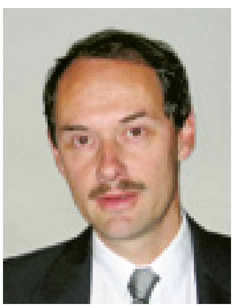
# Seismic Imaging Technology

## PART I: ACQUISITION

**Seismic imaging is considered key to reduce risk and cost in exploratory as well as development drilling. Although we have recently seen important advances, the authors claim that a step change is required to significantly improve the industry's ability to obtain accurate seismic images of oil and gas reservoirs within geologically complex settings.**

IN A SERIES OF ARTICLES WE WILL DISCUSS SEISMIC IMAGING TECHNOLOGY. AFTER A SHORT INTRODUCTION, THE PRESENT ARTICLE FOCUSES ON HOW SEISMIC ACQUSITION GEOMETRY MAY IMPACT THE SEISMIC IMAGE. IN THE NEXT THREE ARTICLES WE WILL FOCUS ON SUBSALT IMAGING DEVELOPMENTS IN THE GULF OF MEXICO, IMAGING FROM OCEAN BOTTOM SEISMIC SURVEYS, AND SUGGEST NEW SURVEYING GEOMETRIES THAT COULD DRAMATICALLY IMPROVE SEISMIC IMAGING.



Martin Landrø is professor in Applied Geophysics at the Norwegian University of Science and Technology (NTNU), Department of Petroleum Engineering and Applied Geophysics, Trondheim, Norway.

Lasse Amundsen is adjunct professor at the Norwegian University of Science and Technology (NTNU) and at the University of Houston, Texas.

Oil and gas exploration is a costly and risky business. This is particularly true in challenging areas such as in deep water and when drilling beneath salt and basalt.

For example, in the last decade the success rate of deep water (300 m and more) Gulf of Mexico (GoM) exploratory drilling has been around 10 %. In 2006 and 2007 combined, according to the US Minerals Management Services (www.mms.gov) statistics, only 17 of 229 deep water GoM exploration wells made commercial discoveries. Since deep water wells cost between US$ 50-100 million this level of exploration risk is unacceptable.

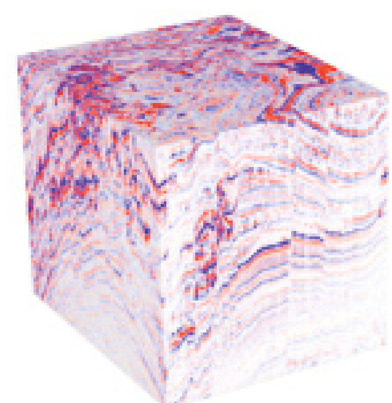
Nevertheless, using *conventional* 3D seismic, fields like Atlantis, Jack, Mad Dog, Shenzi and Tahiti have been found. But the operators state that the *conventional* 3D seismic is not of sufficient quality to create accurate models for reservoir development.

*Therefore, the introduction of new imaging technology is imperative to reduce risk and cost.*

Imaging technology is also considered critical in many other sedimentary basins around the world. This is certainly true in the Campos Basin of Brazil that has recoverable reserves of at least 50 billion barrels of oil.

Other examples include the Nordkapp Basin in the Barents Sea, where high-velocity salt diapirs close to the seafloor cause imaging problems, and the Nile Delta pre-Pliocene section which is covered by anhydrite. Also, many of the Jurassic North Sea reservoirs have suffered from poor seismic imaging.

Seismic cubes generated from 3D seismic have a wide range of possibilities for the curious geologist.



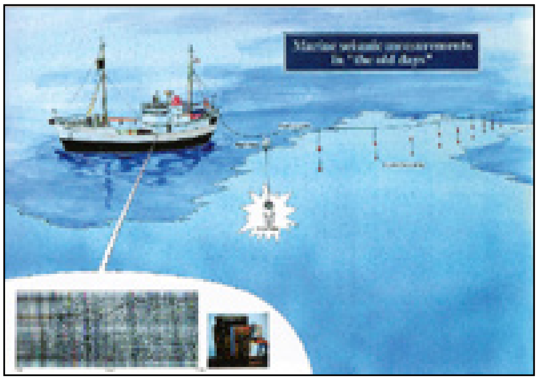


### Beyond Processing

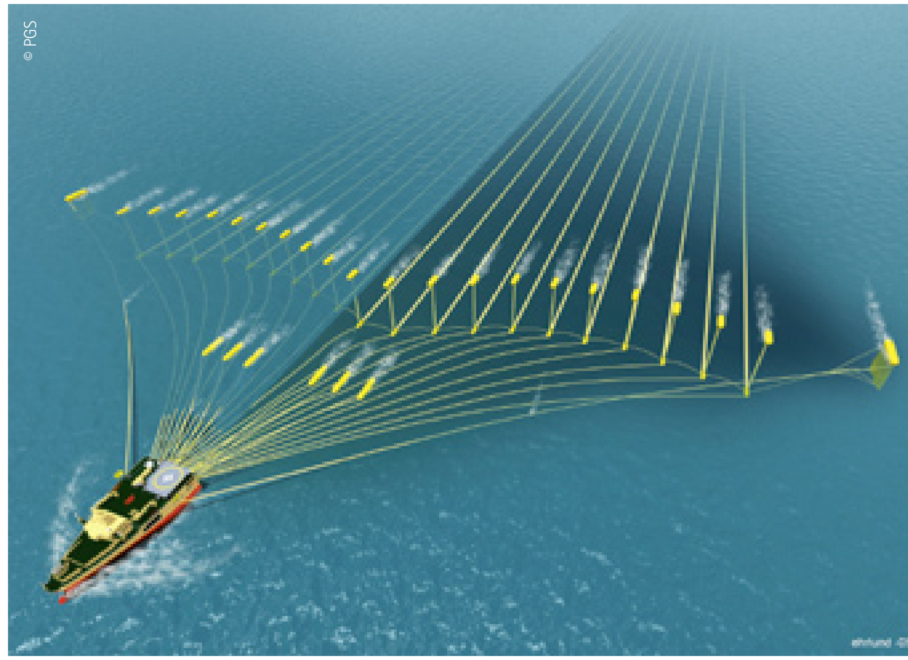
Seismic imaging technology does not only involve *traditional* seismic data processing. Equally important is seismic data acquisition, data integration, seismic migration and computing, and velocity model building, this last being a particularly tricky and crucial issue.

One school believes that velocity building can be significantly improved by geophysical data integration and by establishing a stronger link to geology, but the way of achieving it is not obvious. The objective is to integrate seismic, gravity and perhaps electromagnetic data with geological models and understanding, allowing for personal judgment and margins for uncertainties.

On the other hand, some of the big brains in academia work on techniques that depth-migrate



Acquisition technology as used in a 1969 Svalbard survey. Illustration by Anders Farestveit.




The newly built PGS Ramform Sovereign (see also page 8 in the current issue of GEO ExPro) offers the possibility of advanced acquisition for the purpose of improved imaging.

seismic data with the use of a constant (water) velocity background model only. Using this method, the primary reflections from the subsurface intelligently communicate to find their correct location in depth.

In recent years, we have seen numerous advances in seismic processing, in particular, in removal of multiples. However, processing alone is not always the key to success in imaging. Therefore, new data acquisition techniques, together with accurate velocity models and migration algorithms have been developed in a continuous effort to improve the seismic image below complex geological structures.

We will now focus on the numerous developments in *seismic surveying geometries* in improving seismic imaging. It is possible, however, that the optimal data collection technique has not yet been found: the industry has taken a detour while searching for the optimum solution.

## Illuminating the Target

The problem of collecting seismic data is like attending a football match. Your view of the game depends not only on the lighting system of the stadium but also on where you are sitting. For example, a journalist may prefer to be in the stands where he or she will have a good view of the entire game, which is necessary for analyzing and reporting all of the moves and tactics. A photographer, however, may prefer to be near the touchline where he or she can immortalize the goals, even at the expense of not seeing the rest of the game. The ticket prices for these special positions may be more than that of a standard seat, but the extra cost will pay off handsomely.

As in football matches, the view of the subsurface is determined by the location of the sound sources for 'illuminating' the area of interest. Equally important is the location and types of sensors used to capture the ground motion caused by the passage of seismic waves. Standard 3D towed-streamer seismic surveys may, in fact, be unsuitable for obtaining the very best reservoir images, especially in geologically complex areas.

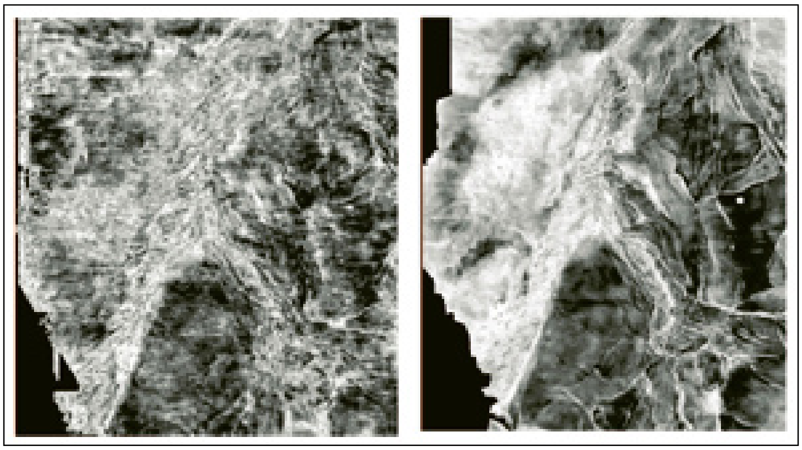
The 3D marine seismic surveys that revolutionized exploration in the 1990's have advanced in many ways. But before we address the new developments in acquisition, let us take a trip back in time.

## From 2D to 3D

In the 1960's marine seismic data were acquired with a single streamer and a dynamite source. Some years later, in the 1970's, reflection seismic was conducted by a vessel towing an array of airguns and a streamer containing a number of hydrophones. This acquisition technique is known as 2D seismic since the survey lines are generally several kilometres apart. A subsurface picture of the geology thus has to be painstakingly reconstructed by interpreting and intelligently guessing what goes on in between.

Following 2D seismic, the next significant step was the emergence of the so-called 3D seismic. This technique basically involves the use of multiple streamers to shoot closely spaced lines. Because of this close spacing, it is possible to represent the data as 3D seismic cubes – an innovation which has gone hand-in-hand with the rapid development of high-performance computers and advanced data-processing techniques. The cubes can be interpreted to reveal likely oil and gas accumulations. Cubes can be viewed as they are or analyzed in greater detail by computer-generating vertical, horizontal (time-slices), or inclined sections through them, as well as sections along interpreted horizons.

©PGS



Differences in seismic imaging between a conventional streamer survey and one with 3 shooting directions (Merchedes-acquisition) acquired on the Varg field in 2002. Shown here is a Base Cretaceous amplitude map Pre-Stack Depth Migration of Multi-Azimuth Towed Streamer Seismic. The figure is from a presentation given by Stian Hegna and Dorothee Gaus at the 65th EAGE Conference & Exhibition in Stavanger in 2003.

*We consider 3D seismic as the biggest game changer in the seismic industry ever.*

Today, the standard in seismic acquisition is to use vessels that tow around 10 streamers at a time, separated by 50 to 150 m, each streamer being from 6 to 8 km long. The source consists of an array of 12 to 18 airguns fired every 10 to 20 seconds. The geophysical objective and economical constraints determine the specific acquisition parameters.

## The Benefit of Several Directions

In the "old days" acquisition wisdom suggested that it was preferable to shoot a survey in the dip direction of the main structural trend. Several examples, however, showed that a new seismic survey in a different orientation improved the image in some areas of complex structure, while the image in other areas was better in the original data. These reports suggested to the geophysicist that the survey direction is an important part of the imaging equation. Ideally, is it necessary to shoot from "all" directions?

In the late 1980's Texaco attempted to develop vertical hydrophone cables for full azimuth illumination of subsalt targets in the Gulf of Mexico. The vertical cable method did not survive, maybe because the horizontal separation between cables was too large - a cost issue.

In 1996 Elf carried out a test in Gabon by acquiring four surveys at different azimuths across a salt body. The result of this experiment showed the incomplete but complementary information extracted from the various acquisition directions.

Between 1997 and 1999 an extensive research program led by Statoil concluded that detailed structural imaging of complex geology requires the acquisition of high-fold seismic data from all directions (full azimuth, or FAZ). Careful planning of the 1997 3D Statfjord field ocean bottom seismic (OBS) cable survey offshore Norway rendered possible an evaluation of image quality versus acquisition geometry by emulating both OBS and streamer surveys.

Since 2000, StatoilHydro have acquired high-fold, FAZ-OBS data over most of its fields offshore Norway. Nearly all surveys have given superior image quality compared to conventional streamer seismic.

In 2001 BP tested wide azimuth (WAZ) acquisition in the Norwegian North Sea using a conventional seismic vessel in combination with an additional source vessel. The company reported improved noise (diffracted multiples) attenuation with increased azimuthal coverage.

## Some Case Studies

Since OBS surveys over large areas (200 sq km or more) at that time was prohibitively expensive, E&P companies started to investigate if new streamer configurations could be a cheaper alternative. Two well-documented surveys are those acquired over the North Sea Varg and Hild fields.

***Varg:*** The Varg reservoir has a combination of relatively thin sands and complex faulting due to salt related tectonics, making the reservoir challenging to interpret and produce. PGS created a new image of the Varg field in 2002 by making passes in two different directions with one conventional cable vessel and combining the data with existing data acquired in a third direction. The survey demonstrated the benefits of multi azimuth (MAZ) surveying on the seismic image, in particular by improving the signal-to-noise ratio.

***Hild:*** Total operated Hild discovery located along the border of the UK and Norway turned out to be difficult to interpret due to strong reservoir compartmentalization and the presence of gas in the overlaying Cretaceous series. As the optimal imaging solution, ocean bottom cable seismic, proved too expensive, a streamer vessel multi-azimuthal solution was chosen. In 2003 the Hild structure was covered by two surveys designed so that the two datasets, together with the existing survey from 1991, made an angle of 60 degrees with respect to each other. The combined surveys resulted in an improved seismic image with better continuity of the reflectors in the reservoir section. The poor signal-to-noise ratio due to the gas cloud was partially compensated for.

***GoM:*** From 1998-2002 BHP, BP, Chevron and Texaco participated in the SMAART joint venture that addressed routes to full azimuth marine seismic acquisition. Modelling studies showed that all source-receiver azimuths were needed for the best possible illumination below complex salt. Further, using a new azimuth, a second conventional 3D streamer survey over the BP operated Mad Dog discovery did not deliver the needed improvements. Therefore, evaluation of OBS nodes at BP's Atlantis and a rich azimuth (RAZ) streamer survey over BHP's Shenzi discovery was acquired in 2006.

## Acquisition Geometry

The examples above demonstrate that seismic illumination and imaging of complex structures clearly depend on the acquisition geometry. High fold and multi azimuth seismic is key to the high quality detailed seismic imaging required to improve our understanding of complex fields.