The *iField* - Enhancing Predicted Field Production Levels Using 4D/4C OBC Seismic

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Abstract

Reservoir management has become a critical aspect in the economics of a producing field. Geophysicists and geologists are continuously looking at potential ways that seismic data can help reservoir engineers make better and quicker decisions during field production.

It has been well documented that a substantial amount of hydrocarbons are left untouched once a field is abandoned. There are numerous enhanced oil recovery (EOR) methods available today to assist in recovering some portion of oil left in reservoirs. Methods such as horizontal drilling, drilling technology, subsea production, completions and fracturing have all played a major role in enhancing oil recovery and reducing exploration and production costs.

Although seismic technology has not received the notoriety it deserves from the oil and gas industry for it's contribution to falling exploration and production cost, it is perhaps the largest contributor in lowering the overall E&P cost. Figure 1 below shows the percentage of contribution that a number of technologies have had on falling exploration and production cost.

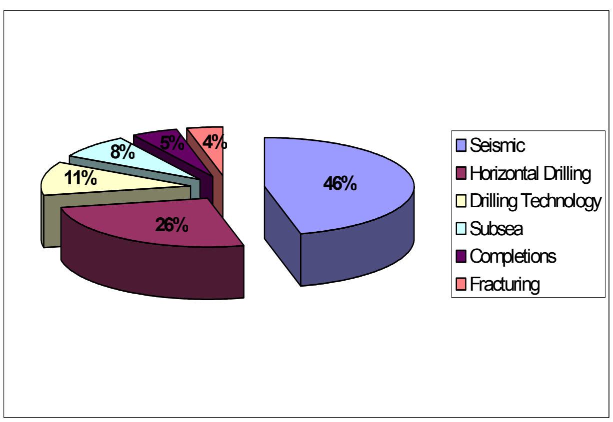

Figure 1: 3D seismic's contributions to falling E&P costs to Scroders oilfield value survey (from Salomon Smith Barney)

The number of companies today considering the need for time-lapse (4D) four-component (4C) seismic datasets during the life of a field confirms that industry is moving into a new paradigm. Instrumented oilfields or "*iField*" with the use of permanent seafloor ocean bottom cables (OBC) to acquire 4D/4C seismic datasets can provide a number of benefits to operating companies. Permanently deployed OBC 4D/4C seismic equipment can provide data to better support facilities planning and development, optimizing drilling programs for improved well placement and when positioned for the life of the field can improve reservoir management and aid in characterizing reservoir properties.

This paper describes the potential benefits of acquiring permanent 4D/4C seismic datasets during the life of a field to aid in better predicting field production levels. The *iField* is a crucial technology in reservoir management. It's potential in increasing oil recovery throughout the life of a producing field will have a major impact in both the drilling and production industry.

Introduction to 4D/4C OBC Technology

During reservoir characterization, field implementation, reservoir monitoring stages, new reservoir data are acquired to update the shared earth model and to reevaluate the reservoir performance. In this way, the simulation can be kept current and accurate. A crucial piece of the puzzle is understanding fluid migration within the reservoir over time. Ocean Bottom Cable (OBC) data such as time-lapse (4D), or multi-component seismic, can play a key role in tracking fluid movement, locating bypassed pockets of oil and identifying opportune areas for further development.

OBC - Better known as "Ocean Bottom Cable" is the technique of acquiring a seismic survey by placing sensors permanently or temporarily on the seafloor. One of the objectives of OBC is to eliminate the problems associated with the water-column such as noise and multiples which can be detrimental to seismic data quality.

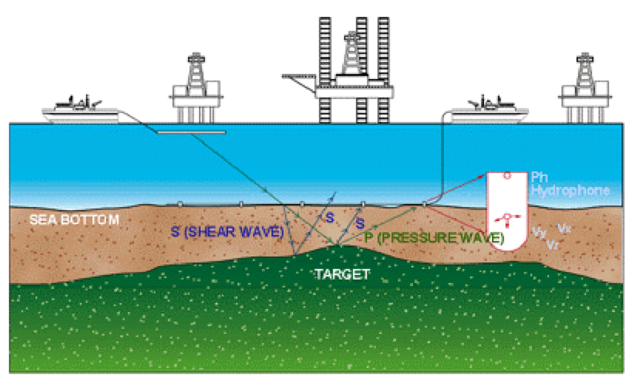

Figure 2: Pictorial of an Ocean Bottom Cable Survey where both P-Wave and S-Wave data is shown being gathered

OBC methods are very attractive when conventional acquisition methods are not feasible due to surface and subsurface obstructions or when reservoir monitoring and characterization is necessary during the life of a field. Surveys using OBC detectors often return additional bandwith, both at the low and high frequency end of the spectrum. This has high potential for improved resolution with immediate benefit to reservoir imaging and characterization.

4C (four component) - Better known as "multi-component" , refers to the number of directional sensors in a individual sensor package. Normally these sensors consist of one hydrophone, which measures the down-going compressional waves (P-Waves), and three orthgonally positioned component geophones, which measures particle movement in three directions. onevertical and two horizontal. The particle movement are converted shear waves (S-Waves).

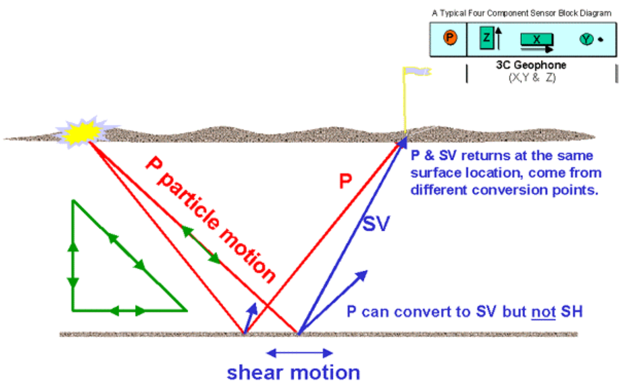

Figure 3: Diagram depicts the P-Wave and S-Wave particle motion during a conventional OBC survey

Shear wave velocities are slower than P-Wave velocities particularly in reservoirs obscured by overlaying gas clouds or plumes. In effect there is less scatter of the shear wavefield, thus the reservoir image produced is better, especially for the converted waves.

4D - Better known as "time-lapse seismic", is the process of taking a seismic snap- shot of a reservoir at various stages within it's production life cycle for monitoring reservoir behavior and characterizing reservoir properties over time.

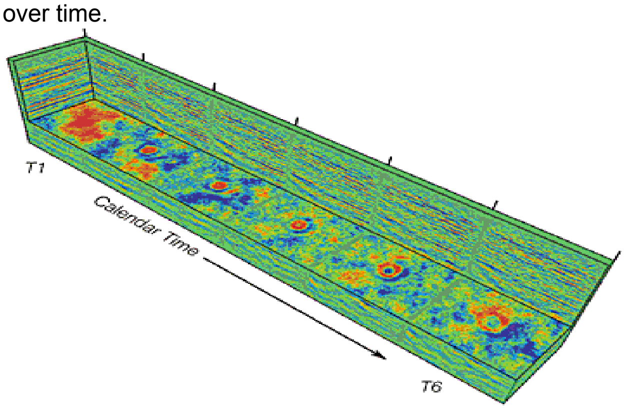

Figure 4: Time-slice amplitude map of time-lapse 3D seismic cubes. (Image courtesy of 4th Wave Imaging)

Conventional seismic processing is performed for each time-lapse survey. The amplitude attribute is then extracted from each seismic section. Subtracting the two amplitude sections from each other yields an amplitude difference plot. Monitoring fluid flow movement within the reservoir is then obtained by comparing the amplitude plots over time (See Figure 4).

Benefits of OBC 4D/4C Seismic Data

4D or time-lapse seismic surveys, which are 3D seismic surveys repeated over time, have been conducted on numerous fields worldwide over the past decade or two. The purpose of these repeated surveys are to detect changes in the reservoir's characterization and to improve the reservoir's depletion quantities and rates.

For the offshore fields, 4D seismic surveys were and are being performed primarily using surface towed hydrophone arrays. Figure 5 illustrated below is a typical field production profile, which demonstrates the utilization of the initial 3D seismic survey, and the subsequent 4D seismic surveys (which were towed hydrophone array surveys) to hopefully improve and extend reservoir production levels.

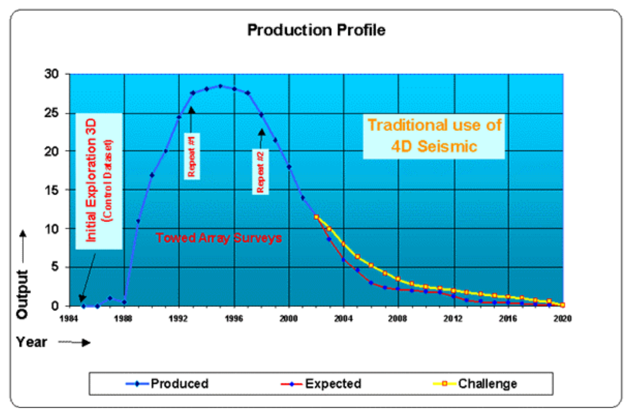

Figure 5: Production Profile displaying the potential advantages of using permanent OBC 4D/4C surveys

While the repeated tow array surveys more than likely provided the field asset team with valuable information throughout this field's life, the much needed information such as rock anisotropy, fluid movement and lithology changes that are measured using geophones, go undetected in these traditional P-Wave only datasets. Characterizing a reservoir requires the means to measure minimal changes, without the impact of externally induced noise into the data set, such as weather (winds/sea states) with subsequent changes in the signal to noise ratios, seismic source and receiver positioning, sensor coupling changes and changes in technology and methodologies. This is much more difficult to accomplish using towed array surveys rather than permanently installed seabed equipment.

To measure fluid movement and lithology changes, the converted S-Wave can only be measured using geophone sensors, which are in contact with the sea floor. This acquisition technique, commonly referred to Ocean Bottom Cable (OBC) to the exploration community, employs sensor arrays, which are laid on the sea floor. These sensor arrays are configured with four-component sensors that record the traditional P-Wave dataset and also the converted waves (P→S-Wave). Converted Waves are unaffected by gas, fluids and other medium changes making this information crucial for measuring a producing reservoir's changes over time.

Better understanding of reservoir lithology is a key driver in the utilization of OBC 4D/4C technology. Many reservoirs, especially sands overlaid by shale have poor P-wave reflectivity as shown in figure 6 below.

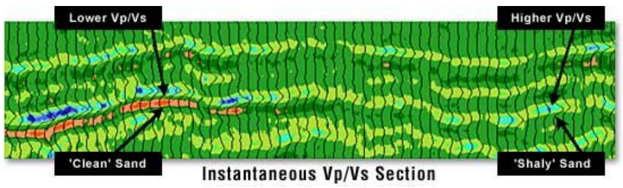

Figure 6: Instantaneous Vp/Vs section lithology prediction (Image courtesy of PGS)

Impedance contrasts for converted waves can sometimes be considerably better under these circumstances, which allows for improved reservoir imaging. The amplitude ratio of P-waves versus converted waves at the top of producing reservoirs is sensitive to saturation in some reservoirs (since saturation effects Vp non-linearly, and Vs linearly). The ability to predict lithology is one example of the potential of multi-component technology to minimize reservoir lithology uncertainty and to exploit and produce reserves faster and at lower cost.

Bright spots are widely used in fluid prediction. However, P-wave data cannot readily distinguish lithology bright spots from fluid bright spots. Since lithology rather than fluids mainly influences shear waves, the need to collect this additional information becomes increasingly important.

Sub-salt and sub-basalt imaging are notoriously difficult with P-wave data. However, the salt and basalt interfaces are good generators of converted wave data. As illustrated in Figure 7 collecting seafloor shear wave data provides a rich supply of additional data with which to image these interfaces.

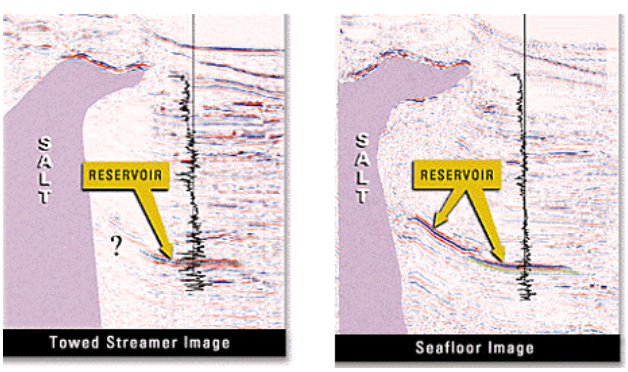

Figure 7: Sub-Salt towed streamer image compared to seafloor image (Images courtesy of PGS)

The illumination advantage combined with the multiple suppression inherent with the seafloor method are responsible for the improvement and enables further mapping of the reservoir reflector beneath the salt structure. Imaging of both the base of the salt overhang and the salt flank of the di-pair was also improved.

Muitiples often contaminate P-wave data so badly that the images are abscured. OBC technology can impact this by allowing for discrimination between upcoming and downgoing wavefields enabling attenuation of the downgoing free-surface multiples. Since shear waves do not exist in the water column, there are no associated free-surface multiples. In addition, shear waves have different velocities, thus interbed multiples occur at different times, which could allow improved reservoir imaging and interpretation.

It is much easier to understand the connection of reservoir properties to fundamental rock properties such as compressibility and rigidity, than it is to understand their connection to traditional seismic attributes, like amplitude and velocity. Differentiating the difference in rocks with the same acoustic characteristics using P-wave is nearly impossible. The polarization of the shear waves and our ability to distinguish the components of the shear wave splitting can provide better information about the reservoirs framework. Information such as stress directions in the overburden and fracture directions in the reservoir can aid in enhancing field production levels.

Benefits of Permanent Installation of OBC Systems

To date, experience with seabed time-lapse seismic is limited. Only two examples of permanent installation of OBC seafloor systems have been documented. Both projects, a 4D-2C at Foinaven, in the North Sea, and a 4D-4C project at Teal South, in the Gulf of Mexico have proven that permanent long-term installation is achievable in relatively shallow waters.

Logistically, it appears that trenching (cable burial) is necessary even where sea currents are not an issue. The disappearance and/or displacement of three separate untrenched cables at Teal South (see Ebrom et al., 1998) in almost 300 feet water depth, suggest that trawling activities are a threat to permanently deployed ocean bottom equipment. The advantage of cable trenching is that it provides greater equipment safety as well as better seafloor sensor coupling.

While seafloor detector systems remain stationary and constant throughout successive repeat surveys, improved repeatability of time-lapse datasets allows for improved imaging and enabling better well planning. Figure 8 clearly shows the improvement in data quality when permanently emplacing sensors. The acquisition footprint of successive surveys will be identical, excepting only problems of source boat access and source location uncertainty. The difference plot of the towed streamer data (top section) had more residual energy and more trace-to-trace variations than the seabed data. The difference plot of the seabed dataset (bottom section) clearly has no coherent residual energy outside the producing reservoir.

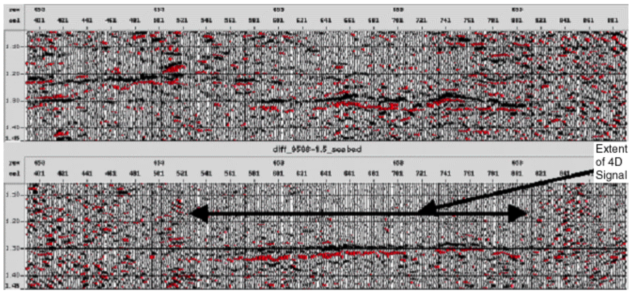

Figure 8: Foinaven 4D-2C towed streamer versus seabed difference plots. (Images courtesy of Bp and Schlumberger)

Today, the *iField* or instrumented field is much more achievable with recent advances in technology, both in the in-water equipment and recording instrumentation, but also with deployment systems and methodologies. A much more complete data set can be acquired with fixed seafloor detectors than with conventional towed-cable systems. Source and receiver distances can easily be extended to include larger offsets and a complete range of azimuths. This allows for an increase in data redundancy with consequent implications for noise attenuation, illumination and image improvement. In addition, permanently positioned sea-bottom detectors systems will allow for very fast and low-cost repeat surveys.

Safe and successfully installation methods, particularly around existing field infastructure, other obstructions and in deep harsh environments are currently been investigated. Equipment cost and reliability along with low-cost, safe deployment and accurate positioning methods are all key factors in the rapid implementation of this technology.

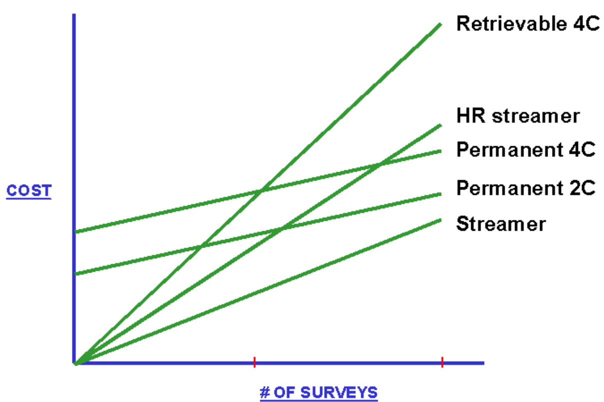

Figure 9: Estimated cost crossover points for the various acquisition methods.

One of leading questions that asset managers are pondering is how many 3D streamer surveys, or other acquisition methodology, will it take before life of field permanent 4C acquisition becomes advantageous? The graph in figure 9 shows the estimated linear relationships of cost associated with the various acquisition methods for a small shallow water field. What's important to note is that at some level in time permanent 4C acquisition becomes advantageous particularly in large deepwater producing fields where large number of repeat surveys over a long extended period of time are needed to help enhance production levels and those production levels show to be substantial.

As with other technology visions within the oil and gas industry, the basic objective of real-time asset management is to enhance a field's profitability by producing more oil or gas faster and for less cost. What is clear is that the cost of acquiring permanent 4D/4C OBC seismic data, particularly in a large deepwater field where the returns are great, when compared to drilling and production related cost, is low. What's not clear is the value associated with permanently positioned detector systems and how that relates to additional barrels of oil per day. Understanding this relationship is an ongoing struggle asset management teams are trying to figure out in order to justify spending the needed capital to implement this technology. As more and more permanent installation 4D/4C OBC projects are implemented and case studies are publicized, the value and benefits of this technology will become evident and this technology will eventually become a routine part of the initial facilities planning and development phase of a field.

Smart Fields – iFields of the Future

As so many market sectors, low-cost computing, access to satellite networks, semiconductor manufacturing, and the internet are affecting the way we do business, in seismic reservoir monitoring. Through the use of commercially available computer and communication technologies, permanent seabed arrays, or field seismic-LAN can be configured for unmanned and remote operations, whereby quality control attributes and seismic data can be transmitted back to the field operations headquarters in near real-time. Providing the field asset team with this type of information will transform strategic fields into *Smart fields*.

Operators are now recognizing the need and value of *Smart Fields* both through ultilzation of sensors in the wellbore and beyond the the wellbore using permanently deployed OBC detector systems. Tying downhole and seabed information together with reservoir rock property information can provide some potential real-time benefits during reservoir monitoring. Some of the benefits include monitoring of flood conformance and water front movement, identification of fault seal/conductivity, imaging of flow anisotropy associated with fracture dominated reservoirs, targeting of new injector/producer well sites, construction and validation of predictive reservoir models, and interpretation and calibration of time-lapse seismic.

The goal is to provide the reservoir engineer real-time snapshots of reservoir images to aid in making fast and accurate decisions based on real evidence. As illustrated in figure 10, data collected from permanently positioned4D/4C OBC sea-bottom detectors systems would travel directly to the field's platform via fiber-optic connection. The data can be viewed real-time from a remote location for quality control and then be transmitted in real-time to remote office locations where the data can be processed and interpreted for further analysis. Results would quickly be transmitted back to reservoir engineers on the platform so crucial decisions can be made.

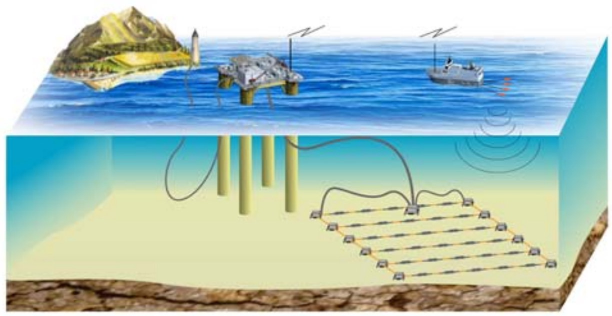

Figure 10: Pictorial of a "Smart Field"

Visualization is another key element in *Smart Fields*. Automated data collection, analysis, and filtering can eliminate or significantly reduce many of the steps in a typical operation surveillance workflow. Visualization can shorten the remaining steps because it can speed the process of analysis and understanding, enabling sound decisions and operating actions.

Smart Fields provide a consolidated view of asset economics, uncertainties, and risk associated with real reservoir models. This view and all associated information and asset knowledge are available through web-based platforms to an extended asset team. Such a process compresses the decision making cycle for prospect generation, field development planning, and well design and drilling programs. The extended asset team can rapidly respond to changes in field performance. This will produce more oil or gas faster and for less cost.

Conclusions

Field asset managers are driven to finding hydrocarbons and exploiting them as efficiently and successfully as possible. Unfortunately they are not always aware or familiar with the technology available to achieve their goals. If they can enhance the amount of oil extracted from a reservoir they can meet the goals of their Enhance Oil Recovery (EOR) program. In addition, if new drilling prospects can be revealed then the risk and cost associated with further development of the field can also be reduced.

The "oilfield of the future" will be operated as a single industrial process, optimizing the oil and gas production from the reservoir through a combination of wells and subsea and surface facilities. Life of field seismic data from permanent 4D/4C OBC systems will play a key role in enhancing predicted field production levels. With better understanding of the reservoir from the use of multi-component technology, Enhanced Oil Recovery (EOR) and infill drilling programs can be optimized. This technology can also play a key role in the exploration phase by helping to identify prospects that are fully or partly stratigraphic plays.

With the improvement of reservoir images, the operator will be able to optimize their infill drilling program, and accurately plot well trajectories through the overburden. These new technologies impact operations in several ways, including data quality, turnaround time, safety, logistics, and economics. With better interpretation of permenent deployed 4D/4C OBC surveys, oil companies gain an improved understanding of reservoir dynamics, and thereby performance of existing wells. As a result, uncertainty in determining potential infill well targets can be reduced and prediction in field production levels enhanced.

4D/4C OBC data and technology will continue to improve in their clarity and usefulness. New more advanced ocean bottom euipment promises higher vector fidelity and reliability. Deployment, burial and positioning permanent deepwater installation methods and technology are improving as well. Acquiring permanent 4D/4C OBC seismic data requires initial extra expenditure of captial, but ultimately provides additional reservoir information and higher quality seismic images. Oil companies need to invest in this technology now so it will be mature and ready for future applications.

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