Treasure hunt

Oilfield Technology Correspondent Gordon Cope explains how the latest seismic processing software is leading the way in the hunt for uncharted resources.

Offshore basins around the world are troves of oil and gas resources, and the majority of that treasure remains uncharted. The United States Geological Survey (USGS), for instance, estimates that basins within the Arctic hold 90 billion bbls of undiscovered, technically recoverable oil, 1670 trillion ft^3 of gas and 44 billion bbls of natural gas liquids.

But this represents only a fraction of all undiscovered reserves. Other offshore plays around the world hold equally impressive potential: the west coast of Africa may have as much as 40 billion undiscovered barrels, the presalt basins off the coast of Brazil may hold over 100 billion bbls, and even the relatively heavily explored Gulf of Mexico may have as much as 31 billion bbls of new oil and 134 trillion ft^3 of gas beneath its ultra-deep waters.

Without a doubt, seismic is the greatest exploration tool in the hands of the petroleum sector. Every year, thousands of miles of 2D and 3D are shot around the world in order to explore uncharted basins and flesh out recent discoveries:

- TGS NOPEC Geophysical Co. and PGS initiated a 22 000 km, multi-client, 2D survey in the Labrador Sea off Newfoundland. The programme, situated north of Hibernia and other oilfields on the Grand Banks, covers areas that have been nominated in the Newfoundland and Labrador Offshore Petroleum Board's call for bids. The programme will allow industry participants to high grade areas of interest.
- Statoil and Chevron are shooting a 3D seismic programme in the Beaufort Sea this summer in order to test structural plays beneath 1800 m of frigid waters, The survey, located 120 km offshore will cover 2060 km^2.
- BP, Eni, Statoil, and Cobalt International Energy, of Houston, recently signed production-sharing agreements (PSAs) with Angola's Sonangol. The PSAs require BP et al to shoot a 4100 km^2 3D seismic survey this year in order to identify presalt structures similar to those encountered in the Santos basin offshore Brazil.
- Rockhopper Exploration, which has already delineated 350 million bbls of oil in the Sea Lion reservoir located in 3000 m of water off the coast of the Falkland Islands, shot a 3D seismic survey over adjacent areas in order to extend the play. Rockhopper intends to invest US$ 2 billion in order to start production from the field by 2016.

In order to improve the quality of seismic, geophysicists continually seek out more sophisticated software, powerful computers and new techniques. Their goal is to peer to the very foundations of the earth and map structures previously undetectable. "We are seeing greatly improved depth imaging of complex structural plays," said Larry Lines, a professor of geophysics at the University of Calgary. "We are increasing the

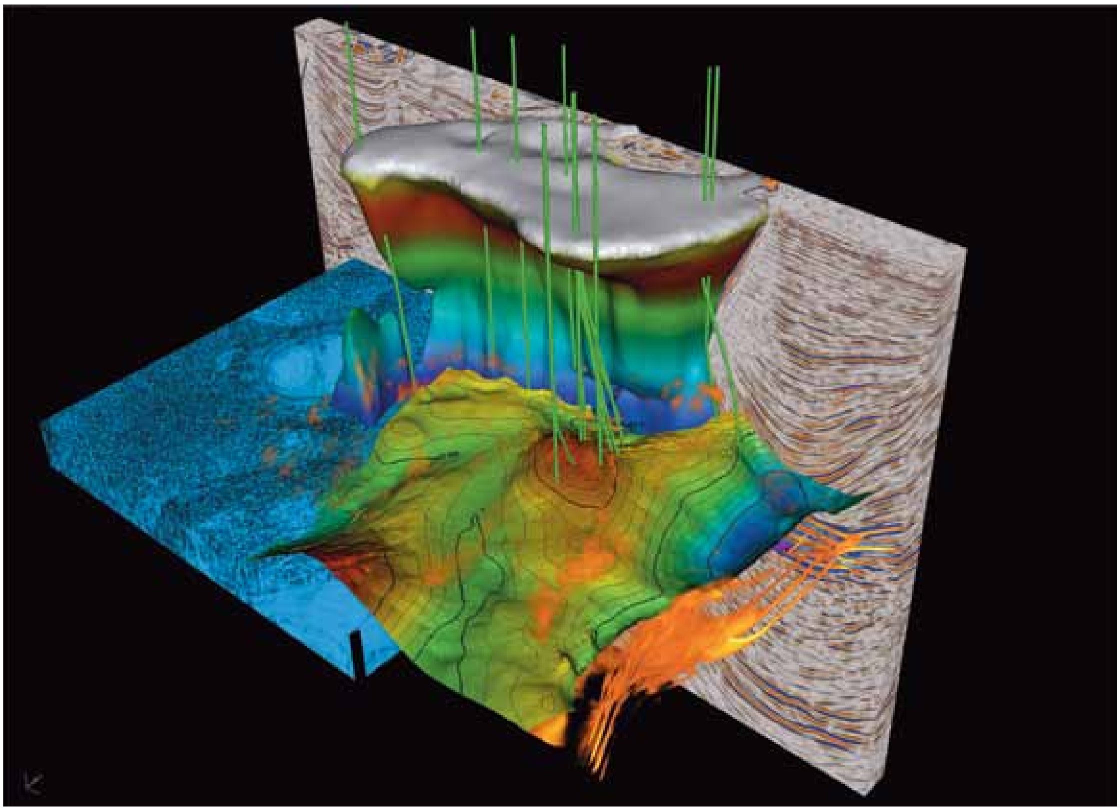

Figure 1. *Landmark's GeoShell™ software technology can be used to accelerate iterative velocity modelling, seismic imaging and interpretation workflows. The result is significantly improved sub-salt images. Data provided and owned by TGS-NOPEC Geophysical Co.*

signal to noise ratio. We are identifying rock properties such as porosity and fluids."

There are three basic components of O&G exploration seismic; acquisition, processing and interpretation. Over the last decade, the seismic acquisition sector has invested millions of dollars in R&D. "Acquisition companies have been raising the bar in the last few years, expanding surveys from hundreds of square miles to thousands of square miles, from one to five traces, and acquiring from every angle," says Kenny Laughlin, manager of geophysics for Landmark, which offers a suite of software and services for upstream E&P.

Offshore seismic data is gathered using purpose-built boats capable of towing sets of 10 km long streamers over the area of interest. Air guns are discharged, sending a pulse downwards through the ocean and into the seabed. Formations beneath the seabed reflect the pulse back to the streamers, where attached hydrophones (or jugs) record the lag time and location of the returning pulse.

In order to improve the quality of data, acquisition companies have made several advances. New boat designs, including the innovative X-BOW created by Norwegian firm Ulstein Design & Solutions, allow the vessel to cut through the water with greater efficiency and smoothness. In order to improve placement and dispersal, streamers are guided by 'birds', which are motor and wing-equipped modules that can be programmed to keep the cable at the same angle and azimuth behind the vessel. Schlumberger's WesternGeco offers the Q-marine system, and CGGVeritas markets the Sentinel solid streamer and Nautilus control device. PGS's GeoStreamer can tow streamers at deeper depths, and record in harsher weather conditions. Thanks to modern GPS and streamer technology, acquisition companies can now position cables and boats to within 10 m, allowing far greater accuracy of measurement.

Service companies have also been devising complex acquisition patterns to increase coverage of data. "Wide azimuth (WAZ) and full azimuth (FAZ) have been the key words in acquisition the last few years," says Nick Purday, director of geoscience and reservoir technology for Landmark. Using convoys of vessels that crisscross the target numerous times, the WAZ and FAZ patterns record data along many different directions. The sheer volume of data (often several terabytes), helps improve target definition and resolution. This permits optimal illumination of deep reservoirs below complex overburden geometries, such as salt bodies.

Although the vast majority of surveys use towed hydrophones, ocean bottom cable (OBC) and nodes (OBN) can be permanently installed on the seabed. The direct coupling to the sediment allows geophysicists to measure elastic waves, which allows greater interpretation of anisotropic effects (in which the velocity of waves traveling through a given formation changes with direction).

OBC also allows the use of multiples for subsurface imaging (multiples are generated when the initial reflected wave bounces off the seafloor layer and re-reflects back through geological layers). This is advantageous when trying to geometrically delineate salt bodies, which are layers of sodium chloride, gypsum, calcite and anhydrite measuring 10 000 ft in thickness, or more. While salt bodies are laid down out as flat, horizontal formations, they are plastic in nature, and tend to deform under pressure, creating uneven boundaries that scatter seismic wave pulses. Multiples, moving at different angles than the original pulse, can be used to look underneath structures.

Processing

After the data is acquired, but before it can be interpreted, it must be processed. This intermediate procedure is necessary in order to separate out the valuable signal (which may represent less than 2% of recorded data), from background noise. But WAZ and FAZ create large databases, making the task difficult. "These new methods of acquisition are creating 'big data' challenges with datasets in the terabyte and petabyte range," says Purday. "Acquiring thousands of channels at a time has overwhelmed the historical processing architecture. One of the major advances in recent years has been javaseis.org, a parallel data infrastructure that allows you to access and efficiently process multi-dimensional surveys on Linux clusters in the cloud."

Traditionally, seismic is processed in the time domain, but geophysicists are also calling for data to be converted to the depth domain. This iterative process can be slow, however, with a number of interpretation, velocity modelling and migration steps required to produce a final output. "Landmark has solved this challenge through the development of a technology we call GeoShell™," said Purday. The technology works by taking incomplete interpretations of geologic features derived from seismic and well data and then constructing and visualising sealed 'bodies' that represent complex, three-dimensional objects. "The interpreter can use all of his existing methods of interpretation and data to generate the body, then apply the GeoShell technology to automatically clean overlapping surfaces and form a sealed volume. These bodies are then used to constrain the velocity distributions that are used in depth migrations."

Much more attention is being paid to pre-stack information, essentially the raw data recorded on each channel prior to integration into a seismic cross-section. "Pre-stacks contain a lot of information about rock properties – porosity and fluids, for instance – and amplitude variation with offset (AVO) is used to draw this out," said Lines.

Best guess

Interpretation is the final step, in which processed seismic data is integrated with well information to create a cohesive model of subsurface geology. Interpretation has benefited from improvements in three areas: the increased potential for collaboration among the various geosciences, the ability to visualise the data, and the increased amount of information that can be plucked from the seismic data. "We have developed the DecisionSpace Desktop to handle these workflows," said Purday. "All the data from seismic to wells and reservoir production and simulation can be visualised in a common view, while the data is managed by a multi user project database called OpenWorks."

Complex visual software creates optical illusions that allow geoscientists to immerse themselves directly into the data. Collaborative visualisation centres, in which professionals wore 3D goggles, have now given way to systems that allow a geoscience team to collaborate in a similar immersive environment right at their desktops, even when separated by thousands of kilometres.

The integration of seismic, geological and reservoir data is giving rise to the ability to better simulate, or predict, how a reservoir will behave once it is on production. Simulation software has been around for several decades to help decide the best placement of wells and surface production facilities. Supermajors have developed some software in-house, and third party vendors also offer powerful applications. But there has been a general awareness of their limitations; building a simulation model can take several months, and running a model with more than a few simple parameters can take even the largest computers more than a day to create one iteration. In addition, because only a few of the most likely scenarios are run, there is significant uncertainty that the most optimal and efficient solution may have been missed.

Oil companies, aware that simulation models gave a 'best guess' solution with an unknown margin of error, began experimenting with probability optimisation theorems to improve the quality of simulation modelling. Optimisation relies on a variety of algorithms, or complex mathematical equations; the choice of algorithm depends on the task in hand. A simple optimiser is the gradient method, mimicking the rolling of a marble on an uneven surface to find the nearest low point. More powerful techniques are the genetic algorithm and evolution strategy methods, which mirror the process of evolution where the best of each generation are used to 'father' subsequent generations, The best of these 'children' then in turn are used to create the next generation, resulting in a steady improvement in the quality of the solution.

Through the use of optimisation, several hundred simulation scenarios are created in a fraction of the time. This allows geoscientists to integrate 4D seismic much more accurately. 4D seismic is a refinement based upon data collected in 3D seismic surveys. A 3D survey uses the same technique as a traditional 2D survey (in which sound waves from a point source travel through the ground and are reflected off the interface between two geologic formations back to acoustic receivers), but the seismic lines are laid out much closer together. The greater density of coverage allows processors to fill in information between the lines, creating a three-dimensional picture of the sub-surface with much greater accuracy and detail.

A 4D seismic survey is simply a 3D survey repeated over the same area in order to show changes that have occurred in the sub-surface over time. "We are excited by 4D and there are numerous case studies that have highlighted the value that 4D can bring to producing fields," said Purday. "The ultimate goal for a 4D study is to validate production from wells by comparing and calibrating with seismic time steps. A common visualisation platform is important to understanding the 4D response."

Protecting Wildlife

Offshore seismic is not without controversy. Although it doesn't have the potential for environmental tragedy such as the TransOcean blowout in the Gulf of Mexico that released 4 million bbls of oil, environmentalists are concerned that the noise associated with marine surveys might have an impact on wildlife. In 2002, the US Minerals Management Service (MMS), set rules governing the use of air guns, requiring them to be slowly ramped up in intensity in order to scare off any marine mammals sensitive to the noise. It also began a three year study of sperm whales to see if seismic was affecting the endangered species. The Office of Naval Research, Texas A&M Research Foundation, and the International Association of Geophysical Contractors participated. Although the study concluded that air guns caused no harm to marine mammals, in 2011, the US Bureau of Ocean Energy Management (BOEM, the reincarnation of MMS), requested the National Marine Fisheries Service study if air guns used in seismic surveys could harm or harass whales and dolphins in the Gulf of Mexico.

New tricks

Geophysicists are exploring better ways of customising seismic surveys to suit the geology of the play. For several years, a consortium has been working on an advanced modelling initiative called SEAM (Society of Exploration Geophysicists Advanced Modelling). Computers and specialised algorithms are used to generate a realistic simulation of various marine seismic surveys, and compare the results. The parameters that produce the best theoretical imaging of the exploration target can then be used in the survey.

Drillers are also using seismic to fine-tune the direction of the drill bit. "Halliburton and Landmark are jointly investigating the use of near real time migration and velocity model building while drilling; this process is called Seismic while Drilling (SWD)," said Sherman Wang-Stockton, manager of marketing for Landmark. The bottom hole assembly (BHA) has a deep-penetrating sonic wireline tool that gathers data that can be transmitted in real time to the interpreter. "This data is then incorporated into a synthetic seismic trace that allows the prediction of key geological surfaces ahead of the drill bit. Real time adjustments to the well prognosis can thereby lead to faster reactions to events and ultimately enable safer drilling practices."

In the more distant future, entirely new processing programmes will open up far greater imaging powers. Full waveform inversion (FWI) is a procedure that attempts to produce a model where amplitude response matches that recorded in a seismic survey. While FWI holds tremendous potential to increase image resolution, it will require much higher signal to noise ratios currently being captured, as well as three orders of computing power greater than currently available. "There's a lot of buzz in the industry over Full Waveform Inversion," said Purday. "It continues to show a great deal of promise, and we expect to see some of that to materialise over the next few years. It will be the next big step in image quality.

OT