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Final Report

U.S. Geological Survey Oil and Gas Resource Assessment of the Russian Arctic

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U.S. Geological Survey Oil and Gas Resource Assessment of the Russian Arctic

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Administrative Report

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DISCLAIMER

ABSTRACT

The U.S. Geological Survey (USGS) recently completed a study of undiscovered petroleum resources in the Russian Arctic as a part of its Circum-Arctic Resource Appraisal (CARA), which comprised three broad areas of work: geological mapping, basin analysis, and quantitative assessment. The CARA was a probabilistic, geologically based study that used existing USGS methodology, modified somewhat for the circumstances of the Arctic. New map compilation was used to identify assessment units. The CARA relied heavily on geological analysis and analog modeling, with numerical input consisting of lognormal distributions of sizes and numbers of undiscovered accumulations. Probabilistic results for individual assessment units were statistically aggregated, taking geological dependencies into account. The U.S. Department of Energy (DOE) funds were used to support the purchase of crucial seismic data collected in the Barents Sea, East Siberian Sea, and Chukchi Sea for use by USGS in its assessment of the Russian Arctic. DOE funds were also used to purchase a commercial study, which interpreted seismic data from the northern Kara Sea, and for geographic information system (GIS) support of USGS mapping of geological features, province boundaries, total petroleum systems, and assessment units used in the USGS assessment.

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EXECUTIVE SUMMARY

Among the greatest uncertainties concerning future energy supply is the volume of oil and gas remaining to be found in high northern latitudes. The potential for resource development is of increasing concern to the Arctic nations, to petroleum companies, and to all concerned about the region's fragile environments. These concerns have been heightened by the recent retreat of polar ice, which is changing ecosystems and raising the prospect of easier petroleum exploration and development. For better or worse, limited exploration opportunities elsewhere in the world combined with technological advances makes the Arctic increasingly attractive for development. Of the 6 percent of the Earth's surface encompassed by the Arctic Circle, one-third is above sea level and another third is in continental shelves beneath less than 500 m of water. The remainder of the Arctic consists of deep ocean basins historically covered by sea ice. Some onshore areas have already been explored and deep oceanic basins have relatively low petroleum potential, but the Arctic continental shelves constitute one of the world's largest remaining petroleum-prospective areas. Until now, remoteness and technical difficulty, coupled with abundant low-cost petroleum, have ensured that little exploration would occur offshore in the Arctic. Even where offshore wells have been drilled – in the Mackenzie Delta, the Barents Sea, the Sverdrup Basin, and in offshore Alaska – most resulting discoveries remain undeveloped.

To provide a perspective on the oil and gas resource potential of the region, the U.S. Geological Survey (USGS) recently assessed the potential for undiscovered conventional petroleum in the Arctic. The U.S. Department of Energy (DOE), through award DE-A126-05NT15538, provided support for parts of the USGS study. In particular, the DOE funds helped the USGS with its purchase of crucial seismic data collected in the Barents Sea, East Siberian Sea, and Chukchi Sea for use in assessment of the Russian Arctic. DOE funds were also used to purchase a commercial study, which interpreted seismic data from the northern Kara Sea, and for partial support of USGS geographic information system (GIS) mapping of geological features, province boundaries, total petroleum systems, and assessment units used in the USGS assessment of the Russian Arctic.

Using a new map compilation of sedimentary elements, the area north of the Arctic Circle was subdivided into 69 assessment units, 48 of which were quantitatively assessed. The Circum-Arctic Resource Appraisal (CARA) was a geologically based, probabilistic study that relied heavily on burial-history analysis and analog modeling to estimate sizes and numbers of undiscovered oil and gas accumulations. The results of the CARA suggest that the Arctic is gas-prone, with an estimated 770 to 2990 trillion cubic feet of undiscovered conventional natural gas, most of which is in Russian territory. Arctic wide, on an energy-equivalent basis, the quantity of natural gas is more than three times the quantity of oil and the median size of the largest undiscovered gas field is expected to be about eight times the size of the largest undiscovered oil field. In addition to gas, the gas accumulations may contain an estimated 39 billion barrels of liquids. The South Kara Sea is the most prospective gas assessment unit, but giant gas fields containing more than 6 trillion cubic feet of recoverable gas are possible at a 50-percent chance in 10 assessment units throughout the Arctic. Approximately 60 percent of the estimated undiscovered oil resource is in just six assessment units, of which the Alaska Platform is the most prospective. Overall, the Arctic is estimated to contain between 44 and 157 billion barrels of recoverable oil. Undiscovered oil resources could be significant to the Arctic nations, but they are probably not sufficient to shift the world oil balance away from the Middle East.

REPORT DETAILS

Introduction

The United States Geological Survey (USGS) recently completed an assessment of the undiscovered oil and gas resources of the Russian Arctic, as a part of the Circum-Arctic Resource Appraisal (CARA). The principal findings and implications of the study are summarized by Gautier and others (2009). The purpose of this introduction is to summarize the organization and methodological protocols used in conducting the USGS assessment and to explicitly recognize the contribution of the Department of Energy (DOE) to the acquisition of data used in assessment of the Russian Arctic.

Periodically the USGS conducts assessments of global undiscovered petroleum resources. The most recent of these was published in 2000 (USGS World Assessment Team 2000). Although that study included several Arctic basins, its main focus was the oil and gas remaining to be found in the known petroleum basins of the world. Thus most of the extensive unexplored areas of the Arctic were left unevaluated in that study.

In 2003 D.L. Gautier and G.F. Ulmishek formally proposed that the USGS undertake a systematic investigation of the undiscovered resources in all sedimentary basins of the Arctic, including those areas assessed in the 2000 study. The proposal was approved for the 2004 fiscal year funding cycle and work began on the Circum-Arctic Resource Appraisal (CARA) that year. The project was conducted under the auspices of the USGS World Petroleum Project, with most funding coming from the USGS Energy Resources Program. The DOE award discussed herein (DE-A126-05NT15538) provided additional funds for mapping and geological interpretation in the Russian Arctic.

The first public presentation of the project was in the summer of 2004, when a research workshop devoted to the Arctic assessment was convened by the Geological Survey of Denmark and Greenland (GEUS) in Illulissat, West Greenland. After four years of work, the CARA was completed in 2008, and initial results were presented at the International Geological Congress in Oslo and published in Science Magazine (Gautier and others, 2009).

The CARA project had three broad areas of activity: (1) geological mapping of the Arctic, (2) analysis of individual Arctic basins in preparation for the assessment, and (3) quantitative estimation of undiscovered petroleum.

Mapping the Arctic for the CARA

Consistent and reliable mapping of sedimentary basins is a prerequisite to any geologically based assessment. Early in the work of the CARA, it became evident that no existing geological map could adequately support the needs the study. In response, Arthur Grantz, a former USGS researcher with long experience in the Arctic, was invited to compile a new map of the Arctic sedimentary successions that would be suitable for use in the CARA. Grantz in turn approached Robert A. Scott and his colleagues of the Cambridge Arctic Shelves Programme at Cambridge University, Sergey S. Drachev of the P.P. Shirov Institute of Oceanology, Russian Academy of Sciences, and Thomas E. Moore, of the U.S. Geological Survey, all of whom agreed to collaborate on the new compilation.

They set to work immediately and completed an initial draft in the summer of 2005. The new map was then reviewed by a multinational group of Arctic experts at a workshop convened in Menlo Park, California, in December of that year. A revised map, reflecting many of the recommendations of the peer review, became available for use by the CARA team as its principal geological base map in the fall of 2006. After additional editing and revision the map was published through the American Association of Petroleum Geologists, where it remains publicly available online (Grantz and others, 2009).

Geological Analysis of the Arctic Basins

Geologically based resource assessments ultimately depend upon the quality and depth of their underlying geological analysis. For purposes of the CARA, a team of USGS scientists was assembled, originally consisting of approximately 20 geologists, geophysicists, geochemists, statisticians, and GIS specialists, most of whom were full-time USGS employees. This team was charged with the geological analyses that were the basis for the assessment. The initial responsibilities for analysis of the Russian Arctic and certain immediately adjacent areas, some of which changed during the course of the project, were as follows:

Barents Shelf: T. S. Ahlbrandt, D. L. Gautier, T.R. Klett, and J. K. Pitman

Arctic Russia and the Siberian Basins: K. J. Bird, T.R. Klett, J. K. Pitman, F. M. Persits, C. J. Schenk, G. F. Ulmishek, and C.J. Wandrey

Continental Margins of Eurasia Basin, Canada Basin, and the Lomonosov Ridge: Arthur Grantz, D. W. Houseknecht, P. J. McCabe, T. E. Moore, and M. E. Tennyson

Methodological support for the project was provided by R.R. Charpentier, D.L. Gautier, T.R. Klett, J.H. Schuenemeyer, and L.P. White. Analysis of potential field geophysical data was by R.W. Saltus, P.J. Brown, and A.K. Shah. Much of the burial-history and fluid-evolution modeling was done by J.K. Pitman, usually in cooperation with the other geologists. Geographic information system (GIS) mapping was by C.E. Anderson, C.P. Garrity, F.M. Persits, and Z.C. Valin.

Although the numerical assessments were the sole responsibility of the USGS, the geological analysis depended upon the good will of an international group of organizations, including (in alphabetical order) the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), the Geological Survey of Canada (GSC), the Geological Survey of Denmark and Greenland (GEUS), the Norwegian Petroleum Directorate (NPD), and the U.S. Minerals Management Service (MMS). Many active industry petroleum geologists and their respective companies also generously offered concepts and data. Work on the Russian basins was supported by contracts with several Russian academic scientists; these contracts were largely purchased through funds provided by DOE Award DE-A126-05NT15538.

The geological analysis of the Arctic basins was developed using publicly available information as well as data and expertise provided by the various cooperating organizations and scientists described above. Burial-history and fluid-evolution models were constructed for most basins using standard industry software such as PetroMod or BasinMod. The models were used to evaluate postulated petroleum systems and to help in selection of analogs for assessment.

The CARA geologists proposed sets of total petroleum systems and explicitly mapped assessment units (AU) within their respective geographic areas of responsibility (U.S.Geological Survey, 2009). Areas of provinces, petroleum systems, and AUs were calculated in a geographic information system (GIS). For basins with discovery histories, data from known accumulations (IHS Energy, 2007) were allocated to assessment units, from which spreadsheets were tabulated and exploration history plots were prepared. On the basis of the geological analysis and burial-history modeling, the geologists selected sets of analogs from an analog database constructed from 246 geologically classified AUs assessed in the 2000 World Petroleum Assessment (Charpentier and others, 2008). Many of the variables required for the numerical assessment were represented in the analog database, including numbers of accumulations per unit area (field density), median and maximum accumulation sizes, and ratios of numbers of oil accumulations to gas accumulations.

Quantitative Estimation of Undiscovered Petroleum with Example

The methods employed by the CARA were similar to those used in the USGS World Petroleum Assessment 2000, but with certain modifications required by the special circumstances of the Arctic. The CARA geologists prepared documentation for each AU and completed a preliminary assessment input form. The entire CARA team then met to review the geological models, petroleum systems, AU definitions, analog sets, and assessment strategies. This process was intended to ensure a consistent treatment for every AU and to provide an important peer review of the geological concepts that were the basis for the CARA. In some cases, the review identified needs for additional geological work and/or changes to AU boundaries. If necessary, areas were recalculated and exploration history plots were updated.

Some time after the initial review a formal assessment meeting was convened, at which time input forms were finalized and any necessary modifications were documented. An example of a completed geological input form used for the CARA is shown in appendix 1. The following paragraphs describe the capture of data for a CARA AU in the Russian Arctic – the South Barents Basin and Ludlov Saddle AU.

South Barents Basin and Ludlov Saddle AU Description

The South Barents Basin and Ludlov Saddle AU (SBBLS) in the East Barents Basins Province is bounded on the east by Novaya Zemlya and Admiralty Arch, on the north by the North Barents Basin, on the south by the Kolguyev Terrace and the Kola-Kanin Monocline, and on the west by the Central Barents High. The AU area is approximately 322,000 km^2. Stratigraphically, the AU includes a sedimentary section from upper Paleozoic through Cretaceous.

Major source rocks are inferred to be Triassic mudstone and possibly upper Paleozoic and Jurassic mudstone, all of which are presumed to be thermally mature in the South Barents Basin. Upper Devonian marine “Domanik Facies” mudstone is a potential source rock; however, it is not observed in the Kolguyev Terrace or in any wells in the South Barents Basin. In the Kolguyev Terrace, Upper Permian mudstone is thermally immature, but it might be mature deeper in the South Barents Basin. Upper Jurassic mudstone also could be a source rock in limited parts of the deeper basin, but it is thermally immature elsewhere. Known reservoir rocks in the AU are primarily Jurassic paralic and marine sandstone and Permian and Triassic fluvial, deltaic, and nearshore marine sandstones. The Permian and Triassic reservoirs are thin and compartmentalized. Jurassic sandstones have good reservoir quality and contain most of the discovered petroleum. Upper Devonian through Lower Permian carbonates and reefs, similar to those in the Timan-Pechora Basin and observed on seismic profiles around the periphery of the South Barents Basin, are potential reservoirs. Lower Cretaceous submarine channel and fan sandstones are also potential reservoirs. Traps in which petroleum was discovered in the South Barents Basin are mainly broad, gentle anticlines that developed from Late Triassic to Early Cretaceous time.

The input for assessment of undiscovered petroleum resources consists primarily of estimates of the number and sizes of undiscovered fields. The estimates are given as minimum, median, and maximum values, and lognormal distributions are fit to these values. Estimates of undiscovered petroleum resources are calculated by statistically combining the number and sizes of undiscovered oil and gas fields along with geological risk in a Monte Carlo simulation with 50,000 iterations. Calculated resource quantities and the largest field size are recorded during every iteration, and the results are given as probability distributions. For areas that are immature with respect to exploration, analogs with real data aid in estimating these input variables.

The main types of analog data used are field density and the median and maximum field sizes of fields exceeding 50 million barrels of oil-equivalent oil or gas (MMBOE), a minimum size cutoff used for this assessment. The number of undiscovered accumulations in an AU was estimated by comparing field densities of the analog datasets (number of fields per 1,000 km^2). Sizes of undiscovered accumulations were estimated by comparing the median and maximum sizes in the analog sets.

Input Data for South Barents Basin and Ludlov Saddle AU

As is the case with SBBLS, most CARA AUs have had little exploration and only a few discoveries. In such cases analog sets were chosen to consistently evaluate resource potential based on geological similarities. The selected analogs were recorded on the input form (appendix 1) (*Analogs Used in Estimating Input*). For example in the case of the SBBLS, numbers and sizes were estimated in reference to the analog set of global AUs in rift/sag basins as the dominant control on trap type, and rift/sag is indicated on the form. A different analog or set of analogs was commonly used to determine the ratio of oil to gas, coproducts, and ancillary data. The form for the SBBLS shows that the discoveries from the South Barents Basin were used as a specific analog for commodity composition.

Only one basic geological model was considered for the SBBLS (that of rift/sag basins) and only a single scenario was used. However, in cases where more than one geological model was postulated and multimodal distributions for numbers or sizes of undiscovered accumulations were needed, each geological model was assigned to a scenario, with an associated probability. When multiple scenarios were specified, the sum of their probabilities must equal one. The input for each scenario was recorded on a separate input form. In the case of SBBLS, the single scenario probability was 1.0.

On the form (appendix 1), a header labeled *Identification Information* names the AU (South Barents Basin and Ludlov Saddle), identifies the assessing geologist (T.R. Klett), and encodes the AU within a hierarchy of: (1) region (Former Soviet Union, region 1), (2) province (East Barents Basins, 1050), (3) total petroleum system (Paleozoic-Mesozoic Composite, 105001), and (4) Assessment Unit (South Barents Basin and Ludlov Saddle, 10500102). The code used in this hierarchy was consistent with that of the USGS 2000 World Petroleum assessment, but with an additional region (region 0) for the central Arctic Ocean. In cases where the newly defined provinces were essentially the same as those of the 2000 study, the original province numbers and names were retained. However, the total petroleum systems and AUs used for the CARA were almost entirely new. Scenarios were recorded as needed.

Next, basic information is captured (*Characteristics of Assessment Unit*), including the area of the AU (322,000 km^2), the minimum accumulation size assessed (50 MMBOE), and the number of discovered accumulations exceeding the minimum size within the AU. In the case of the SBBLS this number is 4. Although the form permits the use of various sizes, in practice a uniform minimum accumulation size of 50 MMBOE was used in every CARA AU. Each AU was classified into one of five categories of data density and uncertainty based on the highest level of exploration achieved within the AU. For the SBBLS, where some discoveries have been made, the appropriate uncertainty category (discoveries) has been identified. The number of discoveries is recorded.

Geological Analysis of Assessment Unit Probability

The CARA is a probabilistic study, so the principal input data were entered as conditional distributions, given the existence of at least one undiscovered accumulation of minimum size within the AU.

The likelihood that the South Barents Basin and Ludlov Saddle AU contains at least one field equal to or greater than the minimum field size of 50 MMBOE is 100 percent (1.00) because four gas fields greater than this minimum size and one natural gas discovery below this minimum size have already been found. The known gas fields in the AU are as large as 100 trillion cubic feet (TCF) of gas (IHS Energy, 2007); no oil fields have yet been found.

Charge Probability – A charge probability of 1.00 was estimated because the AU area has a petroleum system sufficient to charge one field equal to or greater than the minimum size (50 MMBOE).

Rocks Probability – A rock probability of 1.00 was estimated because the AU area has sufficient reservoirs and traps to contain at least one field equal to or greater than the minimum size (50 MMBOE).

Timing of Geological Events – A timing and preservation probability of 1.00 was estimated because the AU is known to contain petroleum accumulations equal to or greater than the minimum size (50 MMBOE).

Geological Analogs for Assessment

Analog data were used to estimate the numbers and sizes of undiscovered accumulations. The analog dataset used in assessment of the SBBLS AU contains 20 AUs representing rift/sag basins in extensional and compressional structural settings, with clastic and/or carbonate rocks. All of the analog AUs have discovered fields greater than the minimum size defined for this assessment, 50 MMBOE. The density of prospects mapped by seismic surveys was used to confirm and adjust the estimated number of undiscovered fields in the AU.

Numbers of undiscovered fields – The total number of undiscovered fields in the AU was estimated by comparing field densities (estimated number of undiscovered fields plus the number of discovered fields greater than 50 MMBOE per 1,000 km^2) in the analog dataset. The density of discovered fields, which is smaller than the density of both discovered and undiscovered fields, was used to calibrate the density of the undiscovered fields. Minimum, median, and maximum densities of approximately 0.01, 0.15, and 0.3, respectively, were used. The median density, 0.15, is lower than the median densities of about 0.25 in the analog data set and is approximately equal to the density calculated for mapped, undrilled prospects should these prospects become fields greater than the minimum specified size. The estimated maximum density (0.3) is less than that of the analog set (1.12, density of discovered fields, and 1.78, density of both discovered and undiscovered fields). Excluding extreme values that do not represent this AU, the maximum density of the analog dataset is 0.4 to 0.6. The estimated total minimum, median, and maximum numbers of undiscovered fields are 3, 45, and 100, respectively. The estimated number of undiscovered oil fields is 0 (minimum), 6 (median), and 40 (maximum) and the estimated number of undiscovered gas fields is 3 (minimum), 38 (median), and 100 (maximum).

Sizes of undiscovered fields – The input minimum, median, and maximum undiscovered, oil and gas accumulation sizes in the South Barents Basin and Ludlov Saddle AU are reported in the appendix. Minimum sizes of undiscovered fields defined for the AU are 50 MMB of crude oil and 300 BCF (billion cubic feet) of natural gas (assuming 6 BCF equals 1 MMBOE). The median undiscovered field sizes in the AU, 110 MMB of crude oil and 660 BCF of natural gas, are approximately equal to the median field sizes (110 MMB of crude oil and 590 BCF of natural gas) of the analog dataset. Absolute maximum undiscovered oil and gas field sizes in the AU are 10,000 MMB and 500,000 BCF. The maximum undiscovered gas field size, 500,000 BCF, is larger than the largest discovered gas field, Shtokmanovskoya, in the South Barents Basin (IHS Energy, 2007). Expected largest undiscovered field sizes in the AU are estimated to be 1,000 MMB of crude oil and 80,000 BCF of natural gas. These expected largest sizes are much smaller than the estimated maximum undiscovered field sizes. The expected largest gas field (80,000 BCF) is smaller than Shtokmanovskoya field (IHS Energy, 2007). However, the estimated maximum field size of 500 TCF allows for the possibility that the largest gas field in the South Barents Basin might not have yet been found and that another gas field might yet be discovered that is comparable in size to Shtokmanovskoya. Large accumulations are expected to occur on structural highs along the basin margins.

Petroleum composition and properties of undiscovered fields – Oil/gas mixture, coproducts, and petroleum-quality properties for the AU were taken from analyses of petroleum discovered in the South Barents Basin, the Kolguyev Terrace AU, and from world statistics. An oil/gas mixture of 0 (minimum), 0.05 (mode), and 0.4 (maximum) was estimated because the inferred source rocks are gas-prone, although some crude oil accumulations might be found around the periphery of the basin, where source rocks are thermally mature with respect to oil, and in the basin center if Jurassic source rocks have expelled petroleum. Drilling depths for undiscovered fields were estimated from interpreted seismic profiles and well penetrations in the AU, and from petroleum-generation models. Estimated depths for undiscovered oil fields range from a minimum of 1.0 km to a median of 3.0 km and a maximum of 5.0 km, and estimated depths for undiscovered gas fields range from a minimum of 1.0 km to a median of 3.0 km and a maximum of 6.5 km.

Gas/oil ratios and quantities of coproducts and various ancillary data appear in the sections labeled *Ratios for Undiscovered Accumulations, To Assess Coproducts* and *Selected Ancillary Data for Undiscovered Accumulations.* An "OilGasPhase" program was developed to help generate distributions for numbers of oil versus gas accumulations in cases where the mix was uncertain. In this approach, which was used most commonly, the distribution for total number of undiscovered accumulations was estimated (commonly from analogs) and a separate probability distribution for oil/gas mix was also estimated. Global distributions of each of these variables were also available as a default.

Using data from the finalized geological input form, a Monte Carlo simulation was used to generate probability distributions for each of the assessed commodities, as well as for coproducts and for accumulation sizes. Monte Carlo programs used in the CARA were modifications of the program developed for the 2000 USGS methodology (Charpentier and Klett, 2000). The programs are Microsoft Excel workbooks requiring Crystal Ball software to run. During the assessment meeting, the Monte Carlo program was initially run with a small (1,000 to 5,000) number of iterations to give real-time feedback to the assessment review team, especially concerning the distribution for largest undiscovered accumulations. If the results of the calculations are considered to correctly reflect the geological knowledge and uncertainty, the input form was finalized. If not, the input was modified and the program was run until the results adequately reflected the geological model. After the assessment meeting, the program was run for 50,000 iterations to give an official set of estimates for each AU.

Assessment Results

The mean undiscovered crude oil resource in the South Barents Basin and Ludlov Saddle AU is 1,939 MMB, with a 90-percent confidence interval of 241 to 5,901 MMB. The mean volume of undiscovered nonassociated natural gas resource is 183,689 BCF, with a 90 percent confidence interval of 44,854 BCF to 472,507 BCF. The largest expected undiscovered oil field size is approximately 937 MMB, and the largest expected undiscovered gas field size is approximately 79,307 BCF. The AU probability is 1.00.

The USGS mean estimate of undiscovered, technically recoverable oil north of the Arctic Circle is more than double the amount of oil that has previously been found (produced plus remaining reserves) in the Arctic. On the basis of the USGS World Petroleum Assessment 2000, and adjusted for discoveries since 1996, the Arctic may contain about 13 percent of the mean estimated global undiscovered oil resource.

The results of the USGS Circum-Arctic Resource Appraisal suggest that all 48 assessed AUs may contain undiscovered oil, but about 60 percent of the resource is concentrated in just 6 of them. The Alaska Platform stands out, with a mean estimate of 27.9 BBO. Other important AUs include the Canning-Mackenzie Deformed Margin (6.4 BBO), North Barents Basin (5.3 BBO), Yenisey-Khatanga (5.3 BBO), the Northwest Greenland Rifted Margin (4.9 BBO), and two AUs on the northeast Greenland Shelf: South Danmarkshavn Basin (4.4 BBO) and the North Danmarkshavn Salt Basin (3.3 BBO).

The USGS study indicates that the Arctic contains more than three times as much undiscovered gas as oil. The estimated largest undiscovered gas accumulation is almost eight times the estimated size of the largest undiscovered oil accumulation (22.5 BBOE versus 2.9 BBO) and therefore more likely to be developed. The aggregated results suggest that there is a high probability (>95 percent chance) that more than 770 TCF of gas occurs north of the Arctic Circle, a one in two chance (50 percent) that more than 1,547 TCF may occur, and a one in twenty chance (5 percent) that as much as 2,990 TCF could be added to proved reserves from new discoveries. The median estimate of undiscovered gas is a volume larger than the total gas so far discovered in the Arctic and represents about 30 percent of global undiscovered conventional gas.

Undiscovered natural gas resources are concentrated in the Russian Arctic. Two thirds of the undiscovered gas is in just four AUs: South Kara Sea (WSB2)-607 TCF, South Barents Basin (EBB2)-184 TCF, North Barents Basin (EBB3)-117 TCF, and the Alaska Platform (AA1)-122 TCF. The South Kara Sea, the offshore part of the northern West Siberian Basin, is the most prospective hydrocarbon province in the Arctic.

These estimates do not include technological or economic risks, so a significant fraction of the estimated undiscovered resources might never be developed. Development will depend upon market conditions, technological innovation, and the sizes of undiscovered accumulations.

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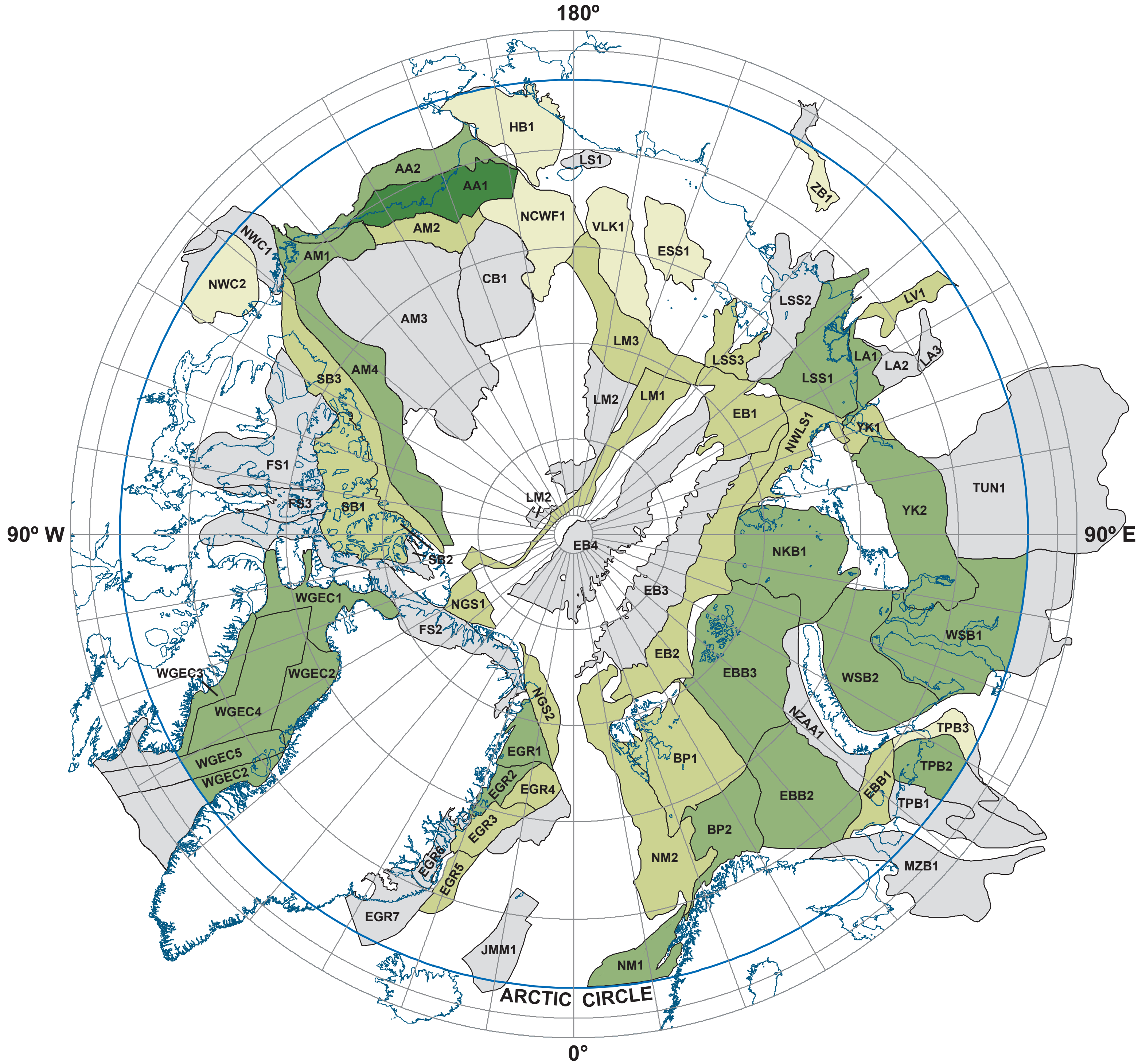
Acronyms

AU	Assessment unit
AUP	Assessment unit probability
BBO	Billion barrels of oil
BCF	Billion cubic feet
BCFG	Billion cubic feet of gas
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
CARA	Circum-Arctic Resource Appraisal
DOE	United States Department of Energy
GEUS	Geological Survey of Denmark and Greenland
GIS	Geographic information system
GSC	Geological Survey of Canada
MMB	Million barrels
MMBOE	Million barrels of oil equivalent
MMS	United States Minerals Management Service
NGL	Natural gas liquids
NPD	Norwegian Petroleum Directorate
SBBLS	South Barents Basin and Ludlov Saddle
TCF	Trillion cubic feet
USGS	United States Geological Survey

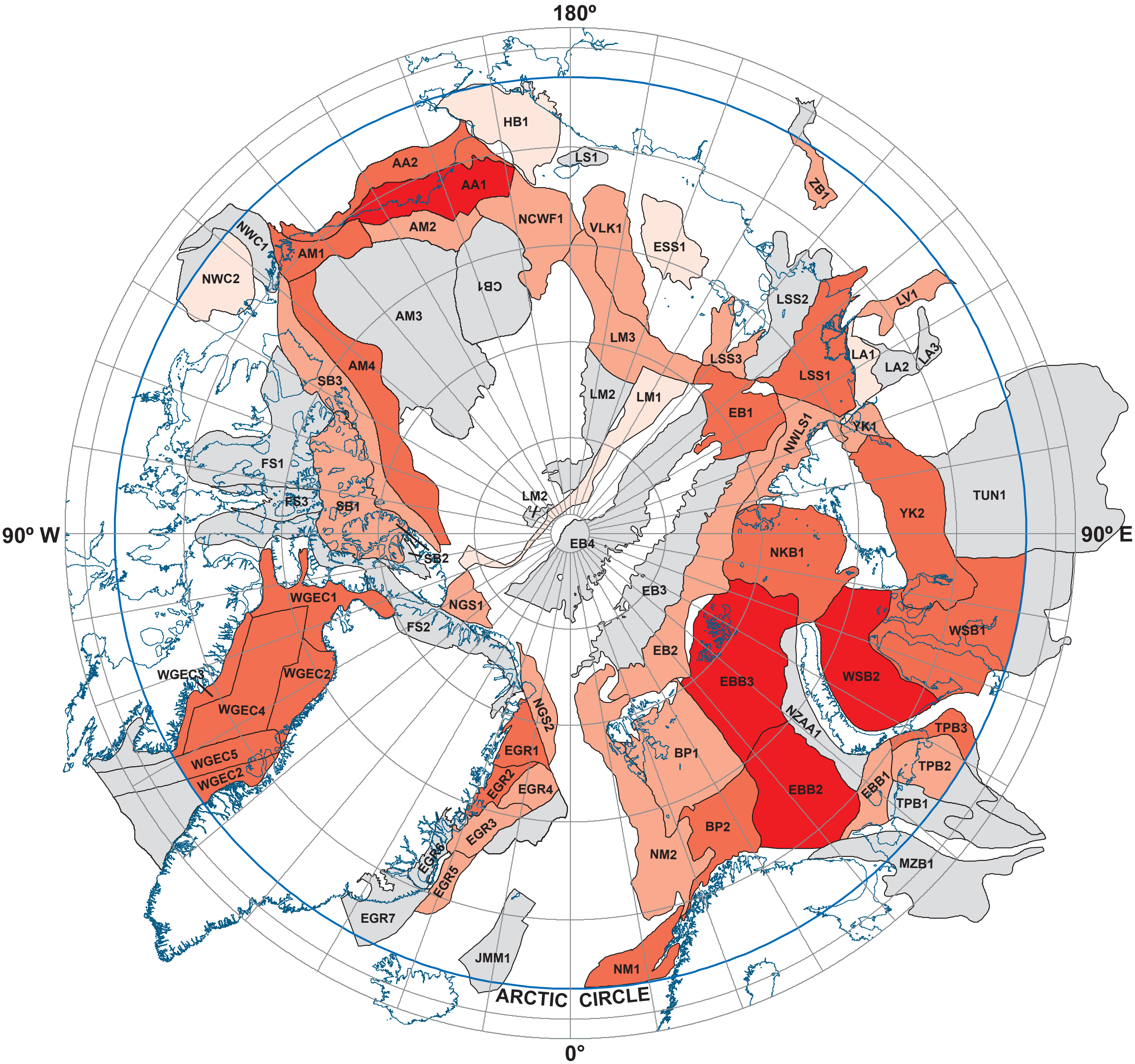
Figure

Maps showing assessment units (AU) of the USGS Circum-Arctic Resource Appraisal (CARA), color-coded for risked mean estimated undiscovered recoverable oil (shown in green) and undiscovered recoverable natural gas (shown in red). Only areas north of the Arctic Circle are included in the estimates. Labels correspond to AU codes in the table. Maps are modified from Gautier and others (2009. DOE funding helped support geological mapping and assessment in the Russian Arctic AUs: HB1, MZB1,TPB1, TPB2, TPB3,EBB1, EBB2, EBB3, NZAA1, NKB1, WSB1,WSB2, YK1, YK2, NWLS1, LA1, LA2, LA3, TUN1, LV1, LSS1, LSS2, LSS3, ZB1, ESS1, VLK1, NCWF1, LS1, LM3, EB1,and EB2.



UNDISCOVERED OIL
(billion barrels)

- >10
- 1–10
- 0.1–1
- <0.1
- Area not quantitatively assessed
- Area of low petroleum potential



UNDISCOVERED GAS
(trillion cubic feet)

- >100
- 6–100
- 1–6
- <1
- Area not quantitatively assessed
- Area of low petroleum potential

Table

Partial results of the USGS Circum-Arctic Resource Appraisal. AU codes correspond to labeled Assessment Units shown on the maps. AUP is Assessment Unit Probability, defined as the probability of the existence of at least one accumulation with 50,000 barrels or more of oil-equivalent oil or natural gas (MMBOE). Oil accumulations are defined as having less than 20,000 cubic feet of gas per barrel of liquids. Oil refers to oil in oil accumulations and non-associated gas refers to gas in gas accumulations. Associated/dissolved gas is natural gas occurring in oil accumulations. Natural gas liquids (NGL) are hydrocarbon liquids separated from associated/dissolved gas. Liquids include both oil and other hydrocarbon liquids in nonassociated gas accumulations. Quantities of oil, NGL, and liquids are reported in millions of barrels (MMBO, MMBNGL, and MMBL, respectively). Fractile values (F95, F50, F5) are not additive. F95 represents a 19 in 20 chance, F50 represents a 1 in 2 chance, and F5 represents a 1 in 20 chance of the occurrence of at least the amount tabulated. Quantities of nonassociated gas and associated/dissolved gas are reported in billions of cubic feet (BCF). Results are only listed for the AUs of the Russian Arctic, the assessment of which was partially supported by DOE award DE-A126-05NT15538. Full results and additional information can be found in Gautier and others (2009) and on the USGS Energy Program Arctic website. (http://energy.usgs.gov/arctic/).

AU Code	Assessment Unit	AUP	Oil in Oil Accumulations				Associated/Dissolved Gas in Oil Accumulations				Natural Gas Liquids in Oil Accumulations			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
North America														
AA1	Alaskan Platform	1.00												
AA2	Alaskan Fold- and Thrust-Belt	1.00												
CB1	Chukchi Borderland	0.05												
AM1	Canning-Mackenzie Deformed Margin	1.00												
AM2	Alaska Passive Margin	0.54												
AM3	Canada Basin	0.05												
AM4	Canada Passive Margin	0.54												
HB1	**Hope Basin**	**0.17**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**0**
FS1	Western Franklinian Shelf	0.09												
FS2	Eastern Franklinian Shelf	0.09												
FS3	Boothia-Cornwallis Uplift	0.09												
SB1	Sverdrup Mesozoic	1.00												
SB2	Sverdrup Upper Paleozoic	0.07												
SB3	Banks Island-Sverdrup Rim	0.22												
NWC1	Devonian Reefs and Clastic Wedge	0.10												
NWC2	Lower Paleozoic Subsalt and Carbonate Platform	0.32												
Greenland														
EGR1	North Danmarkshavn Salt Basin	0.65												
EGR2	South Danmarkshavn Basin	0.72												
EGR3	Northeast Greenland Volcanic Province	0.26												
EGR4	Thetis Basin	0.49												
EGR5	Liverpool Land Basin	0.29												
EGR6	Jameson Land Basin	0.07												
EGR7	Jameson Land Basin Subvolcanic Extension	0.04												
JMM1	Jan Mayen Microcontinent	0.06												
NGS1	Lincoln Sea Basin	0.50												
NGS2	Wandel Sea Basin	0.22												
WGEC1	Eurekan Structures	0.25												
WGEC2	Northwest Greenland Rifted Margin	0.50												
WGEC3	Northeast Canada Rifted Margin	0.50												
WGEC4	Baffin Bay Basin	0.28												
WGEC5	Greater Ungava Fault Zone	0.30												
Europe														
BP1	Barents Platform North	0.36												
BP2	Barents Platform South	1.00												
NM1	Arctic Norwegian Sea	1.00												
NM2	Western Barents Margin	0.49												
Siberia														
MZB1	**Northwest Mezen' Basin**	**0.01**												
TPB1	**Northwest Izhma-Pechora Depression**	**0.02**												
TPB2	**Main Basin Platform**	**1.00**	**1523**	**3008**	**5703**	**3225**	**1836**	**3884**	**7949**	**4262**	**40**	**89**	**190**	**99**
TPB3	**Foredeep Basins**	**0.54**	**0**	**0**	**410**	**96**	**0**	**0**	**573**	**127**	**0**	**0**	**13**	**3**
EBB1	**Kolguyev Terrace**	**1.00**	**0**	**110**	**398**	**145**	**0**	**155**	**973**	**275**	**0**	**2**	**14**	**4**
EBB2	**South Barents Basin and Ludlov Saddle**	**1.00**	**241**	**1300**	**5901**	**1939**	**312**	**2175**	**11900**	**3669**	**3**	**27**	**163**	**50**
EBB3	**North Barents Basin**	**0.50**	**0**	**1197**	**21424**	**5322**	**0**	**1748**	**41460**	**10145**	**0**	**20**	**557**	**137**
NZAA1	**Novaya Zemlya Basins and Admiralty Arch**	**0.09**												
NKB1	**North Kara Basins and Platforms**	**0.50**	**0**	**488**	**6810**	**1807**	**0**	**519**	**11246**	**2845**	**0**	**12**	**272**	**68**
WSB1	**Northern West Siberian Onshore Gas**	**1.00**	**309**	**1252**	**4070**	**1601**	**1724**	**7367**	**24644**	**9527**	**35**	**152**	**513**	**197**
WSB2	**South Kara Sea Offshore**	**1.00**	**572**	**2053**	**6023**	**2507**	**3183**	**12064**	**36779**	**14933**	**64**	**248**	**763**	**308**
YK1	**Khatanga Saddle**	**0.50**	**0**	**0**	**1376**	**327**	**0**	**0**	**932**	**206**	**0**	**0**	**25**	**6**
YK2	**Yenisey-Khatanga Basin**	**1.00**	**2201**	**4847**	**9716**	**5257**	**11604**	**26571**	**55375**	**29078**	**305**	**710**	**1528**	**786**
NWLS1	**Northwest Laptev Sea Shelf**	**0.40**	**0**	**0**	**894**	**172**	**0**	**0**	**1435**	**267**	**0**	**0**	**38**	**7**
LA1	**Lena-Anabar Basin**	**0.46**	**0**	**0**	**7207**	**1913**	**0**	**0**	**6022**	**1502**	**0**	**0**	**163**	**40**
LA2	**Lena-Anabar Basin Updip**	**0.08**												
LA3	**Sukhan-Motorchun Riphean Rift**	**0.07**												
TUN1	**Tunguska Basin**	**0.06**												
LV1	**Northern Priverkhoyansk Foredeep**	**0.40**	**0**	**0**	**1741**	**379**	**0**	**0**	**1455**	**298**	**0**	**0**	**39**	**8**
LSS1	**West Laptev Grabens**	**0.54**	**0**	**815**	**12911**	**2646**	**0**	**1008**	**17982**	**3897**	**0**	**26**	**475**	**105**
LSS2	**East Laptev Horsts**	**0.03**												
LSS3	**Anisin-Novosibirsk Basins**	**0.43**	**0**	**0**	**1837**	**469**	**0**	**0**	**2901**	**693**	**0**	**0**	**79**	**19**
ZB1	**Zyryanka Basin**	**0.50**	**0**	**0**	**286**	**72**	**0**	**0**	**496**	**106**	**0**	**0**	**13**	**3**
ESS1	**East Siberian Sea Basin**	**0.22**	**0**	**0**	**118**	**20**	**0**	**0**	**246**	**39**	**0**	**0**	**4**	**1**
VLK1	**Vilkitskii Basin**	**0.29**	**0**	**0**	**530**	**98**	**0**	**0**	**1043**	**198**	**0**	**0**	**19**	**4**
NCWF1	**North Chukchi-Wrangel Foreland Basin**	**0.24**	**0**	**0**	**493**	**86**	**0**	**0**	**948**	**172**	**0**	**0**	**17**	**3**
LS1	**Long Strait**	**0.08**												
Arctic Ocean														
LM1	Makarov Basin Margin	0.14												
LM2	Podvodnikov-Makarov Basins	0.04												
LM3	**Siberian Passive Margin**	**0.42**	**0**	**0**	**4027**	**984**	**0**	**0**	**6592**	**1538**	**0**	**0**	**179**	**42**
EB1	**Lena Prodelta**	**0.43**	**0**	**0**	**4326**	**979**	**0**	**0**	**6985**	**1524**	**0**	**0**	**189**	**41**
EB2	**Nansen Basin Margin**	**0.25**	**0**	**0**	**2087**	**364**	**0**	**0**	**3383**	**568**	**0**	**0**	**91**	**15**
EB3	Nansen Basin	0.08												
EB4	Amundsen Basin	0.07												

Assessment Unit	Gas in Gas Accumulations				Liquids in Gas Accumulations				Largest Oil Accumulation				Largest Gas Accumulation			
	F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
North America																
Alaskan Platform																
Alaskan Fold- and Thrust-Belt																
Chukchi Borderland																
Canning-Mackenzie Deformed Margin																
Alaska Passive Margin																
Canada Basin																
Canada Passive Margin																
Hope Basin	0	0	4458	650	0	0	78	11	55	72	132	80	483	960	2538	1154
Western Franklinian Shelf																
Eastern Franklinian Shelf																
Boothia-Cornwallis Uplift																
Sverdrup Mesozoic																
Sverdrup Upper Paleozoic																
Banks Island-Sverdrup Rim																
Devonian Reefs and Clastic Wedge																
Lower Paleozoic Subsalt and Carbonate Platform																
Greenland																
North Danmarkshavn Salt Basin																
South Danmarkshavn Basin																
Northeast Greenland Volcanic Province																
Thetis Basin																
Liverpool Land Basin																
Jameson Land Basin																
Jameson Land Basin Subvolcanic Extension																
Jan Mayen Microcontinent																
Lincoln Sea Basin																
Wandel Sea Basin																
Eurekan Structures																
Northwest Greenland Rifted Margin																
Northeast Canada Rifted Margin																
Baffin Bay Basin																
Greater Ungava Fault Zone																
Europe																
Barents Platform North																
Barents Platform South																
Arctic Norwegian Sea																
Western Barents Margin																
Siberia																
Northwest Mezen' Basin																
Northwest Izhma-Pechora Depression																
Main Basin Platform	1789	4951	12286	5718	37	108	279	127	192	448	1286	549	555	1156	3172	1404
Foredeep Basins	0	6147	21218	7018	0	130	477	155	65	125	388	163	1010	1772	3536	1946
Kolguyev Terrace	973	2039	4605	2313	22	54	129	62	68	110	232	125	516	851	1673	940
South Barents Basin and Ludlov Saddle	44854	142293	472507	183689	126	460	2080	714	108	527	3235	937	9519	46515	277248	79307
North Barents Basin	0	36814	450041	117467	0	98	1808	456	527	2576	14503	4284	12417	57977	305028	92348
Novaya Zemlya Basins and Admiralty Arch																
North Kara Basins and Platforms	0	4115	44522	12129	0	105	1198	322	209	707	2725	968	1404	4548	16851	6148
Northern West Siberian Onshore Gas	8669	26154	70336	31136	269	825	2241	984	123	342	1061	431	1652	4547	13298	5560
South Kara Sea Offshore	154681	513304	1372510	607289	4799	16000	44090	19171	183	551	1831	712	31734	134633	553436	189354
Khatanga Saddle	0	0	6764	1797	0	0	182	48	81	184	495	221	405	733	1994	898
Yenisey-Khatanga Basin	38629	66089	108413	68883	1009	1754	2929	1835	381	922	2534	1108	3791	7960	18396	9057
Northwest Laptev Sea Shelf	0	0	18992	4221	0	0	513	112	64	160	649	232	804	2431	8641	3242
Lena-Anabar Basin	0	0	2538	604	0	0	69	16	236	620	1654	731	417	550	755	563
Lena-Anabar Basin Updip																
Sukhan-Motorchun Riphean Rift																
Tunguska Basin																
Northern Priverkhoyansk Foredeep	0	0	4341	1044	0	0	117	28	105	295	1032	393	479	605	807	619
West Laptev Grabens	0	15070	90382	25194	0	395	2392	670	152	325	3091	749	1398	2678	18234	5082
East Laptev Horsts																
Anisin-Novosibirsk Basins	0	0	10694	2779	0	0	286	74	93	183	467	217	562	1096	2765	1294
Zyryanka Basin	0	942	7746	2175	0	22	209	58	63	108	282	132	586	1128	2613	1296
East Siberian Sea Basin	0	0	3377	579	0	0	61	10	56	72	133	80	410	802	2227	989
Vilkitskii Basin	0	0	29850	5544	0	0	528	98	53	108	721	215	1163	4325	19122	6359
North Chukchi-Wrangel Foreland Basin	0	0	34335	5894	0	0	607	103	53	110	739	218	1480	5115	21098	7247
Long Strait																
Arctic Ocean																
Makarov Basin Margin																
Podvodnikov-Makarov Basins																
Siberian Passive Margin	0	0	20118	4684	0	0	541	125	148	279	571	307	780	1527	3295	1705
Lena Prodelta	0	0	55538	13982	0	0	1489	373	150	571	2513	843	1987	6097	21017	8002
Nansen Basin Margin	0	0	18855	3401	0	0	504	91	116	314	1006	402	967	2396	7024	2946
Nansen Basin																
Amundsen Basin																

APPENDIX: GEOLOGICAL DATA INPUT FORM FOR THE CIRCUM-ARCTIC RESOURCE APPRAISAL WITH INPUT DATA FROM THE SOUTH BARENTS BASIN ASSESSMENT UNIT

IDENTIFICATION INFORMATION

Assessment Geologist:	T.R. Klett	Date:	12-Feb-08
Region:	Former Soviet Union	Number:	1
Province:	Eastern Barents Basins	Number:	1050
Total Petroleum System:	Paleozoic-Mesozoic Composite	Number:	105001
Assessment Unit:	South Barents Basin and Ludlov Saddle	Number:	10500102
Scenario:		Number:	
Based on Data as of:	IHS Energy (2007)		
Notes from Assessor:			

CHARACTERISTICS OF ASSESSMENT UNIT

Area of assessment unit: 322,000 square kilometers

Minimum assessed accumulation size: 50 MMBOE (grown)

No. of discovered accumulations exceeding minimum size: Oil: 0 Gas: 4

Uncertainty Class:	Check One	Number
Producing fields		
Discoveries	X	4
Wells		
Seismic		
No seismic		

Median size (grown) of discovered oil accumulations (MMBO):
1st 3rd ______ 2nd 3rd ______ 3rd 3rd ______

Median size (grown) of discovered gas accumulations (BCFG):
1st 3rd ______ 2nd 3rd ______ 3rd 3rd ______

ANALOGS USED IN ESTIMATING INPUT

Purpose	Analog or Analog Set
1 Number and sizes	Rift/sag
	Prospect maps
	Possibility of reefs
2 Composition	Produced hydrocarbons on Kolguyev Island and analyses of
	South Barents hydrocarbons
	IHS Energy (2007)
3	
4	

Assessment Unit (name, no.) South Barents Basin and Ludlov Saddle, 10500102
Scenario (name, no.)

Probability of occurrence (0-1.0)

Scenario Probability:

Assessment-Unit Probabilities: (Adequacy for at least one undiscovered field of minimum size)

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge:	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals:	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing:	1.0
Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3):	1.000

UNDISCOVERED ACCUMULATIONS

Number of Undiscovered Accumulations: How many undiscovered accumulations exist that are at least the minimum size?: (uncertainty of fixed but unknown values)

Total Accumulations:	minimum (>0)	3	median	45	maximum	100
Oil/Gas Mix:	minimum	0	mode	0.05	maximum	0.4

X number of oil accumulations / number of total accumulations
___ number of oil accumulations / number of gas accumulations
___ number of gas accumulations / number of oil accumulations

Oil Accumulations:	minimum	0	median	6	maximum	40
Gas Accumulations:	minimum	3	median	38	maximum	100

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accumulations?: (variations in the sizes of undiscovered accumulations)

Oil in Oil Accumulations (MMBO):	minimum	50	median	110	maximum	10000
Gas in Gas Accumulations (BCFG):	minimum	300	median	660	maximum	500000

RATIOS FOR UNDISCOVERED ACCUMULATIONS, TO ASSESS COPRODUCTS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum	median	maximum
Gas/oil ratio (CFG/BO):	0	1300	20000
NGL/gas ratio (BNGL/MMCFG):	0	11	82

Gas Accumulations:	minimum	median	maximum
Liquids/gas ratio (BLIQ/MMCFG):	0	2	75

Assessment Unit (name, no.) South Barents Basin and Ludlov Saddle, 10500102
Scenario (name, no.)

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum		median		maximum
API gravity (degrees):	30		40		55
Viscosity (centipoise)					
Sulfur content of oil (%):	0		0.3		1.5
Depth (m) of water (if applicable):	100		200		350

	minimum	F75	median	F25	maximum
Drilling Depth (m):	1000		3000		5000

Gas Accumulations:	minimum		median		maximum
Inert gas content (%):	0		2		60
Carbon dioxide content (%):	0		0.2		10
Hydrogen sulfide content (%):	0		0		0
Depth (m) of water (if applicable):	100		200		350

	minimum	F75	median	F25	maximum
Drilling Depth (m):	1000		3000		6500

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: July 2010

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