Proving up petroleum prospectivity offshore Greenland

Jens Christian Olsen, TGS-NOPEC Geophysical Company, explains how the application of 'good old fashioned geophysics' may ultimately reveal a world-class deepwater petroleum province offshore West Greenland

Until recently, interest in the petroleum prospectivity offshore West Greenland has been sporadic at best. No surprise then, that exploration off the country's western coast dates back to a previous era of high-priced oil in the early 1970s. At that time, some 21,000 line km of non-exclusive 2D seismic data were acquired. The surveys provided enough promising geologic indicators to convince six groups of investors, led mainly by major integrated oil companies, to acquire another 16,000 line km of seismic data and to spud five wildcat wells.

The spate of exploration in the 1970s was short-lived. All five wildcat wells were declared dry holes and plugged and abandoned. The petroleum industry quickly turned its search for new resources to supply an energy-hungry world to areas perceived to be more promising - and more climatically hospitable - below the Arctic Circle.

It was left to the Geological Survey of Greenland, now the Geological Survey of Denmark and Greenland (GEUS), and Greenland's state oil company, Nunaoil, to reconsider the early seismic and well-control data during the 1990s. They were encouraged in these endeavours by evidence that onshore oil seeps in the Disko-Nuussuaq-Svartenhuk area could be tied to Jurassic, Cretaceous, or Tertiary source rocks. An argument could be made that the region was home to an active petroleum system. Geophysical surveying offshore West Greenland by GEUS and Nunaoil during these years confirmed the presence of cross-cutting reflectors west of Nuuk in the Fylla area and a thick sedimentary geological section off West Greenland's southern coast near Nuussuaq.

Yet, beyond the work of these two state agencies, little new geophysical data were acquired, minimal response was generated by exploration licensing rounds, and exploratory drilling was almost non-existent. However, the sole onshore wildcat drilled onshore Nuussuaq on West Greenland provided a very positive indication that live hydrocarbons were present at least somewhere.

When TGS-NOPEC Geophysical Company (TGS) came to Greenland in 1999, only two areas offshore West Greenland were held by licences, and all offshore exploratory drilling wells in the region had been unsuccessful. The total seismic coverage amounted to only 60,000 line km of generally poor to extremely poor quality 2D data, including the 37,000 line km of data acquired in the 1970s.

Even today, Greenland is still extremely under-explored, its prospectivity as a petroleum province virtually unknown to the world. Hopefully this may change as a result of work being carried out by a relatively small group including TGS, a handful of oil companies, and officials from GEUS, Nunaoil, and the Bureau of Mineral Resources and Petroleum (BMR). Relying initially on older geophysical data and well-control evidence, these organizations have been collaborating for the past six years on a regional study over a 126,000 km^2 area offshore West Greenland. The emerging picture from this regional re-evaluation is a potential world-class petroleum province stretching from the Labrador Sea to the south, northward through the Davies Strait separating Greenland and Canada and into Baffin Bay.

In 1999, a non-exclusive reconnaissance seismic survey was carried out to acquire modern 2D data with the goal of tying the five unsuccessful wildcat wells from the 1970s into a coherent regional geological setting. Since then, 19 non-exclusive surveys offshore West Greenland and one survey along the Labrador coast have been added. The non-exclusive data have been supplemented with exclusive surveys within the non-exclusive coverage area, including the Labrador Sea, Davies Strait, and Baffin Bay.

With the cooperation, encouragement, and counsel of public officials in Greenland's energy agencies and the sup-

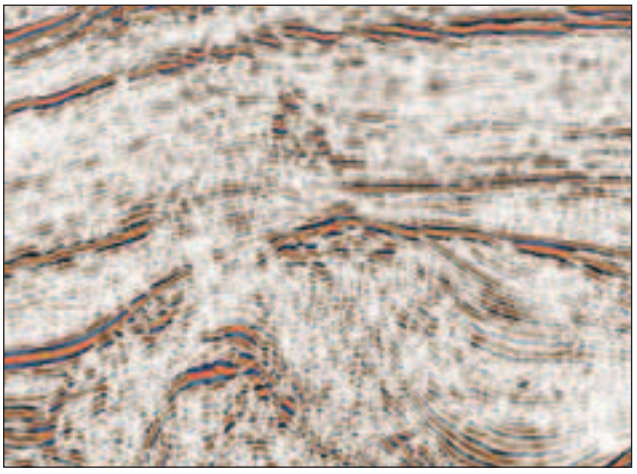
Photo example of Cretaceous oils from Nussuaq Penninsula.

port of a handful of oil companies, TGS has acquired and interpreted modern, non-exclusive 2D seismic data almost every year since 1999, amassing a non-exclusive data base containing 35,000 line km of modern 2D seismic data. This might seem like pretty thin coverage in an area at least three times the size of the North Sea, where by comparison close to 3,000,000 line km of 2D seismic data have been acquired. But the steady pace of work has enabled the application of 'good old-fashioned geophysics' in which gravity and magnetic data are integrated to create a more comprehensive model of the subsurface. Old-fashioned geophysics means that as the data from each successive survey have been added to the non-exclusive data base, there has been time to fully study and consider how the newly compiled data might influence conceptual models and what it might add to the overall geological picture emerging offshore West Greenland.

Because this is a frontier exploration programme, the interested group has taken the time to sit down and thoroughly consider what to do next.. As a result, virtually each seismic line in the ongoing evaluation has been set carefully to reveal specific pieces of information about the subsurface. For example, if gravity data indicate a deep graben and that interpretation is supported by magnetic data, a seismic line across the area can be called for to confirm or refute whether a graben might be present.

Challenging fundamental beliefs

Frequently during the past five years, this process has generated reliable geophysical evidence that contradicts some of the scientific community's fundamental beliefs about the geology offshore West Greenland, and how it might relate to the geology of northeastern and maritime Canada or the North Atlantic Ocean and Europe. Since the beginning, it was thought a bit premature to decide offshore West Greenland was bone dry. Three of the so-called dry holes drilled offshore encountered good shows of hydrocarbons, and one structure in possibly commercial quantities. In addition, a 2.3 trillion ft^3 gas discovery has been reported in the northernmost well drilled offshore Labrador, just a few miles beyond the western boundary of West Greenland's new offshore data area.



Mesozoic trap and confirmed DHI.

The first survey acquired offshore West Greenland, *Green99*, was designed to test what existing geophysical data and well-control information actually meant. A few years earlier GEUS had found several active Tertiary, Cretaceous, and Jurassic oil seeps in onshore sedimentary areas close to the marine environment. The *Green99* survey demonstrated that there certainly were deep basins in the area, and the data also revealed very deep local grabens in what hitherto had been interpreted as volcanic areas. Another positive *Green99* surprise was the find of large and deep Paleozoic basins along part of the coastline opening for Newfoundland Paleozoic type plays.

Gravity mapping was initiated to understand the regional distribution of the local, very deep pull-apart graben seen on the modern data. The conclusion was that the Davies Strait between the Labrador Sea and Baffin Bay was most likely hiding a rift system the size of Viking-Central graben in the North Sea. The idea of a rift system in Davies Strait was especially interesting if it could be proven to connect old large stranded hydrocarbon discoveries on the Labrador Shelf with the oil seep areas onshore West Greenland covering an area the size of the East Shetland basin.

To define some of the deep graben areas on seismic, the *SW00* reconnaissance survey was commissioned, consisting of two regional seismic lines going from the coast of Greenland to the coast of Canada, plus one strike line within the west graben of the Ungava rift system. In addi-

2006 field trip

TGS, VBPR, and GEUS are organizing a week-long field trip during July 2006 for petroleum geologists evaluating this increasingly promising region. The excursion will visit the exposed Cretaceous and Paleocene sediments in the Disko-Nuussauq area. Data indicate these are analogous to the prospective basins offshore West Greenland. Field observations of the properties and deposition of potential reservoir sandstones, oil seeps, and evidence of multiple source rocks, as well as facies variations and petroleum implications of volcanic rocks in Nuussuaq basin, will be integrated with offshore seismic data and regional geologic models to help participants assess the prospectivity of this frontier exploratory play. The aim is to help companies ahead of Greenland's current licensing round, which is expected to close before year end 2006.

tion to confirming the presence of the rift system suggested by the gravity models, the *SW00* survey also indicated some very interesting geology up-dip on the shelves of both continents and a much thicker Mesozoic package than had been anticipated.

Immediately following the *SW00* survey, the regional *Green00* survey was acquired to fill in and expand the *Green99* shoot, by focusing on leads gleaned from *Green99* data and by extending into new areas in the basin as mapped from gravity data. Also in 2000, a denser seismic grid with a survey called *KR00* was carried out to better delineate a complicated 1200 km^2 ridge, where a well that partially penetrated the subsurface structure had logged some hydrocarbons.

Dry hole setback

Data acquired in 2000 provided evidence that convinced TGS that it was on the right track and that the company should continue fleshing out the regional geology offshore West Greenland, as well as pursuing specific leads. However, growing international interest in the prospectivity offshore West Greenland declined abruptly in September 2001 when Statoil and partners reported the Qulleq 1 wildcat well, in the Fylla license area, about 140 km west of Greenland's capital city of Nuuk, would be plugged and abandoned as a dry hole. The location was in fact well south of and up-dip of the TGS study area. It was concluded that one dry hole over such a large area - especially one targeting a reputed direct hydrocarbon indicator (DHI) that later proved to be a quartz-opal transition zone embedded in mudstones - should not discourage TGS from continuing.

With continuing support of Greenland's energy officials, the company resumed acquisition of seismic data offshore west Greenland in 2001. The *GRC01* survey, consisting of 600 km long seismic lines tying the northernmost hydrocarbon discovery offshore Labrador with the geology of Canada's and Greenland's coasts, left TGS in little doubt about the existence of the Ungava rift zone and the prospect of a new frontier hydrocarbon province. The *Green01* survey later that year provided some more helpful evidence by imaging the geology of the oil seeps onshore Greenland and farther north, the eastern segment of the Ungava rift.

By 2002, the time was right to delineate other geologic anomalies mapped from gravity data. The *GRC02* survey in the deepwater northern Labrador Sea was an extension to the *GRC01* survey to further document the Ungava rift and to demonstrate the extreme thicknesses of Labrador Sea sediments previously believed to be volcanic strata of Eocene age. This survey also demonstrated that the Basin of Lady Franklin was an isolated major pull-apart basin with several large prospects.

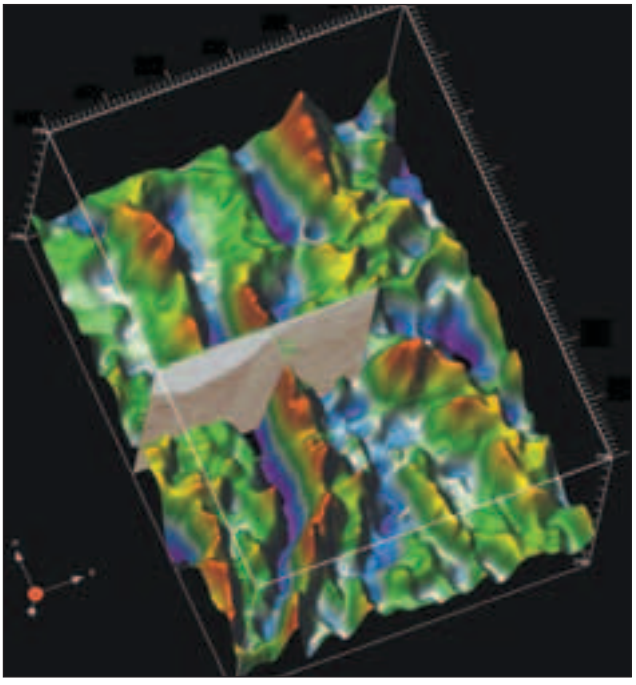
The *KF02* survey off the Kap Farvel at the southern end of Greenland generated great surprise because it was very difficult to see the differences between the seismic signal generated by an implied basin in the area and Canada's Orphan basin. The results from the regional *DW02* survey and the *Green02* survey acquired over individual prospects in southern Baffin Bay stimulated sufficient excitement that BMP immediately decided to suspend Greenland's Open Door licensing procedure in the northern areas and to start planning for future rounds in the area.

Although several oil companies showed interest in Greenland's 2002 offshore licensing round, only EnCana made it all the way through the process. It was awarded the 3965 km^2 Atammik licence area in 200-1000 meters of water in the Nuuk basin, which exploration data suggest is connected to the Ungava East graben system.

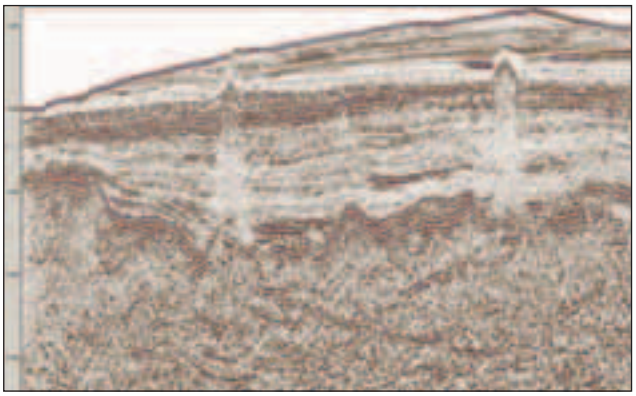
Detailed mapping reveals DHIs

One development in 2002 was the launch of the *Geophysical Atlas of the West Greenland Basins* as a reference for oil companies, produced by TGS and Volcanic Basin Petroleum Research (VBPR), in cooperation with GEUS.

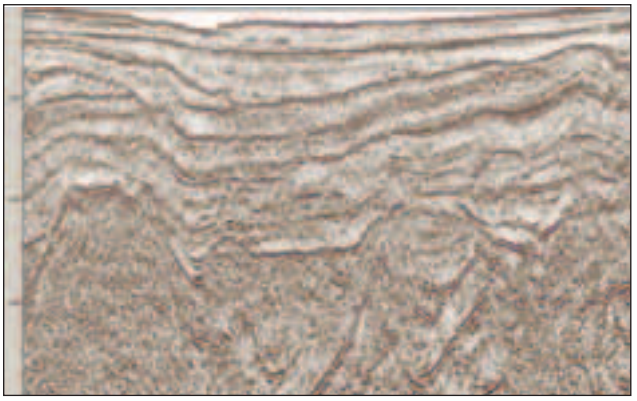
In 2003, TGS proceeded with the acquisition of a further 7400 line km of non-exclusive 2D data. Results from the five surveys offshore West Greenland - *KF03*, *BLF03*, *FBSE03*, *Green03,* and *KW03* - for the first time revealed strong DHIs. The *KF03* survey - the longest seismic line, acquired from Greenland to 200 nautical miles from the Canadian coast north of the Orphan Basin - revealed a 1400 kmr long, 100 km wide regional graben in the middle of the Labrador Sea, with potential major traps on the graben shoulders and deep sediments. *KF03* also outlined several potential major Mesozoic traps controlled by growth faulting on the



3D gravity visualization of the Ungava Rift.



Paleozoic and live hydrocarbon systems



Traps in basin of Lady Franklin.

shelf. The last seismic line was shot in mid-December and the seismic vessel only left the area because the survey was completed. Being able to perform effectively in December suggests that seismic operations may be possible year-round across most of West Greenland's offshore.

Non-exclusive data acquired during 2003 was available to companies participating in Greenland's 2004 licensing round. But again, only Encana made it all the way. The company was awarded a two-year exploration and exploitation licence for a 2897 km² tract in the Basin of Lady Franklin in January 2005.

After a year to consider the options, marine seismic and gravity data acquisition was resumed last year with a 7000 line km survey over five basins offshore West Greenland to support an ongoing licensing round announced by the BMP in January 2005. Line locations for data acquired last year were designed to fill gaps in existing data coverage and to provide more details about possible exploration models in local and regional basins, half-grabens, and four-way dip closures in the Labrador Sea, Baffin Bay, and offshore Kap Farvel, including some with DHIs.

The *ENC05* survey was small but intended to fill in the *Green99*, *Green00,* and *Green03* surveys so as to evaluate DHIs in the Nuuk basin. The *BFL05* survey provided infill over prospects in the Basin of Lady Franklin, and the *LSG05* survey secured information for future shoots in the Labrador Sea by confirming a number of four-way dip closures with DHIs.

The most important survey for the current licensing round, however, was the *DW05* survey complementing previous surveys over the license round areas. The grid for this survey covers deep basins, potential hydrocarbon migratory routes, and four-way dip closures and potential traps of many sizes, offering hope for elephant hunting, but also room for more traditional scale exploration. Once again the seismic vessel left Greenland during December!

Understanding the opportunities

Throughout the past five years, the challenge has been to put the geophysical data being acquired into the proper geologic perspective. For example, it was disappointing that surveys in 1999 and 2000 didn't find any DHIs to speak of. It was then realized that with at least 20 to 30 km separating the seismic lines, traps with areal closures as big as 1000 km² could be lost between the big structures that were being seen. That meant it was unlikely that DHIs would be found in those first reconnaissance shoots. Once some of the subsequent surveys were scaled down to a 10x10 km grid, we did identify a number of DHIs during interpretation.

The onshore oil seeps in the Disko-Nuussuaq area of West Greenland also provide an intriguing indication of the possible dimension of Greenland's offshore petroleum potential. A 450 m deep test well drilled in one of the valleys with extensive oil seeps encountered oil saturation in a 90 m predominantly volcanic interval with 10% porosity and 50% net. Calculations suggest the valley could contain about 4.5 billion barrels in place. An interesting extrapolation would be that the adjacent graben sources the valley. If this is the case, then there must be a significant hydrocarbon kitchen extending from Baffin Bay. The pull-apart basin at the edge of Baffin appears to have a row of grabens extending for 800 or 900 km, down through the Davies Strait. They terminate off the coast of Labrador where Canada's northernmost big gas discovery is located. TGS data show that just one of the big four way dip closures in a major graben in the Baffin could have an areal closure in the order of 3500 km². So if there is a correlation between the hydrocarbons of Canada and the oil seeps of Greenland, then maybe in between there's a new North Sea.

Arguably even more exciting, the data indicate that, in offshore settings in the northern part of the Davies Strait adjacent to the Disko-Nuussuaq oil seeps, there are deeper and broader basins holding huge structures, some of which have areal closures 10 times the size of the oil filled valley.

So even though it still lacks modern geophysical data in many places, the petroleum potential offshore West Greenland could be huge.