

# **Successful 3D Seismic Exploration offshore West Greenland using Dual-sensor Streamer Technology\***

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## **Abstract**

Seismic exploration in Arctic waters offshore West Greenland face a multitude of challenges. The ice-free season is short, weather conditions are rough causing bad quality seismic data, and last but not least, the subsurface conditions are far from ideal for good seismic imaging. The last constitutes a very hard, rocky sea floor, full of dropstones and thick volcanic rocks almost impenetrable to seismic energy. Husky partnered with PGS in the summer of 2009 and embark on an exploration campaign to cover more than 2200 square kilometers of high-quality 3D seismic data in Blocks 5 and 7 offshore West Greenland.

## **Introduction**

In recent years, with the onset of oil prices beginning to breach the \$100/bbl threshold, there has been an elevated level of industry interest for hydrocarbon exploration in some of the more challenging areas in the world, such as the Arctic. In order to conduct safe and successful marine seismic acquisition in these areas with extremely frigid climates, icebergs and sea ice, there are significant factors to consider in acquisition planning, as well as in the day-to-day operations. Harsh weather conditions that potentially slow production or cause down-time, and a short ice-free acquisition season, are special factors to consider when attempting to complete ambitious surveys within a single acquisition season.

In June 2009, Husky Energy, as operator of West Disko Blocks 5 & 7, deployed PGS to acquire two seismic surveys comprising more than 2200 square kilometers of 3D dual-sensor data in Offshore West Greenland in a single season ([Figure 1](#)). In addition to the challenges presented by icebergs and sea-ice, it has been long recognized that West Greenland also poses difficult seismic imaging conditions. These are owing to relatively recent glacial till and dropstones creating very strong water-bottom multiples as well as thick volcanic flows existing in the geological record. It was anticipated that dual-sensor 3D GeoStreamer technology with deep-tow capabilities would offer a

viable solution to address the challenges at hand. Despite a 3- to 4-month ice-free operation season, the survey was completed on time, within budget. The dual-sensor technology proved invaluable to the survey efficiency as well as to the very good data quality.

This article presents some of the pre-survey planning aspects critical to achieving good seismic imaging as well as optimizing the efficiency of the acquisition itself. Specific emphasis was placed on the deep-tow capabilities of dual-sensor 3D streamer technology as well as proper survey design to optimise the acquisition parameters. Earlier seismic experiments in the area have shown that deep-towed streamers enhance the low-frequency component of the data, improving the seismic image quality beneath the volcanics, but compromising the high-frequency spectrum in the shallower section.

## **Background**

West Greenland has an intriguing history of hydrocarbon exploration, with 2D seismic acquisition beginning in the 1970s. Albeit with no discoveries to date, five wells were drilled during the 1976 and 1977 seasons and the most recent, Qelleq-1, was drilled by Statoil A/S in 2000 in the Fylla region. The earlier wells were located using relatively short offset streamers on 2D grids with limited areal extent. A significant 2D seismic campaign occurred in 2008, with approximately 30,000 km of 2D being acquired, predominantly as a result of oil companies obtaining licenses in the 2006 West Disko Licensing Round. Data quality in most of the Tertiary section is generally good. However, common to much of the data acquired prior to 2008 is a very weak deeper primary signal, if any, owing to limited penetration below a Paleocene-Eocene volcanic section where present.

With the given risks and challenges, the potential for a hydrocarbon discovery is considered high. Upper Cretaceous sedimentary sections cropping out along the coast of the nearby Nuussuaq Peninsula reveal excellent quality reservoir, source and seal rocks overlain by Paleocene-age volcanics ([Figure 2](#)). These offer excellent analogues to sections potentially buried deep beneath the ocean floor. Total relief of these spectacular outcrop exposures are commonly in excess of 2000m above sea level, comprising a coastal mountain range barren of notable vegetation cover. Additional positive hydrocarbon indicators include numerous oil seeps ([Figure 3](#)) discovered along the coast in the Disko-Nuussuaq-Svartnhuk Halvo region, and have been typed by the Geological Survey of Denmark and Greenland (GEUS) to five different source intervals, Cretaceous to Paleogene in age. Vintage seismic data in the West Disko area, albeit with sub-basalt data quality issues, allow mapping of large four-way structural closures. Finally, interpreted gas clouds, amplitude anomalies, some having favourable AVO signatures, can be observed in shallower Tertiary section hinting at potential deeper hydrocarbon charges.

[Figure 2](#) demonstrates how the Paleocene basalt-flows overlie the Cretaceous sedimentary section, giving rise to difficult seismic imaging conditions. In onshore exposures, basalt thickness ranges from approximately 100 m to over 1 km, with similar thicknesses expected offshore. The Hellefisk-1 well, drilled near the survey area penetrated 680 m of basalt before reaching TD. In addition to volcanic flows, swarms of intrusive dikes and sills can be observed in outcrops, adding to the potential distortion of the seismic image. Examples of Husky 2008 vintage 2D seismic sections over the 3D survey prospect areas are shown in [Figure 4](#). Primary seismic reflectivity below the

volcanics is limited. However, the data was of adequate quality to high-grade prospect areas and progress to a 3D acquisition decision for further prospect definition. The need for 3D seismic before drilling in challenging areas such as these is enhanced to reduce risk to an acceptable level.

### **Survey Design and Infill Analysis**

Prior to the acquisition phase of the project, 3D survey design planning was performed. Considerable effort was spent on analysing and understanding the shortcomings of previously acquired data. A key aspect to successful imaging below basalt was the need for low-frequency penetration. The seismic source design was optimised by extending the sub-array separation, increasing the air pressure and towing the air guns as deep as possible (9 meters). In an effort to increase the fold, and finding through modelling that the maximum required recording time was 7.5 seconds, the shot-point interval was reduced from 25 to 18.75 m for one of the 3D surveys. This resulted in a 33% increase in fold.

Migration aperture was investigated to ensure that the survey outlines were indeed capturing the needed data for proper structural imaging. A complete earth model was built using key horizon picks from existing 2D seismic grids. 3D ray tracing was then performed. Aperture analysis was investigated at each major horizon of interest, and as a consequence, the survey polygons for both surveys were extended appropriately so that the proper migration apertures were recorded.

Given that this large acquisition project had to be executed in the short 3- to 4-month ice-free season, and that icebergs would likely obstruct sail lines, efficient infill management was vital to the success of the project. A proprietary infill method commonly referred to as the stop-light system (Day and Rekdal, 2005 or Strand et al., 2008) proved to be invaluable. The previously established earth model along with navigation plots was the inputs to calculating the actual coverage to ensure it satisfied pre-determined tolerances. These stop-light plots were then reviewed online by the client and office to determine the need for extra infill lines. The Block 5 and 7 surveys ended up with 21% and 28% infill, respectively, which were well within expectations as icebergs were indeed encountered during acquisition.

### **Dual-sensor 3D Acquisition**

Upon arrival to the survey area it was clear that seismic acquisition in the iceberg-prone area would be a serious challenge. A high tech ice-radar was installed to navigate through the ice as well as possible. The survey spread of 500 by 6000 meters (six cables) made it impossible to turn quickly in order to avoid obstacles. [Figure 5\(A\)](#) shows a snapshot of the navigation planning needed to avoid striking the icebergs. [Figure 5\(B\)](#) shows the chase vessel scouting for ice.

One benefit of dual-sensor streamer technology (Carlson et al., 2007) is that it allows for deep-towed streamers (15 m in this case) without compromising the high-frequency spectrum. The resulting data-quality uplift and frequency comparison between the vintage deep tow,

conventional cable 2D seismic, and the deep-tow geostreamer seismic acquired in this project can be observed in [Figure 6](#).

Another important benefit to the dual-streamer technology is that weather windows were increased and acquisition was only halted for a few days throughout the whole seismic campaign. Downtime for weather was 3% and 12% for Blocks 7 and 5, respectively. This is significantly lower than expectations if streamers were towed at a more conventional depth. Late in the season, during the latter part of the 2<sup>nd</sup> survey (Block 5), weather conditions deteriorated with increasingly strong winds and cold temperatures. The deeper towed cables allowed for continued good quality acquisition. Production, however, was reduced because the water temperature dropped to below freezing, and operation of the air guns and other equipment became intermittent. Ultimately, however, the project would not have been completed in the season without the increased weather window that was experienced.

### **Conclusions**

A very successful marine seismic 3D campaign has been conducted offshore West Greenland north of the Arctic Circle. Over 2200 square kilometers of 3D data was acquired in just over 3 months. Dual-sensor technology has proven to be very valuable in these challenging conditions, addressing both weather and the seismic-imaging challenges. Along with this technology, the success was also achieved through excellent project management and novel seismic survey planning.

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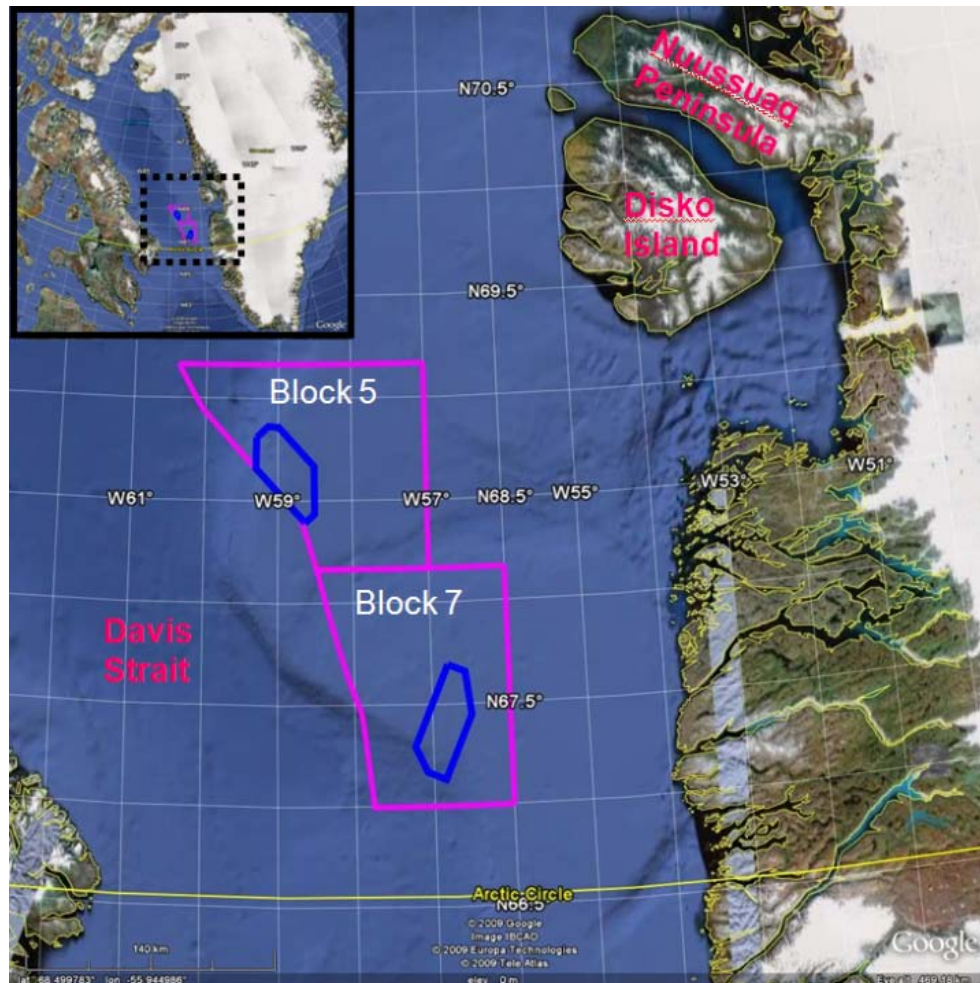


Figure 1. Location map of West Disko Blocks 5 and 7 with 3D survey polygons in blue. Location inset with respect to Greenland is shown in upper left.





Figure 2. A 200-m-thick sandstone overlain by basalt along the coast of the Nuussuaq Peninsula suggests analogous potential for reservoirs in the adjacent offshore environments.



Figure 3. Basalt cobbles with live oil in vuggy pores found on a beach near a known seep locality along the South Nuussuaq coastline.

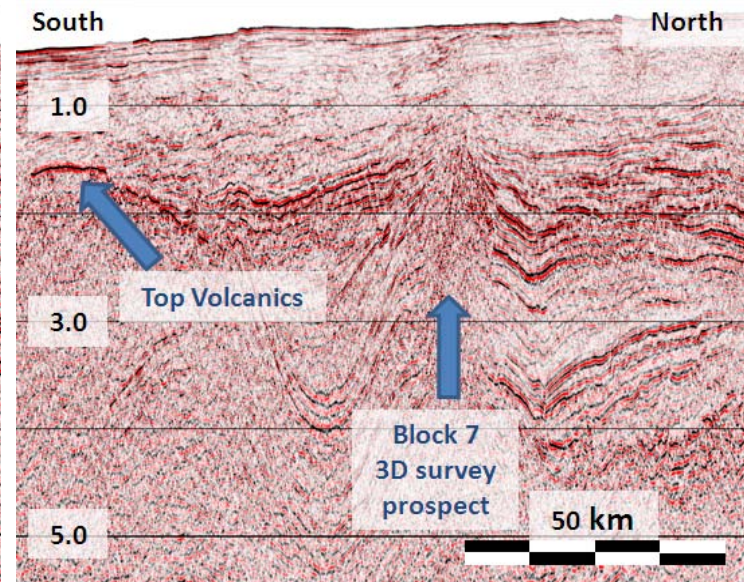
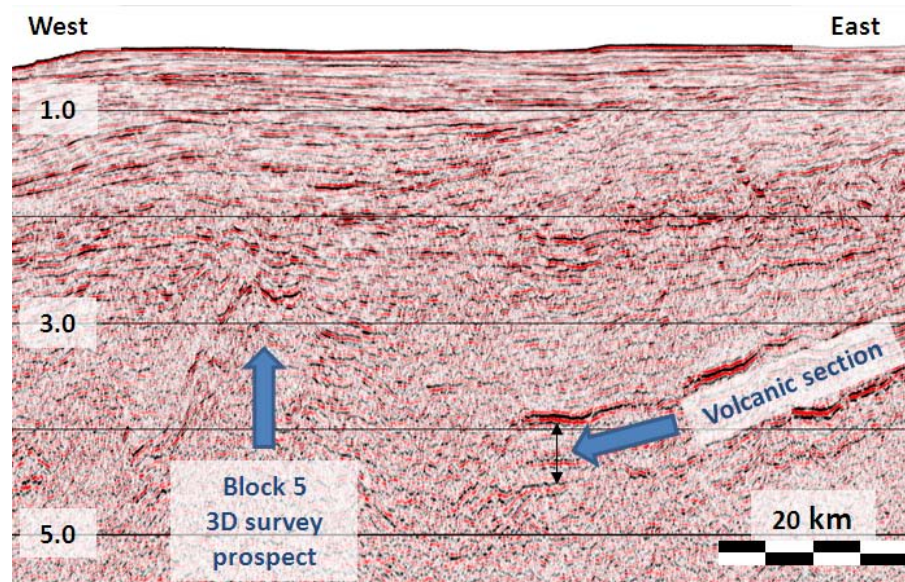


Figure 4. Vintage seismic 2D data over both blocks 5 and 7. Note the general deterioration of image quality beneath the volcanic sections.



Figure 5. (A) Snapshots from the ice-radar and the navigation screen used to navigate round the icebergs.(B) Iceberg scouting.



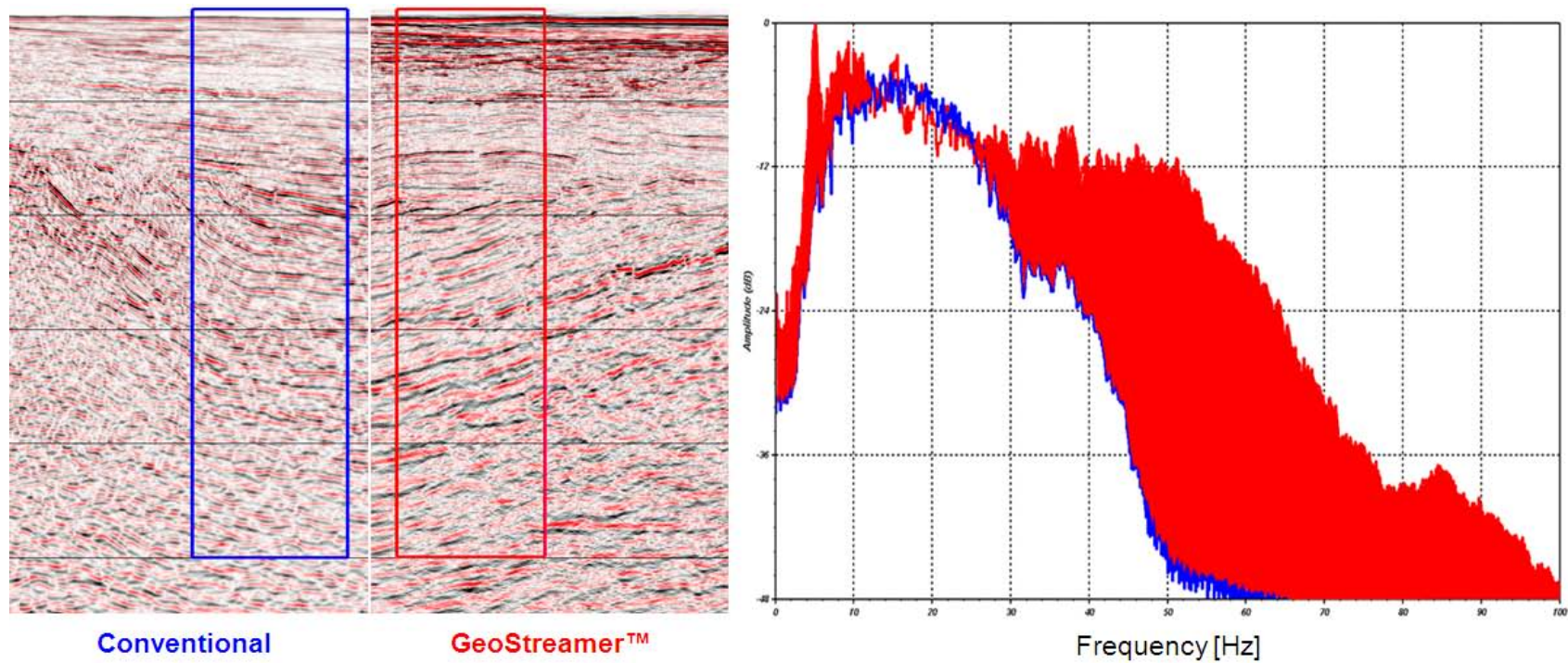


Figure 6. Comparison between a conventional cable 2D line (source at 13 m and streamer at 22m) and 3D GeoStreamer data (source at 9 m and GeoStreamer at 15 m). The frequency comparison illustrates the uplift achieved using the dual-sensor streamer technology.