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Oil and Gas Resources of Northeast Greenland

The new assessment carried out by USGS indicates that northeastern Greenland may be a very important future petroleum province. If the mean estimate of 31 BBOE were discovered and proven, this huge basin would rank 19th out of the world's 500 known petroleum provinces.

Donald L. Gautier, U.S. Geological Survey, Menlo Park, California

Northeast Greenland was selected as the prototype for the Circum-Arctic Resource Appraisal. The view is from Jameson Land towards east (Liverpool Land) with Caledonian basement rocks. The tents rest on Triassic rocks.





The East Greenland Rift Basins belong to the Arctic realm. Note that the basins are juxtaposed the Norwegian Sea sedimentary basins with significant oil and gas reserves proven. The Mid Atlantic Ridge, midway between Norway and Greenland, is clearly seen northeast of Iceland in this image.



Jurassic sandstones on Jameson Land, equivalent to Jurassic rservoir rocks on the continental shelf off shore Mid Norway (Haltenbanken), are studied in detail by Statoil to improve their reservoir characterization.

^{photo}: Arild Andresen

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In collaboration with GEUS, northeast Greenland was subdivided for the purposes of assessment into seven geologically distinct Assessment Units (AU).

Previous exploration

A group headed by ARCO was granted an exploration licence in Jameson Land, East Greenland, in 1984. 1800 km of seismic data were acquired. The area was relinquished in 1990 without the drilling of an exploration well. All data from Jameson Land are open file and available from GEUS at cost of copying.

Kanumas project

The Kalaallit Nunaat (meaning Land of the Kalaallit (Greenlanders) in Greenlandic) Marine Seismic (KANUMAS, 1990-1996) project was a seismic reconnaissance survey in the extreme northern frontier areas offshore eastern and western Greenland. The project was financed by 6 major oil companies (BP, Exxon, Japan National Oil Company, Shell, Statoil, and Texaco), with Nunaoil as carried partner and operator. In all, 7000 km of seismic data were acquired off North-East Greenland and central East Greenland. The KANUMAS group holds a preferential exploration position in the areas covered by the seismic surveys. Seismic data from the KANUMAS surveys are available for sale.

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A team of U.S. Geological Survey geologists has recently completed a new assessment of undiscovered oil and gas resources in northeastern Greenland. Following a press release in Washington, the results of the study were delivered on September 6 to scientists attending the Arctic Conference Days 2007 in Tromsø, Norway (www. geologi.no).

The USGS is working on a comprehensive assessment of potential additions to oil and gas reserves from north of the Arctic Circle; the study of northeastern Greenland is the first public release of results from that study. Assessments of various other Arctic provinces will be released over the next nine months, with the overall findings to be presented at the International Geological Congress in Oslo in August, 2008. The USGS study, called the Circum-Arctic Resource Appraisal (CARA), is the first systematic, geologically-based assessment of the undiscovered petroleum resources of the Arctic to be completed in the public domain.

A Conjugate Margin

Northeast Greenland was selected as the prototype for the CARA, because it exhib-

its several typical characteristics that make Arctic resource assessment particularly difficult. These include: extreme geological uncertainty, technical difficulty, high operating costs, and great environmental sensitivity. The northeast Greenland part of the Arctic study area is large, covering more than 500,000 km² (The North Sea fairway is roughly 220,000 km²) with a near-absence of subsurface information. The continental shelf is technically challenging to exploration; being covered by sea ice nearly every month of the year, it has never been drilled. Subsurface geologic data consist mainly of a proprietary seismic survey collected by an industry consortium (KANUMAS) during particularly favorable ice years in the 1990's.

Northeast Greenland has intriguing geological characteristics that suggest large resource potential. Detailed studies of outcrops along the east coast, carried out by the Geological Survey of Denmark and Greenland (GEUS) and other organizations, coupled with potential field (gravity and magnetic) surveys and the KANUMAS seismic lines, indicate that northeast Greenland is the pre-Paleocene conjugate margin of western Norway, and that the continental shelf is probably underlain by more than 14km of Devonian through Holocene age sedimentary rocks.

Onshore studies indicate that at least four stratigraphic intervals may contain potentially good source rocks for liquid petroleum. Particularly interesting is a succession of Upper Jurassic marine shale similar to those found in the Norwegian Sea and the Viking Graben. Such shales are known to be among the world's most prolific petroleum source rocks and their presence suggests the possibility of a world-class petroleum province offshore. Subsurface mapping completed by GEUS and initial burial history modeling by USGS predict that Upper Jurassic strata are present and have been buried to depths appropriate for oil and gas generation over large areas of the continental shelf.

Seven Assessment Units

In collaboration with GEUS, northeast Greenland was subdivided for the purposes of assessment into seven geologically distinct Assessment Units (AU). These are: Northern Danmarkshavn Salt Basin, Southern Danmarkshavn Basin, Thetis Basin, Northeast Greenland Volcanic Province, Liverpool Land Basin, Jameson Land Basin and the Jameson Land Basin Subvolcanic Extension.

For each of the assessment units, the USGS CARA team assessed the geological likelihood (the marginal probability) that a significant petroleum system was present and viable; on the basis of that evaluation, five of the seven assessment units were quantitatively assessed using a geologically-based probabilistic methodology. Jameson Land Basin and the Jameson Land Basin Subvolcanic Extension were defined as assessment units but not quantitatively assessed.

Possible petroleum trapping mechanisms are expected to vary widely from AU to AU across the province. Potential traps in the Northern Danmarkshavn Salt Basin AU are dominated by structures formed through salt tectonics; those in the Southern Danmarkshavn Basin AU and the Northeast Greenland Volcanic Province AU are thought to be controlled by extensional structures and by stratigraphic traps in submarine fan complexes. Prospective inversion structures of Tertiary age may be present along the western margin of South Danmarkshavn Basin AU and the large horst-like structures of the Danmarkshavn Ridge, which separates the Danmarkshavn and Thetis basins, may provide numerous opportunities for traps in fault-blocks, along a major unconformity and along various facies-related permeability barriers. Possible reservoirs are considered most likely within marginal marine to nonmarine sandstones of Middle Jurassic age, in Upper Jurassic syn-rift deposits, in Cretaceous sandstones deposited in submarine fan complexes, within progradational sequences of Paleogene age, and in Upper Carboniferous to Lower Permian warm-water carbonate rocks, especially in the Northern Danmarkshavn Basin, Marine shales are expected to provide the main sealing lithologies in most AUs.

Of course, significant risks and uncertainties concerning potential petroleum systems and resources remain. Each assessment unit was judged to have a significant risk to the presence of a working petroleum



Colorful Neoproterozoic sediments (right) juxtaposed high-grade gneisses (left) along a top-to-the-East $\frac{2}{5}$ detachment fault. This and other late Caledonian faults were reactivated and controlled later basin development in North-East Greenland.

National Park

Northeast Greenland National Park, the only national park in Greenland, is the largest national park in the world, with an area of 972,000 square kilometers, 3 times the size of Norway. The park encompasses the entire northeastern coastline and interior sections of Greenland. Originally created in 1974, the park was expanded to its present size in 1988. In January 1977 it was designated an international biosphere reserve. Most of it is inland ice, the rest is a composite fjord landscape.

system. In particular, the presence of Jurassic source rocks of the necessary volume and quality, with a burial history appropriate for petroleum generation, has yet to be demonstrated. On the westernmost margin of South Danmarkshavn Basin and in the northern half of the North Danmarkshavn Salt Basin, Tertiary uplift may have negatively impacted seal integrity and caused the displacement of oil from traps by gas expansion. Moreover, the consequences of salt deformation may be either positive or negative with respect to trap integrity, and the timing of trap formation with respect to oil generation and migration is highly uncertain in many of the major trapping geometries.

Four Probability Distributions

The sparse seismic and drilling data in the Arctic mean that many of the usual tools and techniques used in USGS resource assessments, including discovery process modeling, prospect delineation, and deposit simulation, are not generally applicable. As a result, the USGS CARA relies on a probabilistic methodology based upon geological analysis and analog modeling.

In the USGS approach, four probability distributions are assessed for every assessment unit. These are 1) the marginal probability that a viable petroleum system is present, as indicated by the presence of at least one accumulation greater than the minimum size of 50MMBOE; 2) the probability distribution of the number of undiscovered oil and/or gas accumulations: 3) the size distribution of undiscovered accumulations; and 4) the distribution of oil versus gas as the principal commodity in each of the undiscovered accumulations. After these distributions are assessed, they are combined using a Monte Carlo simulation involving 50,000 trials. The results

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²hoto: Arild Andresen

Field work on North-East Greenland is done by a combination of Twin Otter, helicopter and inflatable boats, in addition to hiking long distances.

reflect the wide range of uncertainty inherent in a frontier geological province such as northeast Greenland.

Most of the undiscovered oil, gas and natural gas liquids are expected to be found offshore. The average (mean) of the 50,000 trials of the Monte Carlo simulation suggests that northeast Greenland contains approximately 31,400 MMBOE of oil, natural gas, and natural gas liquids. Of the five assessed AUs. North Danmarkshavn Salt Basin and the South Danmarkshavn Basin are estimated to contain the most of the undiscovered petroleum resources.

Possibly a Significant Province

The new study supersedes a previous USGS assessment, published as part of the USGS World Petroleum Assessment 2000. Compared to the earlier USGS study, the current assessment estimated significantly less total resource, significantly more natural gas and NGL and an increased ratio of gas to oil. The 2000 assessment estimated about 47 BB of oil, 81 TCF of natural gas and 4 BB of natural gas liquids compared to 9BB of oil, 86 TCF of gas and 8 BB of natural gas liquids estimated in the new study. The new assessment estimated a smaller largest oil field (mean of 2.5+ vs. 6.1 BBO) but a larger largest gas field (mean of 18+ vs. 7.1 TCF). The minimum accumulation size considered in the new assessment is 50 million barrels of technically recoverable oil or 300 billion cubic feet of technically recoverable gas. The previous USGS assessment of northeast Greenland used a 20MMBOE minimum field size.

The new assessment indicates that northeastern Greenland may be a very important future petroleum province. If the mean USGS estimate of 31 BBOE were discovered and proven, northeastern Greenland would rank 19th out of the world's

500 known petroleum provinces, placing it above the known (cumulative production plus remaining reserves) resources of northern Alaska and having a resource volume similar to the Alberta Basin in western Canada and roughly one third that of the North Sea.

Giants and Supergiants may be found

Estimated field sizes are particularly important for the economics of potential development. According to this estimate, there is a 50/50 chance of an undiscovered field larger than 1.5 billion barrels and a five percent chance of an oil field larger than 8.1 billion barrels. The average (mean) size of the largest field calculated in each of the 50,000 trials of the Monte Carlo simulation for south Danmarkshavn Basin is about 2.5 billion barrels. If discovered, this field would rank 72 among the 870 giant fields in the



world. Prudhoe Bay oil field in northern Alaska would rank tenth on the same list and Forties field, one of the largest oil fields in the Central Graben of the North Sea.

The average largest undiscovered gas accumulation in the northern Danmarkshavn salt basin is estimated to contain more than 18 TCF of recoverable gas. With

this volume, the field would place 49 out of

870 giant oil and gas fields. For comparison,

the super giant Shtokman gas field, in the

Russian Barents Sea, would rank 14th, while

Troll field in the northern North Sea would

would rank 93rd.

rank 42.

Donald Gautier is Project Director and has for a long time been involved in the U.S. Geological Survey's world-wide resource assessments. In Tromsø, Norway, he gave a presentation this fall at a conference hosted by the Norwegian Geological Society about the Northeast Greenland assessment that has recently been completed.

Total Petroleum Systems (TPS) and Assessment Units (AU)	AU Probability	Field Type	Total Undiscovered Resources													
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)					
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean		
North Danmarkshavn Salt Basin AU	0.65	Oil	0	1,989	11,793	3,274	0	3,827	26,779	7,255	0	264	2,123	570		
		Gas					0	23,820	107,409	32,756	0	2,284	10,730	3,237		
South Danmarkshavn Basin AU	0.72	Oil	0	3,228	13,996	4,384	0	6,325	32,081	9,700	0	449	2,603	761		
		Gas					0	19,344	83,621	26,251	0	1,844	8,362	2,598		
Northeast Greenland Volcanic Province AU	0.26	Oil	0	0	2,757	497	0	0	6,212	1,105	0	0	492	87		
		Gas					0	0	16,551	3,003	0	0	1,651	297		
Thetis Basin AU	0.49	Oil	0	0	2,095	537	0	0	4,908	1,184	0	0	397	93		
		Gas					0	0	12,489	3,206	0	0	1,251	317		
Liverpool Land Basin AU	0.29	Oil	0	0	1,122	209	0	0	2,528	464	0	0	200	37		
		Gas					0	0	6,740	1,255	0	0	672	124		
Jameson Land Basin AU	0.07	Oil	Nota	Not quantitatively assessed												
		Gas	NULY													
Jameson Land Basin Subvolcanic Extension AU	0.04	Oil	Nota	Not quantitatively assessed												
		Gas	1,01.4	ivot quantitatively assessed												
Total Conventional Resources						8,901				86,179				8,121		

Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). F95 represents a 95-percent chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. TPS, total petroleum system; AU, assessment unit. Gray shading indicates not applicable]

MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liauids.