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Seismic Surveillance in the Field of the Future

G. Watts, BP; O. Barkved, BP Norge; and J. Dickens, BP

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Abstract

Seismic 4D data has traditionally been acquired using repeat towed streamer surveys every 2-5 years. This is used to track fluid and pressure and has proved highly effective for influencing infill well locations and calibrating the reservoir simulator. Over the last 10 years the technology has evolved and is now relatively mature with several well documented case-studies demonstrating value of 3-5% reserves increase in post-plateau oil fields with a strong fluid response (1).

However, the long elapsed time between surveys limits its value in Reservoir Management where we would like to use time-lapse seismic to monitor the pressure field and the fluid flood fronts and therefore make decisions which maximise the sweep conformance and achieve ‘technical limits’ rate and reserves.

To do this, seismic data needs to be acquired at a frequency consistent with the timescale on which the decisions are made. Thus monitoring gas movement to minimise gas production in oil field may require seismic surveys every 3-6 months whilst providing data useful for optimising Base Well Management decisions on reperforations, restimulations, water shut-off and injection rates may benefit from seismic data every few months or even weeks.

As a first stage towards active management using “seismic surveillance”, and specifically to aid in waterflood management, BP has installed a permanent seismic array over 70% of the Valhall field. The array cost $45million but the results have been technically spectacular (2, 3, 4). Learnings from this experience are still evolving but already cover aspects of reservoir management, infill drilling, Base Well Management, flow performance prediction and surveillance including the use of “Seismic PLTs” (2).

Following on from this success, BP is looking at the next wave of field applications as an integrated part of its FIELD OF THE FUTURE programme (5). Plans are now at an advanced stage to take forward two new projects in 2006 and several more are being discussed for application later this decade.

1. Seismic Surveillance in the FIELD OF THE FUTURE

1.1. Concepts of the FIELD OF THE FUTURE

Rapid changes in digital technology are revolutionising the ways in which we acquire and process data and are improving the quality and efficiency of decision making. Through the application of these digital technologies, both new and existing, BP aspires to operate its assets at the technical limit of efficiency, recovery and cost.

To make this aspiration a reality, BP has implemented a programme called FIELD OF THE FUTURE (1). The scope of this programme covers development and deployment of technology and business process solutions to most aspects of oil and gasfield operations - from reservoir to export, in both mature and new fields, onshore as well as offshore.

1.2. Remote Performance Management and Optimisation

Remote Performance Management includes technologies for well/reservoir and facilities monitoring and is currently an area of focus in BP (6, 7). A large part of this activity is to do with developing and applying new tools for managing and post processing real time data. Optimisation needs to be carried out in a variety of different technical areas and at many different timescales. In the subsurface, it is about developing improved methods for maximising production and reserves.

The elements required for an effective decision can be described by the OODA cycle. Here four components are identified: Observation, Orientation, Decision and Action.

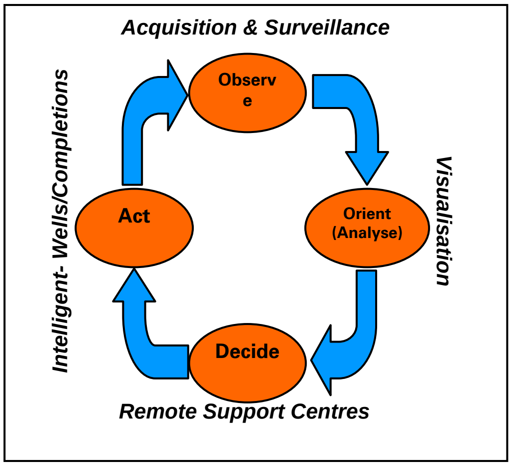

Figure 1: OODA Cycle

In the subsurface, the observation of reservoir information (pressure, temperature, saturation) is carried out through a number of surveillance technologies based both at the well and away from the well including seismic surveillance. Orientation refers to the analysis of this information which may be carried out interactively and collaboratively in a specialist visualisation environment (e.g. Highly interactive Visualisation Environment or "HIVE"). Decisions are taken on the basis of this information and these are implemented (or acted on) through a host of activities including infill drilling programs, Base Well Management activities, production/injection rate optimisation and downhole flow control through the use of intelligent well activity (5).

2. Seismic Surveillance

2.1. What is Seismic Surveillance

Seismic Surveillance is the use of time-lapse seismic data to monitor dynamic changes in the subsurface. The information usually sought is pressure and saturation (Sw, So and Sg) but the seismic often responds to other properties including temperature, stress, porosity and sometimes mineralogy as well (2,4).

Time-lapse seismic is the only widespread source of surveillance information away from well which is why it is so useful. Although the vertical resolution is poorer than for log data, the spatial resolution is often as good as 25m which is much better than in most simulator models. Experience shows that a map-based approach to understanding reservoir flow performance is surprisingly effective despite the lack of vertical resolution. Frequently a single map summarising information over the whole reservoir interval is surprisingly effective in tracking meaningful reservoir changes and brings important insights into the dynamic behavious of the overall system.

2.2. Seismic Surveillance Technologies

There are a variety of seismic technologies available for seismic surveillance. Offshore this includes towed streamer 4D, repeat 4D/4C, repeat node surveys, permanently entrenched cable systems and inwell seismic.

Towed Streamer 4D

Traditionally, 4D seismic surveys are acquired offshore by repeating 3D towed streamer surveys every 2-5 years. The vessel trails an array of sensors behind it to capture sound waves reflected back from the various rock formations. By carefully repeating these measurements periodically, the dynamic changes in the reservoir can be measured.

Towed streamer surveys are usually fit for purpose so long as the dynamic changes have a large seismic signal, narrow azimuth single-component suffices and surveys are required infrequently. Where these assumptions break down, other technologies should be considered or the value of the data will be affected.

4D-4C repeat OBS

Repeat OBS surveys (cables or nodes) may be practical only where infrequent surveys are required. Cable based surveys may be repeated even if retrenching is required (as demonstrated by a survey acquired by Multiwave Geophysical in Vorwata, Indonesia for BP in 2005 where ocean bottom were trenched and recovered up to 12 times). Nodes are particularly suited to deep water where cables have yet to be tested or areas with a large amount of subsea equipment and anchoring.

Permanent Seismic Array

With permanent seabed systems, the seismic sensors are laid in shallow trenches on the sea bed and connected back to the platform via cables. Generally they provide better static images of the reservoir because of the higher number of stacked measurements and wide-azimuth geometry. They also provide better dynamic picture of the reservoir because the repeatability is better giving better sensitivity to small changes in pressure and saturation in the reservoir (7, 2, 3).

A summary of the advantages of a permanent seismic array are given below:

- A step change in repeatable seismic data quality giving 2-3 times better than the best towed streamer data to detect smaller dynamic changes
- A breakthrough in turnaround times - acquisition "on demand" and processing time to depth migrated p-wave data reduced to less than a week if required (8)
- Improved static images – multi-azimuth for better imaging in complex areas and multi-component for seeing through gas clouds.
- More flexible shooting with a small source-only boat so less interference with other oilfield activities
- Ability to acquire data 'On Demand' with time interval between surveys of less than 2 months. This enable the

data to impact Reservoir Management and Base Well Management decisions are well as infill drilling.
- Cheaper, faster surveys allowing for more cost effective ‘Life-of-Field’ solutions for seismic surveillance.

Inwell Seismic

Inwell seismic systems involve clamping a string of geophones in the wellbore. The image generated is available in the vicinity of the well, and although the fold of the data is generally low, there are several distinct advantages to this type of geometry. First, rays only have to penetrate the overburden once so images are usually higher frequency; second, the separation of upgoing and downgoing waves means the multiples can be reduced; and third, the latest interferometric techniques can be used to generate “virtual sources” at the receiver positions which have led to some spectacular imaging improvements (9). In addition, by placing the receives close to the reservoir, passive listening for micro-seismic events is possible.

It is likely that inwell seismic will play an important part in seismic surveillance both for calibration of the other field-wide methods but also in complex areas where surface based techniques are not suitable such as sub-salt and on land.

2.3. Valhall Permanent Seismic Array

BP installed the first field-wide permanent seabed seismic array in the Valhall Field in 2003 enabling reservoir performance to be monitored through Seismic Surveillance (4D seismic) on demand.

The permanent seismic array (LoFS) at Valhall consists of just over 120km cable with 25000 4C geophone-hydrophone sensors installed every 50m. The lines are laid about 300m apart and cover over 45km2 which represents about 70% of the field (10, 11). The array was installed in October 2003 and by the end of 2005 six surveys had been acquired over the whole field with an average frequency on one every 5 months.

Shooting was carried out with a specially converted supply vessel with a dedicated arigun array. Data is received into an automated recording system on the platform and sent via an optical fibre cable to the cable manufacturer (for QC), the processing contractor (PGS) and BP’s offices in Stavanger and Houston. Some basic QC is also available on the boat. Surveys take about 6 weeks to complete in average weather conditions.

A primary objective of the LoFS array was to better manage the waterflood through better placement of injector and producer wells and by observing the flood fronts control the breakthrough of water in adjacent producers. The combination of improved sensitivity due to fixed receivers positions and frequent time-lapse seismic surveys provides a robust scheme for imaging of the 4Dseismic response.

Figure 2 shows timeshift differences between surveys 1 and 2 (acquired 3-4 months apart) and surveys 1 and 3 (acquired 6-7 months apart). The growth of the pressure halo around the production well can be clearly seen (2, 7).

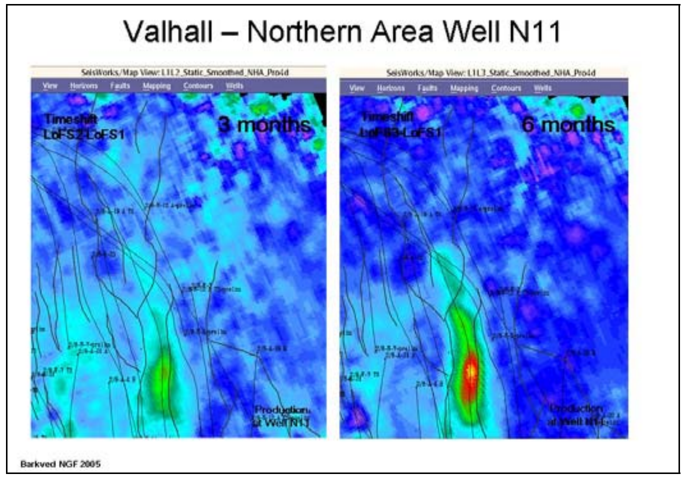

Figure 2: Timeshift maps from Valhall

3. The Future of Seismic Surveillance

3.1 Getting Serious about Seismic Surveillance

Seismic surveillance is a “life-of-Field” activity that needs to be planned as a piece of core infrastructure for implementation before production start-up. Seismic surveillance needs to be a standardised, highly repeatable, semi-continuous operation that will carry on during most of the field life. It is certainly not a series of one-off activities (or ‘projects’) such as the seismic industry is used to delivering. For this reason, it is expected that there will have to be significant changes to the services provided by the seismic industry in order to supply this new demand.

3.2 Seismic on Demand ?

By “Seismic on Demand”, we mean that seismic surveillance should be available to inform a variety of asset decisions as they arise without the need for a huge planning and approvals process which currently means most surveys have to be planned 6-18 months in advance.

As the interval between surveys reduces and the flexibility of where the data is acquired increases, so Seismic on Demand also draws into question the concept of a “survey” itself. For example, a ‘survey’ might be focused around a particular well where water injection is starting up or a particular sector where the impact of faults on fluid flow is not well understood. Spare shooting may also be appropriate in certain circumstances depending on the quality of the data required. For example the crest may be acquired with higher density data than the flanks. What is important is that each shot is date stamped. How these shots are linked together into understandable time-lapse information becomes a question of processing data sampled irregularly in space and in real-time.

3.3 Seismic Surveillance during the Life of the Field (LoF)

Any asset planning a "Life-of-Field" seismic surveillance program needs to consider when the key decisions are being taken and therefore when new seismic data should be acquired. Given BP's experience in this area, the following general guidelines are recommended for use in oil fields:

1. Baseline Survey. There must be a baseline survey before first production. This is by far the most valuable survey. Frequently problems are caused because a baseline is not acquired and so any time-lapse information must be related back to a post-production period when reservoir conditions are not so well known. ***The strong recommendation is that a survey must be acquired before production starts.***

2. Very Early Production. This is also a critical period in the field life. Much can be done to calibrate the simulator with dynamic information that is not available from wells particularly with regards the overall connectivity of the system. During this period the initial pressure depletion diffuses out into the reservoir. Careful (and frequent) monitoring of this initial drawdown could give a basic connectivity map of the whole reservoir and could ultimately lead to local estimates of effective permeability. ***Recommend surveys every 3 months in this initial period***

3. Early Production. During this time, the impact of the aquifer may be felt which is often one of the key dynamic uncertainties. If the development is phased, then early information on the aquifer strength may significantly influence decisions in the later phases. Early in production, gas management can also be an issue. Gas is sometimes stored in the reservoir until an export facility has been built and this can lead to gas handling constraints. Monitoring gas cap development and storage capacity can be critical at this stage. ***Recommend surveys every 3 months to monitor mobile gas in critical cases, otherwise every 6-12 months should be sufficient.***

4. Mid production. During this time general reservoir management starts to become very important. This includes monitoring the different fluid phases in the reservoir and also Base Well Management decisions on failing wells. Also, during the field life there will probably be some key strategic decisions taken such as when to start water injection, infill drilling, gas compression or gas blow-down for example. Getting the right timing for these decisions is very valuable. A confident prediction of production capacity means reducing spare capacity and delaying costly projects. ***Recommend surveys every 2-3 years for the strategic decisions but every 6-12 months for general reservoir management.***

5. Post Plateau. Infill drilling campaigns will typically begin sometime around the end of plateau production as spare capacity from the initial development wells begins to reduce. Effective infill drilling is essential to keeping the production profile up. Seismic surveillance can make a real positive difference to the timing of infill drilling campaigns, the risking and optimising of individual wells and in contingency planning. The data is thus useful both for assuring the base plan but also realising the upside. ***Recommend surveys every 6-12 months before and during infill drilling campaigns.***

6. Late Field Life. During late field life the production period may be extended by drilling the occasional infill well. Often smaller and smaller pools of hydrocarbons are targeted and the cost of the surveillance is difficult to justify. If a permanent seabed array is in place, the capital costs will have all been written off and the processing sequences defined so the incremental cost of a survey is much reduced. This means that targets may be justified later in field life and the field can be extended later. ***Recommend surveys every 2-3 years at the end of field life until they can no longer be justified.***

3.4 Economics of LoF Seismic Surveillance

Oilfields in the 100-500mmboe category generally last on production for 15-25 years. If the surveys are spaced traditionally every 2-3 years there will be 6-12 surveys during field life. For the higher frequencies recommended, this number expands to around 25-50.

For a nominal field of size about 25 km2 the field-of-life economics suggest that, even for surreys every 2-3 years a permanently installed array is justified and more cost effective to a towed streamer solution. This is particularly apparent given the current high price for towed streamer surveys. For the higher survey frequencies recommended above, a permanent installation becomes the only feasible solution for Life-of-Field Seismic Surveillance.

4.5 Systematic, regional deployment

As seismic surveillance develops into a regular, semi-continuous operation so it lends itself to sharing of resources between several fields. Thus, rather than considering fields separately, the equipment for seismic surveillance (boats, operational staff, logistics etc.) may be shared between fields of a common operator or even shared between several operators in a geographic area bringing down the costs of each survey.

To do this, a philosophy of standardisation is required which is totally different from today's seismic data where each survey is tailor made and uses a different acquisition design. In practice, there is little in the acquisition system that could not be standardised from the receiver cables and recording system to the vessels used for installation and acquisition. Savings are made because continuous operations can be refined and polished as experience grows. In addition all the logistical operation from supply of spares, to maintenance of equipment can be optimised. What is required is long term planning.

Of particular mention is the source vessel. For the Valhall surveys, a supply vessel was kitted out with a dedicated omni-directional Bolt APG source array with 2000 psi / 2000 cu. in.

capacity (10, 11). After the initial 6 surveys, a dedicated source-only vessel will be contracted suitable for surveys over the Valhall and Clair fields; and possibly for other fields not operated by BP in the North Sea.

The acquisition geometry should also be standardised as far as possible. There is little excuse to make large variations in orientation or receiver/source density unless the fields are at very different depths or have very specific imaging or structural issues. Use of cables with a standard receiver spacing, say 50m, and a crossline spacing of 300-500m will suffice most fields. Whilst, the wide-azimuth nature of the acquisition surveying means there is less requirement for a preferential acquisition direction making possible further standardisation.

4. Conclusions

Seismic Surveillance is a valuable technique for planning and optimising Reservoir Monitoring, Base Well Management, Infill drilling, static reservoir description and for calibrating performance prediction and forecasting.

A variety of technologies are available for Seismic Surveillance but, compared to the other surface-based technologies, arrays of permanent trenched 4C receivers give the highest quality data, fastest processing, most flexible acquisition and the lowest cost data if multiple surveys are acquired during the life of the field. Inwell seismic also has a bright future for specialist high-frequency applications, in complex imaging areas (e.g. sub-salt), for passive monitoring and possibly for Seismic Surveillance on land.

Standardised, regional solutions will provide the most cost effective and valuable means of acquiring Seismic Surveillance data at a frequency that matches decisions being made on the field. This involves treating seismic surveying as a long-term operation not a series of one-off projects; and this will require a fundamental change in the way the seismic contracting industry is structured.

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