

# **Ex. PGS 1033**

## F-01 THE USE OF 4D SEISMIC IN RESERVOIR MANAGEMENT

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### Summary

In mid 1999, BP acquired a 3-D survey over the West of Shetland area specifically for time-lapse interpretation of the reservoir dynamic behavior over the component fields. This was described at the EAGE meeting last year<sup>1</sup>. This formed a turning point in BP's use of 4-D from experimentation to commercial use. The results were very useful in field management and well planning. Before that, it had acquired a number of repeat 3-D seismic surveys which in addition to their prime objective, were found to be useful for time lapse interpretation. Since then, BP has in 2000 acquired a further five '4-D' datasets, covering nine producing fields. These have all been undertaken with the express purpose of obtaining data that will allow a tighter control of reservoir management, and thereby enhance commercial value.

In all cases a major objective has been to influence infill well locations. Specific problems differ from field to field. In the West of Shetland area, the 4-D is a powerful tool in assessing hydraulic communication. Forties is using it to identify unswept oil and to improve reservoir characterisation for proposed EOR. In Montrose, the data will help determine remaining options for field development. Accurate determination of the movement of the gas-oil contact is important in Harding, and in Marnock the data will be used to improve the reservoir description.

### Context

The increase in the use of 4-D seismic within BP has reflected that in the industry (Figure xx). Although the 1999 West of Shetland survey was the first acquired by BP for 'commercial' rather than experimental purposes, repeat survey data collected for other reasons had been used for time lapse interpretation in Magnus, Gulfaks and Forties.

Prior to conducting a survey, a number of important questions must be answered:

- Are the rock and fluid properties suitable?
- Is the seismic data quality adequate?
- How will the reservoir characteristics affect interpretation?
- Has there been sufficient disturbance of the initial conditions as a result of production?
- Will the seismic answer the reservoir management questions in a useful timescale?
- What will its value be, and the risks involved?

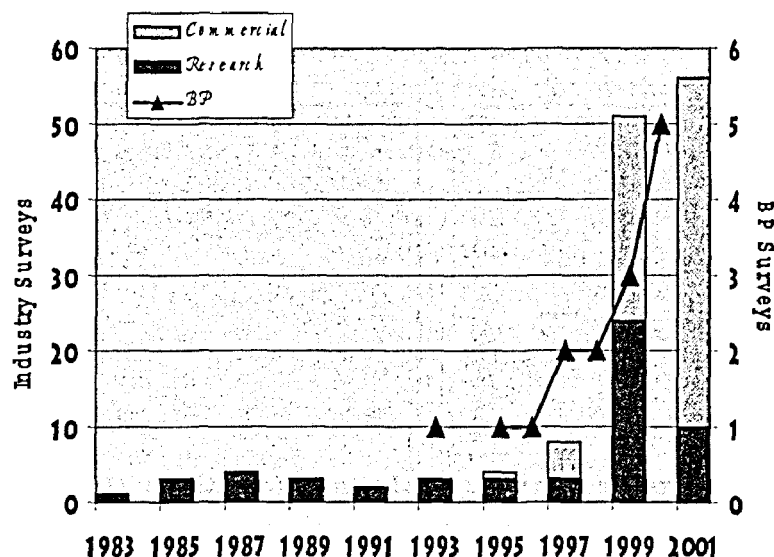


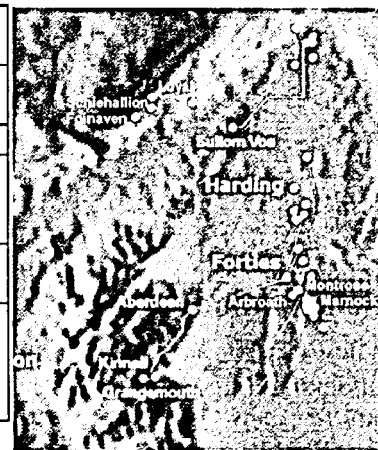
Figure 1: Growth in Use of 4-D in the North Sea.  
(Industry data supplied by JNOC)

The candidate areas for 4-D acquisition in 2000 were selected on this basis, and are summarized in the table below.

**Table 1: BP 4-D Seismic Surveys Acquired in 2000.**

	<i>Area (km<sup>2</sup>)</i>	<i>Partnership</i>	<i>Question?</i>
Forties	210	BP*, Shell, Esso, Agip (ENI), Noble Affiliates Inc.	Detection of unswept oil for infill well placement.
Harding	65	BP*, Repsol, Ranger	Oil-water contact movement.
Arbroath Arkwright Montrose	440	BP*, Enterprise Oil, Amerada Hess	Identification of remaining development options.
Marnock	180	BP*, Shell, Esso, Agip	Reservoir description; locating unaccessed areas.
Foinaven Loyal Schiehallion	390	BP*, Marathon BP*, Shell BP*, Shell, Murphy, Statoil, Amerada Hess, OMV	Optimisation of production strategy and drilling opportunities.

Operator



## Case Studies

### Forties

Forties infill drilling commenced in 1992. By 1995 it was apparent that the process of identifying infill targets from simulation models would fail to deliver economic targets beyond 1997 due to a lack of resolution in these models. A second 3D survey was shot in 1996 to complement the first Forties 3-D volume acquired in 1988, thirteen years after the start of production. Since 1997 Forties infill targeting has relied on images of lithology, fluid, and fluid saturation change derived from these seismic volumes. This has allowed those areas of the field with significant pools of remaining oil to be identified.

The application of this technology has allowed well targets to be ranked, and as a consequence, there has been a progressive improvement in the average size of target accessed and initial well rate achieved. It is anticipated that the 2000 data will provide an up to date fluid image and improved reservoir characterisation. Together with continuous improvements in processing technology this will enable infill drilling to be sustained until at least 2002, and will support planning of the potential EOR project.

### Foinaven

Preliminary examination of the results of the 2000 4D seismic data over Foinaven has shown no major surprises. It has strengthened confidence in reservoir management strategy, and emphasized the importance of water injection.

In common with Schiehallion and Loyal, amplitude brightening is indicative of increasing gas saturation or oil pressure (with no change in phase); dimming is indicative of increasing water saturation or reducing gas saturation. In the example shown, the overwhelming observation is a brightening between 1993 and 1999 and a dimming between 1999 and 2000. Although subtle details remain to be worked, this supports the interpretation that the water injection campaign has been effective in raising reservoir pressure. This is demonstrated by the drop in production GOR of most of the Lower T34 wells. Other sands in the field demonstrate the same phenomenon, but the uppermost sand, which was first produced after the 1999 survey had been acquired, shows a significant brightening, attributable to pressure reduction below bubble point and gas evolution. This is similar to the brightening seen in the underlying sands evident in 1999. The reduction of gas production is significant in reservoir management, as reservoir energy is conserved, and production is at less risk of restriction by facility constraints.



Figure 2: Foinaven Example.

## Schiehallion

The 2000 4-D largely confirmed the understanding of the field that had developed during 2000. This understanding and the increasing trust in the simulation model is rooted in the history matching of both production data, and well test results together with the 1999 4D interpretation. Strong qualitative correlations between the 4D amplitude data and simulator pressure plots indicate that an increased level of confidence in the two independent 'measures' of reservoir pressure is justified.

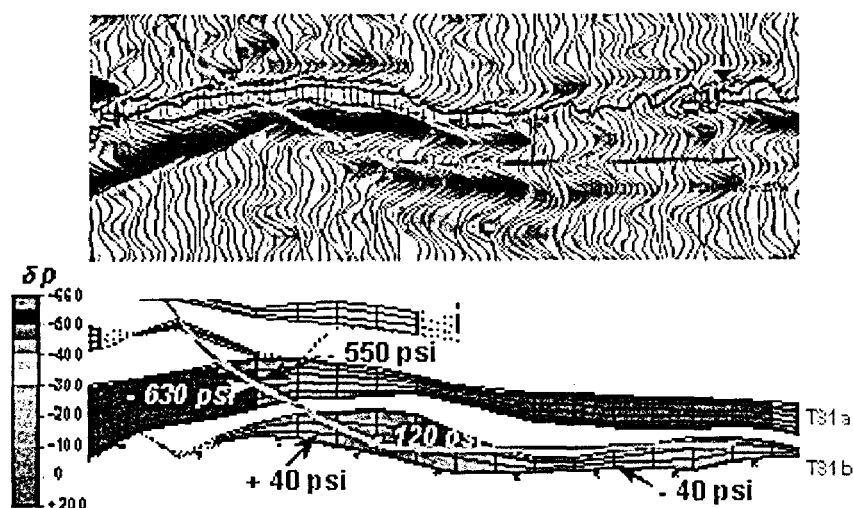


Figure 3: Schiehallion Example.

Initial processing of the 2000 data was carried out on board in a little under three weeks, so that data would be available for planning the 3Q/4Q drilling programme. Comprising two wells, this was designed to drain a significant unswept pool in the centre of the

field in a deeper sand, which from the 1999 appeared to be largely unaffected by existing wells. This was the lower sand shown in ().

The simulator predicted that the sand would show slight depletion in the east, with weak support from the west. When drilled the sand section was depleted by about 120 psi. The overlying sand, already accessed by a nearby producer has strong indications of seismic brightening, interpreted to be due to evolved gas as a result of production. The simulator predicted depletion of around 550 psi, MDT measurement showed this to be around 630 psi. The pressure predictions were good, partly as a result of using the 4-D data in matching the simulator. A downdip injector has since been drilled to support both sands in preference to an additional producer, which was the original plan. This decision was made as a direct result of the 4-D information.

## Loyal

The Loyal field is located in the West of Shetland area adjacent to Foinaven and Schiehallion. It is currently being developed as part of the Schiehallion project. Oil production started in 1998 and to date, four out of the six planned development wells have been drilled. Since start-up, two 3-D seismic surveys have been acquired over the field with the aims of optimizing the remaining wells and improving production forecasts. The time-lapse seismic data shows a strong response to pressure reduction around producing wells. This is because the bubble point pressure of the oil is close to initial reservoir pressure. As a result, gas evolves and its presence increases seismic reflectivity. In the longer term, seismic images of water movement are likely to have a bigger impact on reservoir management. This places bigger demands on seismic quality, attribute analysis and interpretation. However, having multiple repeat

surveys goes a long way to help separate signal from noise and so aids the interpretation effort. Current work programmes are focused on this area and are revealing some very interesting images.

### Harding

Harding field is situated on the western flank of the Crawford ridge. The main development consists two heavy oil pools, in massive homogeneous sandstones of the Eocene Balder formation with 35% porosity and very high permeability, in excess of 10 Darcies.

There is a free gas cap in both pools with a clear GOC seen on seismic as a discrete event in Harding Central and as amplitude changes on top reservoir in Harding South. There are ten horizontal producers (seven in Central and three in South) located 75 ft below the GOC to minimize gas coning. Waterflood reservoir management strategy has been to maintain reservoir pressure, although pressure has in fact dropped by about 70 psi since production started in 1996.

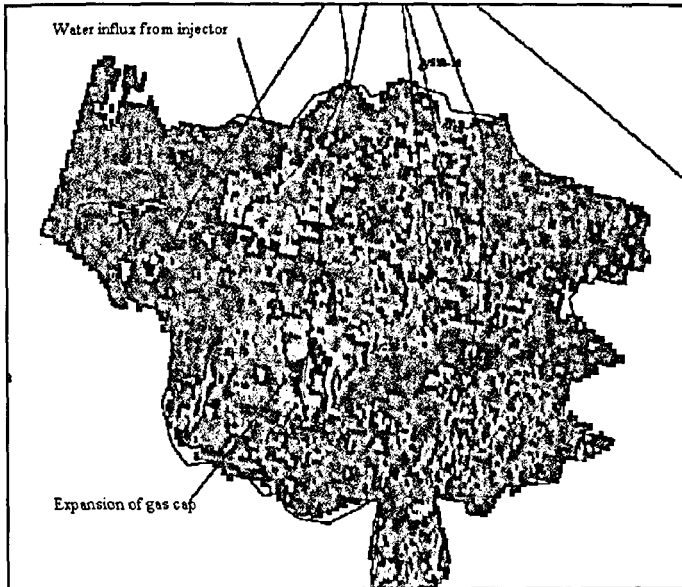


Figure 4: South Harding Top Reservoir amplitude Difference 1990 - 2000

In response to production and water injection, models predict that the GOC has tilted. This could be as much as 80ft down in the East and 50ft up in the West. Multilateral infill wells are planned to target the attic oil between the existing wells and the GOC. As these will be drilled closer to the GOC than the earlier wells, the changes in the location of the GOC need to be mapped over the whole field. To this end a repeat of the pre-production 3D seismic survey was carried out in September 2000 and is currently being processed in parallel with the pre-production survey acquired in 1990. A fast track dataset has been produced, and results from this have qualitatively confirmed both the gas movements predicted by the reservoir model and also the movement of injected water.

### 'MonArb'

The Montrose and Arbroath fields together with subsea tieback Arkwright are located south of Forties and in an equivalent age Paleocene reservoir. The significant rock properties and predicted 4D response is expected to be comparable across these three fields and similar to the pre-existing Forties seismic reservoir survey. This survey successfully reduced the risk on new well targets.

Field production commenced on Montrose in 1976 and on Arbroath in 1990, whilst the Arkwright field was tied in during 1996. Development drilling is currently taking place on Arbroath.

The baseline 'Monarb' 3D survey was acquired in 1993 and the 475 km<sup>2</sup> 4D survey was acquired during the summer of 2000. Time lapse processing of both surveys is currently underway and data delivery is expected in March 2001. Interpretation will focus on understanding sweep and identifying the remaining infill and short range sidetrack options.

### Marnock

The Marnock field is part of a development which consists of seven oil and gas fields. It is a gas condensate field with approximately 1TCF gas and 110MMstb condensate in place in a combined stratigraphic/ structural trap. Triassic fluvial sandstones form the reservoir and have porosities of 18 – 21% and permeabilities of 0.1 – 2000mD. Initial reservoir pressure was close to 9000 psi.

Rock property modelling on Marnock shows that observed pressure changes in wells, from 9000 – 5000 psi, results in large acoustic impedance (AI) changes, which could be detectable using 4D methods. Fluid saturation changes give rise to small AI changes and may not be observable.

Production data acquired since start-up in 1998, suggests that the field is more compartmentalized than originally thought. Detection of pressure changes may allow un-drained compartments to be identified, thus optimising the location of any future producers. Successful results from 4-D may also improve the prediction of drilling hazards. Finally, as the field is at an early stage of production, interpretation of the 4D seismic data can improve understanding of reservoir behaviour and thereby impact reservoir management.

The baseline seismic dataset is provided by a 3D survey acquired in 1986, while a survey acquired in 2000 by Shell, operator of the neighbouring block, provides the second dataset. Differences in acquisition parameters between the two surveys, most notably the shooting direction, will present a number of processing challenges.

### ***Conclusions***

4-D has become an important tool in reservoir interpretation and management in BP. Available results have been put to immediate use in solving problems of dynamic performance, and in optimization of the design and location of infill wells in a number of fields. Processing and interpretation of the datasets acquired in 2000 is not yet complete, but initial results obtained from fast track processing are already providing useful results, and the remainder of the results will be obtained in the next few months. Further surveys are planned for 2001.

### **Acknowledgement**

The authors thank BP and its coventurers for permission to publish this abstract. The views expressed are the opinions of the authors and do not necessarily represent the official position of BP or any of its coventurers.

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<sup>1</sup> Parr, R S and Marsh, M. Development of 4-D Reservoir Management, West of Shetland. World Oil, September 2000, pp39 - 4