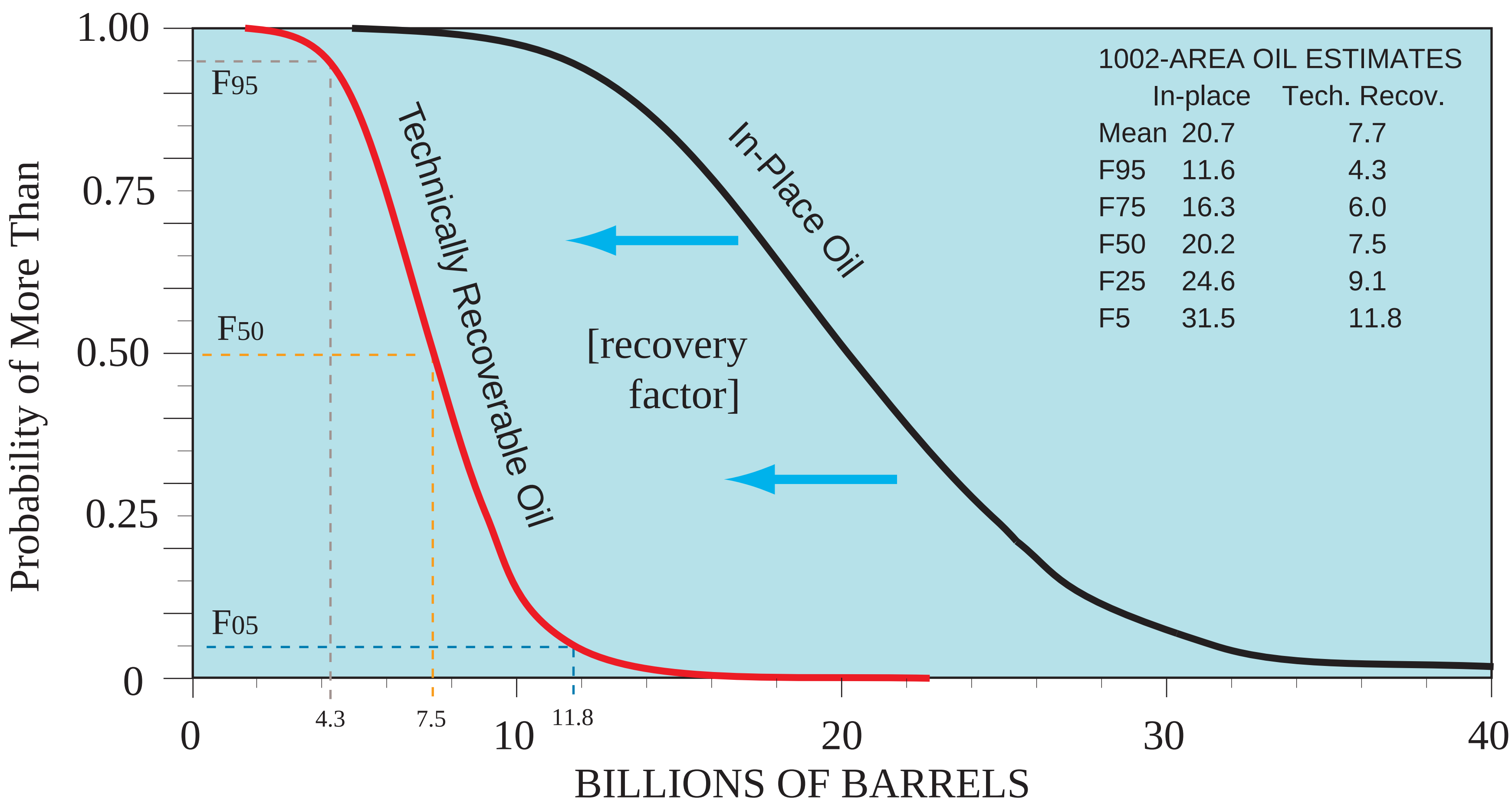

Figure AO17. Graph illustrating oil volumes and probabilities for the 1002 area. Curves represent categories of oil in assessment. The larger volumes of oil are represented by the in-place curve and lesser amounts by the technically recoverable curve. An example of how one reads this graph is illustrated by the dashed lines projected to the red curve for technically recoverable oil. There is a 95-percent chance (i.e., probability F_{95}) of at least 4.3 billion barrels of technically recoverable oil; there is a 50-percent chance (F_{50}) of at least 7.5 billion barrels of recoverable oil; and there is a 5-percent chance (F_{05}) of at least 11.8 billion barrels of recoverable oil. The F_{05} and F_{95} values are considered reasonable maximum and minimum values, while the mean expresses the average or expected value.

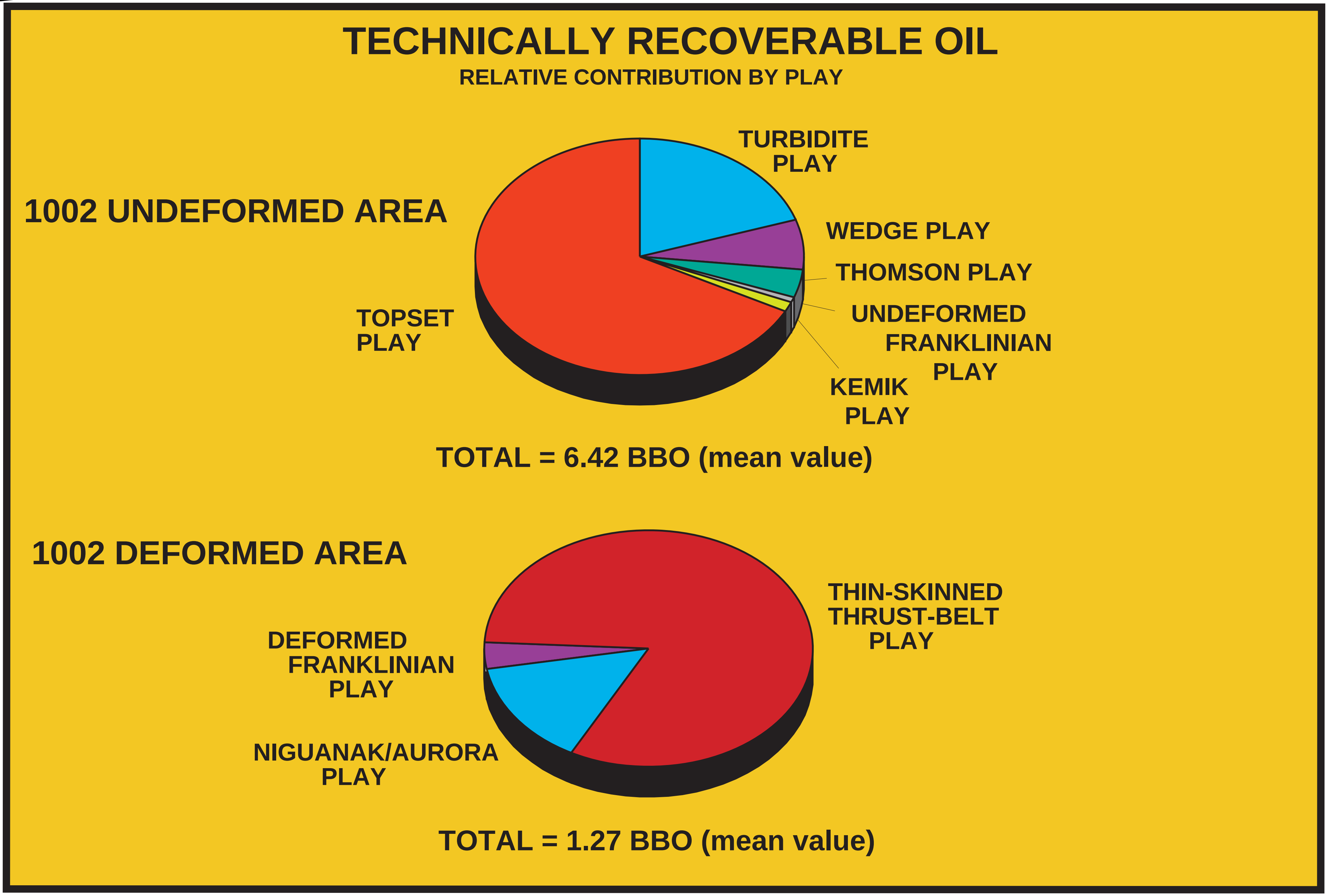

Figure AO18. Diagrams showing relative contribution of individual plays to the total expected (mean) technically recoverable oil resources in the 1002 deformed and undeformed areas of the Arctic Refuge.

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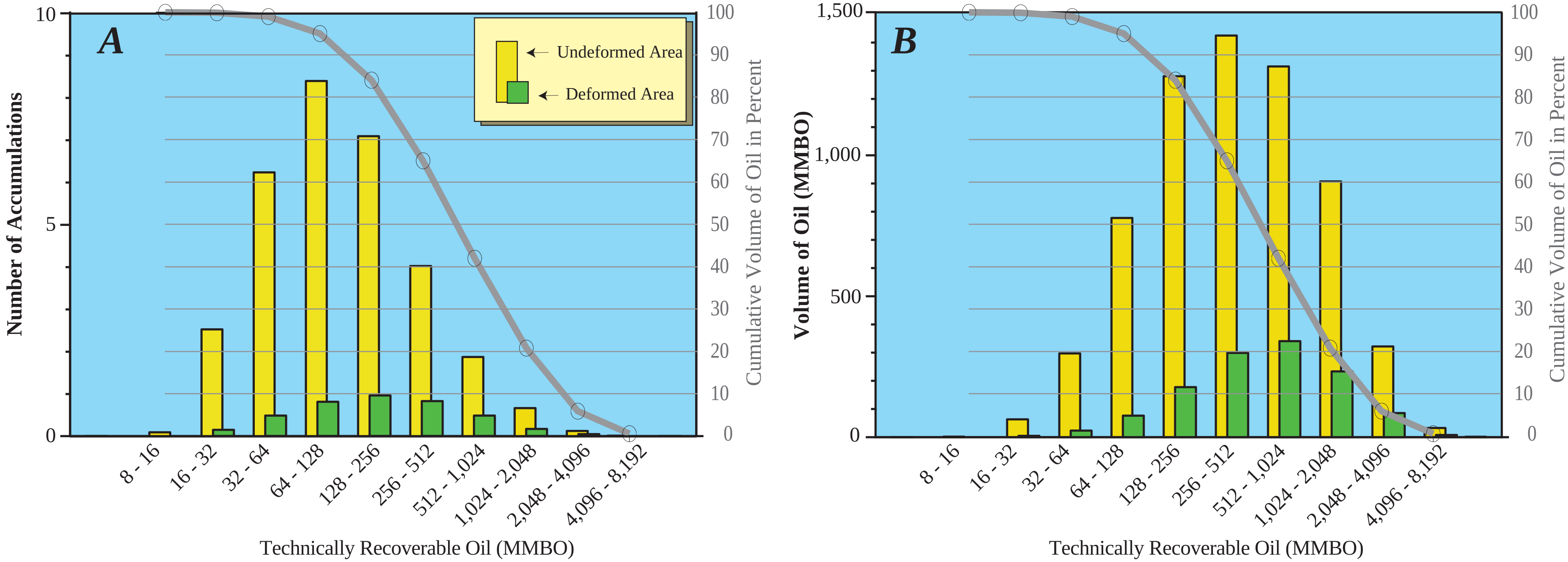

Figure AO19. Histograms showing numbers of oil accumulations and volumes of oil in the 1002 area. A. Histogram showing the expected (mean) number of petroleum accumulations estimated to exist in various size categories of technically recoverable oil resources in this assessment. Odd-looking size categories are based on a logarithmic, powers of two scale. The histogram is read as follows: It is estimated that the undeformed area (yellow bar) contains approximately two accumulations containing between 512 and 1,024 million barrels of technically recoverable oil. Adding the accumulations in the undefomed area to those of the deformed area (green bar) for each size category gives the total number of those sized accumulations for the entire 1002 area. Gray curve shows the expected (mean) volume of oil in the 1002 area as a cumulative percentage. It shows, for example, that 42-percent of the technically recoverable oil in the 1002 area is expected to occur in fields 512 million barrels or larger.

B. Histogram showing the expected (mean) volume of oil estimated to exist in each size category of technically recoverable oil resources. The histogram is read as follows: It is estimated that the undeformed area contains approximately 1,300 million barrels of technically recoverable oil in accumulations containing between 512 and 1,024 million barrels of technically recoverable oil. Adding the volume of oil in the undeformed area to that of the deformed area for each size category gives the total volume of those sized accumulations for the entire 1002 area. Gray curve shows the expected volume of oil in the 1002 area as a cumulative percentage.

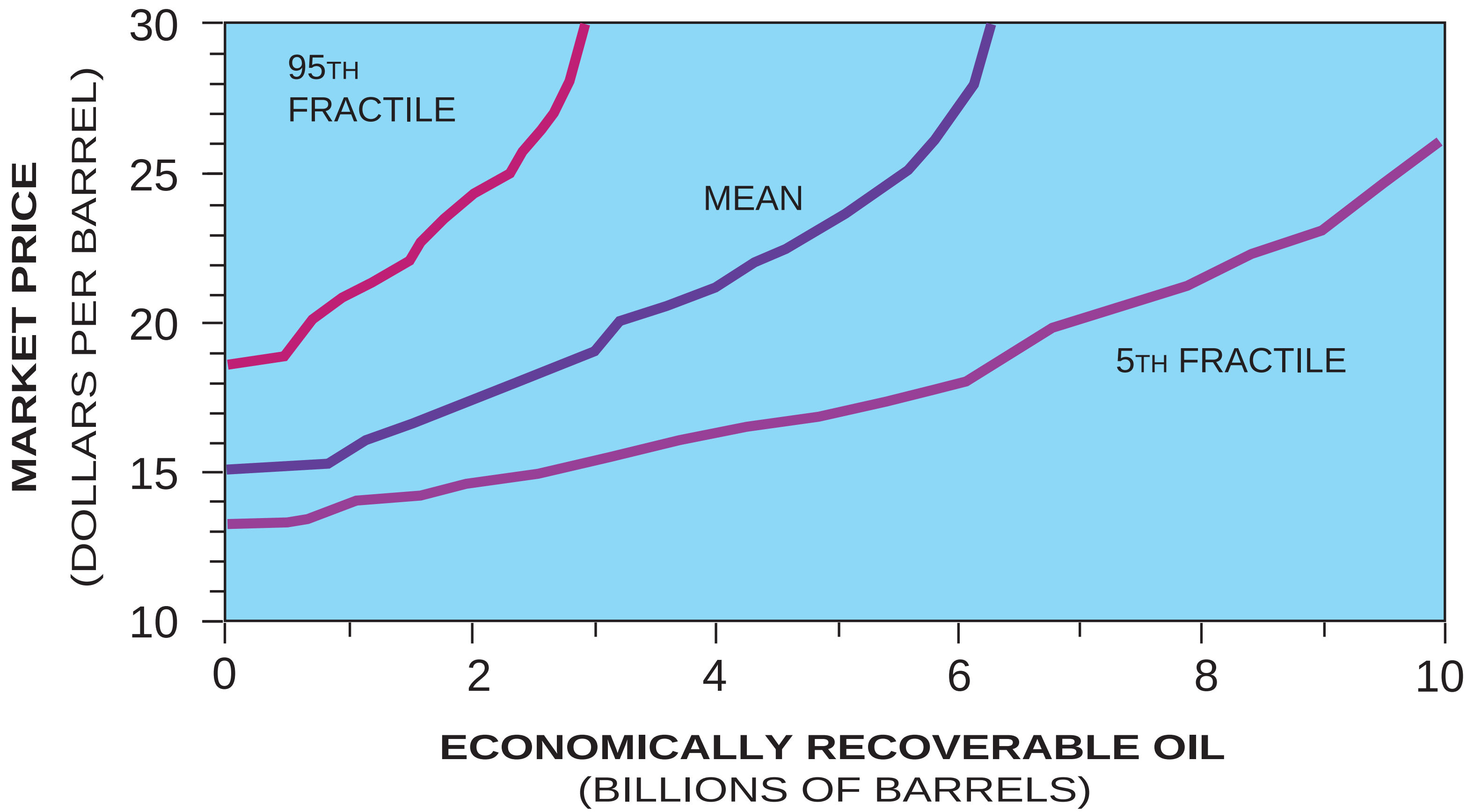

Figure AO20. Graph showing increasing volumes of oil that could be profitably recovered at increasing commodity prices from undiscovered fields in the 1002 area of the Arctic Refuge. Analysis includes costs of finding, developing, producing, and transporting oil to market, as well as a 12-percent return to capital.

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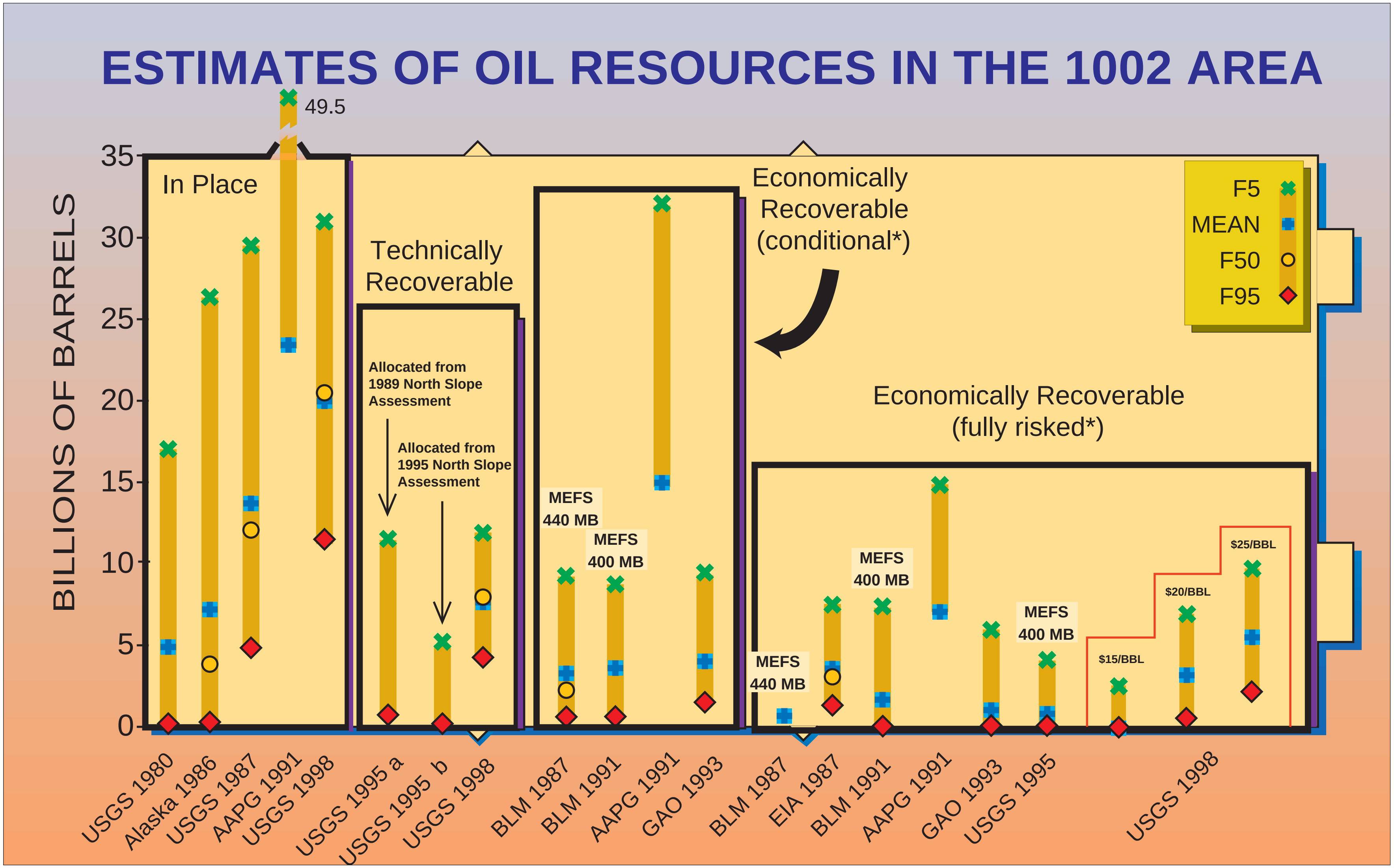

Figure AO21. Comparison of previous estimates of Arctic Refuge 1002 area oil resources with estimates from the current assessment. See text for description of previous assessments and Table AO4 for numbers. USGS 1998 economically recoverable estimates were taken from Figure AO20. MEFS, minimum economic field size. MB, millions of barrels. * See text for explanation of 'conditional' and 'fully risked'.

Table AO1. Assessment project personnel and collaborators.

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Gary Solin	Gordon Dolton	Dan Hayba
Bronwen Wang	Don Gautier	Dave Houseknecht
	Chris Giberson	David Root
MENLO PARK, CA	John Grow	Jack Schuenemeyer
Kenneth Bird	Curt Huffman	Tom Sheehan
Frances Cole	Joyce Kibler	
Kevin Evans	Tim Klett	**WOODS HOLE, MA**
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Leslie Magoon	Paul Lillis	
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Minerals Management Service
Stanford University
University of Alaska
University of Manchester
University of Wyoming

Table AO2. Technical highlights of the 1998 USGS assessment of the 1002 area of the Arctic National Wildlife Refuge.

- This is the first 1002 area assessment to report numerical estimates for all three resource categories (in-place, technically recoverable, and economically recoverable) using the same method of assessment and accomplished by the same group of scientists.

- Assessment methodology was thoroughly reviewed by experts within and outside of the USGS. Modifications were made to ensure consistency, improve understanding, and incorporate new engineering details.

- Economic analysis, for the first time, reports findings as continuous curves showing variations in amounts oil with variations in market price.

- All 1002-area seismic data were reprocessed, stacked, migrated, and depth-converted.

- Improved seismic resolution from reprocessing and the use of computer workstations resulted in a clearer understanding of structural and stratigraphic relations and improved prospect identification.

- A Brookian sequence stratigraphic framework was developed and was tied to surface exposures of the rocks within and adjacent to the 1002 area.

- Thermal maturity of rocks at the surface is shown by contour map of vitrinite reflectance isograds. Subsurface reflectance gradients are plotted for 23 wells.

- Apatite fission-track analyses confirmed findings of previous fission-track studies regarding the timing of uplift/deformation.

- Basin modeling studies using three different computer applications (Thrustpack, Basin2, and BasinMod) give insight into timing and location of hydrocarbon generation, possible migration routes, and potential trapping areas.

- Data for 39 nearby wells were archived in digital format. Physical rock properties were derived by systematic analysis of these data.

Table AO2, continued.

- Hydrous pyrolysis oil generation experiments were run on potential source rocks, a first for North Alaska. Experimentally generated oils were used for correlation with naturally occurring oils.

- All previously known surface oil localities were resampled and re-analyzed using advanced techniques. New surface oil localities were found and new samples from wells were obtained. Three oil types are identified: Prudhoe type, Hue type, and a Tertiary (Mackenzie delta) type.

- The petrographic setting and temperature measurements on fluid inclusions combined with apatite fission track analysis of host rocks places additional limits on the timing of hydrocarbon migration.

- Well logs were used to calculate source rock richness and thickness.

- Structural modeling, based on a balanced cross section, shows time and style of trap development in relation to hydrocarbon generation and migration.

- Gravity and magnetic data were analyzed by filtering techniques, thus allowing analysis of both shallow and deep structures. Analyses were integrated with seismic.

- Summaries of current field work are included as are field notes and maps by C.M. Molenaar and field parties for field work conducted during the early 1980s.

- Investigations of basement rock reservoir potential include new details from well cores and an interpretive map of rock types postulated to occur at the top of pre-Mississippian rocks in the 1002 area.

Table AO3. Summary of estimates of volumes of in-place and technically recoverable petroleum resources in various parts of the study area based on the current assessment. See Schuenemeyer (Chap. RS) for complete details, including estimates of associated gas and natural gas liquids. Basic statistical principles determine that mean values can be added and subtracted, but F_{95} and F_{05} values cannot. For example, the means for the undeformed and deformed parts of the ANWR 1002 area sum to the mean for the total ANWR 1002 area, but the F_{95} and F_{05} values do not. F_{95}, 95-percent probability level; F_{05}, 5-percent probability level. BBO, billions of barrels of oil. TCF, trillions of cubic feet.

IN-PLACE RESOURCES

	Oil Fields Oil (BBO)			Gas Fields Non-associated Gas (TCF)		
Part of study area	**F_{95}**	**Mean**	**F_{05}**	**F_{95}**	**Mean**	**F_{05}**
Entire assessment area	15.58	27.78	42.32	0	5.12	14.47
ANWR 1002 area	11.59	20.73	31.52	0	4.64	13.35
Undeformed part	9.43	17.48	27.44	0	0.48	2.38
Deformed part	0	3.25	8.14	0	4.16	12.58

TECHNICALLY RECOVERABLE RESOURCES

	Oil Fields Oil (BBO)			Gas Fields Non-associated Gas (TCF)		
Part of study area	**F_{95}**	**Mean**	**F_{05}**	**F_{95}**	**Mean**	**F_{05}**
Entire assessment area	5.72	10.36	15.96	0	3.84	10.85
ANWR 1002 area	4.25	7.69	11.80	0	3.48	10.02
Undeformed part	3.40	6.42	10.22	0	0.36	1.79
Deformed part	0	1.27	3.19	0	3.12	9.44

Table AO4. Summary of previous estimates of undiscovered oil resources in the ANWR 1002 area.
See text for discussion and Figure AO21 for graphical comparison.

Arctic National Wildlife Refuge, 1002 area Assessments	Undiscovered Oil Resources (in billions of barrels)			
	F_{95}	F_{50}	Mean	F_{5}
In-place resources				
1980 USGS	0.2	--	4.9	17.0
1986 State of Alaska	0.1	3.8	7.2	26.5
1987 USGS	4.8	11.9	13.8	29.4
1991 AAPG (Gunn)	--	--	23.3	49.5
Technically recoverable resources				
1995 USGS (allocation of 1989 USGS assessment)	0.7	--	--	11.7
1995 USGS (allocation of 1995 USGS assessment)	0.1	--	--	5.2
Economically recoverable resources (Conditional)				
1987 BLM (19-percent marginal probability)	0.6	2.2	3.2	9.2
1991 BLM (46-percent marginal probability)	0.6	--	3.6	8.8
1991 AAPG (Gunn)	--	--	15.2	32.2
1993 GAO (27-percent marginal probability)	1.5	--	4.0	9.4
Economically recoverable resources (Fully risked)				
1987 BLM	--	--	0.6	--
1987 EIA	1.2	3.0	3.5	7.4
1991 BLM (as reported in 1993 GAO table II.1)	0	--	1.6	7.2
1991 AAPG (Gunn)	--	--	7.0	14.8
1993 GAO (table II.2)	0	--	1.1	5.9
1995 USGS (using BLM 1991 MEFS)	0	0	0.9	4.1