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Time-lapse seismic analysis of the North Sea Fulmar Field

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Summary

Time-lapse seismic analysis has been applied to two 3-D seismic surveys acquired over the Central North Sea Fulmar Field -- a pre-production survey shot in 1977, reprocessed in 1987, and a 1992 survey. The Upper Jurassic reservoirs in the field have been under production since 1982. Water is the main drive mechanism, supported by flank injection. Although the field is currently at over 80% water cut, there are infill opportunities. Petrophysical analyses for Fulmar indicate that water replacing oil will result in an increase in seismic impedance. In addition, a pressure decline of about 1000 psi during the time between the two seismic surveys will result in a further impedance increase. These impedance changes are observed between the two seismic surveys. In order to overcome inherent differences in the seismic data due to acquisition and processing differences, the data are equalized and then inverted to obtain impedance which is then averaged between the top of the reservoir and the position of the original oil-water contact. Differences in averaged impedance between the 1977 and 1992 surveys clearly show the effects of water influx and pressure decline. The changes observed in the seismic data are overall consistent with predictions obtained from a full-field, history-matched flow simulation. Differences in details may suggest areas of bypassed oil. However, data quality is not sufficient to serve as the sole basis for drilling decisions.

Introduction

In the later phases of a field's life, reservoir surveillance is a key to meeting goals of reduced operating costs and maximized recovery. Differences between actual and predicted performance are typically used to update the geological model of the reservoir and to revise the depletion strategy. The changes in reservoir fluid saturation, pressure, and temperature that occur during production also induce changes in the reservoir acoustic properties of rocks that may be detected by seismic methods under favorable conditions.

The key to seismic surveillance is the concept of differential imaging using time-lapse measurements. While one seismic image of a reservoir may not show any obvious production-related effects, differences in repeated surveys may be able to detect even subtle changes in reservoir properties. Acquisition of a seismic survey before production or intervention establishes the baseline conditions of the reservoir. Subsequent monitor surveys are differenced from the base survey. The result is a seismic difference volume which, when integrated with reservoir characterization and flow simulation, may be used to track the movement of fluid in a reservoir between well control.

However, the difference between two seismic surveys is not only sensitive to changes in reservoir rock properties but is also sensitive to differences in acquisition and processing, and errors in navigation. As a result, the repeatability of seismic data is a key issue. For legacy seismic data, differencing the horizon-keyed average of attributes such as impedance is more robust in the presence of noise and data artifacts.

The Fulmar Field

The Fulmar Field lies in the Central North Sea approximately 270 km southeast of Aberdeen. The field was discovered in 1975 and is between 9900 and 11000 feet TVSS. It consists of an eroded triangular anticline (Figure 1) with a relatively small area1 extent. Oil is found in two Upper Jurrasic reservoirs, the shallow marine sandstones of the Fulmar Formation, containing over 90% of the reserves, and the overlying deep-marine turbidite Ribble sand. The Fulmar formation is as thick as 1200 feet with an original oil column greater than 900 feet. The sands are well sorted and fine-to-medium grained with excellent reservoir properties. The average porosity is 23.4% and permeabilities range from 500 to 4000 mD. The Ribble has porosities of 30% and permeabilities from 1000 to 4000 mD. Field OOIP volume is roughly 853 MBO (40 degree API and 614 scf/stb GOR).

Water is the main drive mechanism but limited acquifer support has required downflank water injection in both reservoirs. Produced gas has been injected at the reservoir's crest forming a secondary gas cap. Development has taken place from a six-slot subsea template installed in 1978 and a thirty-six slot platform installed in 1980. To date, 35 wells have been drilled consisting of twenty oil producers, fourteen water injectors, and one gas injector. Production at Fulmar plateaued at 165 KBD in 1983 and came off plateau in 1990. At the time of the 1992 seismic survey acquisition, production was 104 KBD with a 30%

water cut. Currently the water cut is over 90 %. The oil-water column has decreased from 900 feet to less than 100 feet. Potential infill opportunities at Fulmar have motivated the time-lapse seismic study.

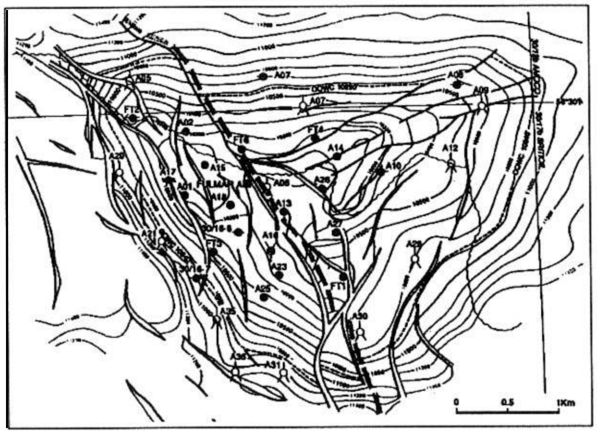

Figure 1. Fulmar Field top reservoir structure map.

Seismic Data

Two 3-D seismic surveys have been acquired over Fulmar. The I977 pre-production survey was shot using a single 48 channel analog cable with a 25 m group spacing and a 75 m crossline spacing. The source was a 2000 in3 airgun my. The survey was reprocessed in 1987 using an improved migration scheme and the bins were interpolated to a 25 x 25 m spacing. The second survey was acquired in 1992 to help identify infill targets. A 3470 in^3 airgun array was used with triple 3000 m streamers resulting in 30 fold coverage and 12.5 x 12.5 m bin spacing.

The two surveys have comparable data quality as shown in Figure 2. While not laterally extensive on the seismic throughout the reservoir, the original oil-water contact is quite prominent on the line illustrated in Figure 2. The OOWC occurs at about 3.060 sec. and is, in part, the result of preserved porosity in the original oil leg. Although the contact has moved over 500 feet, a flat reflection event remains on the 1992 survey albeit somewhat broken up. Reflection amplitudes within the reservoir interval change between the two surveys. However, a trace-to-trace comparison is difficult because the two surveys were migrated using different velocities.

In order to robustly difference the seismic data, the methodology illustrated in Figure 3 was used. The key step is inversion of the data using a model-based algorithm which equalizes the two surveys by removing the seismic wavelet. The resulting 3-D impedance models were then averaged between the top of the Fulmar Formation (the Rihble is excluded from the time-lapse analysis) and the position of the OOWC. Averaging increases the signal-to-noise of the seismic difference at the expense of vertical resolution. The methodology was tested by differencing the average impedance calculated for the Cretaceous chalk which unconformably overlies the field. Presumably there should be no change in the chalk's impedance between 1977 and 1992. Over a majority of the survey area the method results in changes of only 2% or less.

Figure 4 illustrates the change in average impedance for the main Fulmar reservoir between I977 and 1992. Increases in impedance are observed along the western and southern flanks of the reservoir. No change or even a decrease in impedance is seen at the reservoir's structural crest.

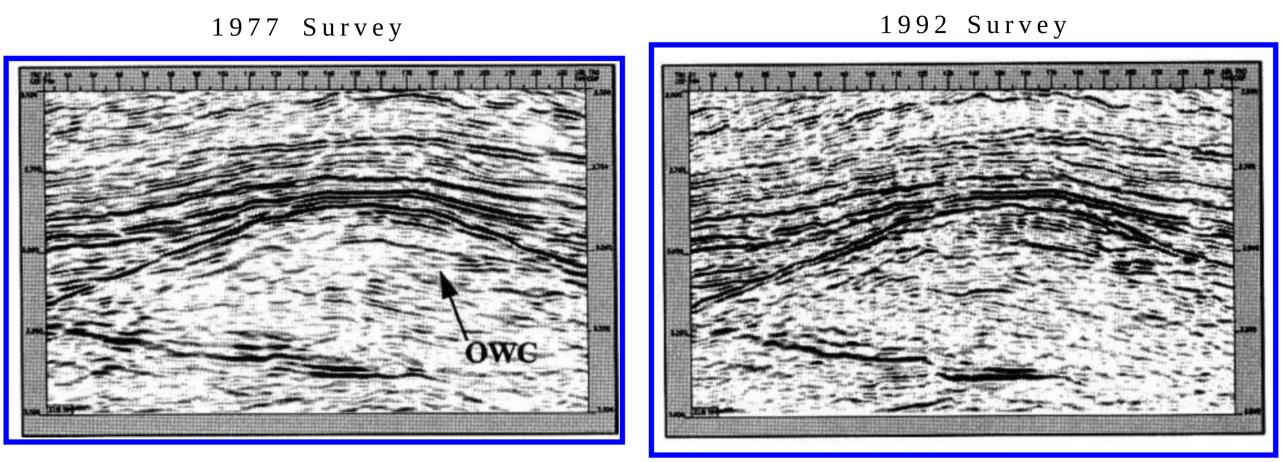

Figure 2. Comparison of 1977 baseline seismic survey and the 1992 repeat survey.

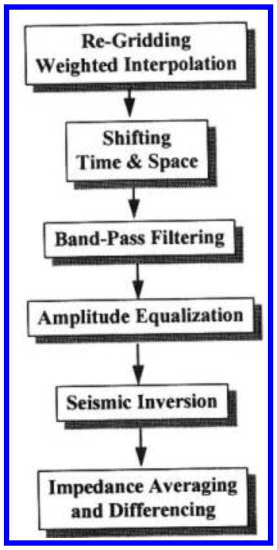

Figure 3. Differencing Methodology

Flow Simulation

The flow simulation model for the Fulmar Field was originally developed by Exxon in 1991 and is currently stewarded by Esso Exploration and Production UK. The 32,736 grid block model (32 x 33 x 31) is fully history matched to include production, individual well pressures, and fluid contact movements. To compare to time-lapse seismic behavior, two time steps were extracted from the model, one at the beginning of production in January 1982, and the other at the time of the acquistion of the second survey in April 1992. Figure 5 illustrates water saturation changes calculated between the two simulation time steps. Saturation increases as high as 65% are seen. In map view the saturation changes look similar to the seismic changes shown in Figure 4.

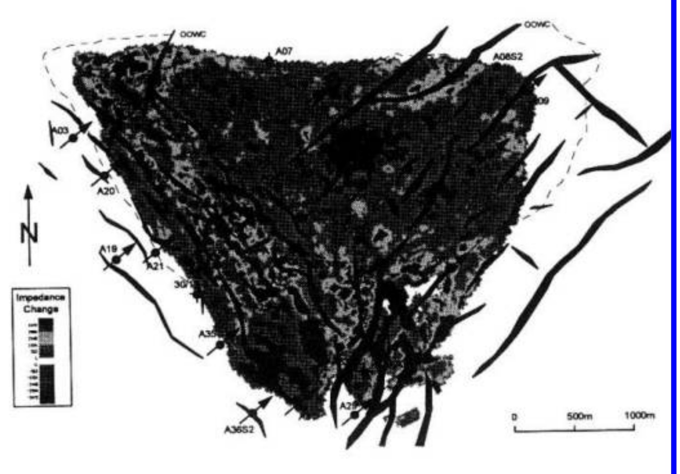

Figure 4. Change in Fulmar reservoir impedance between 1977 and 1992.

According to the flow model, gas saturation increases of over 90% occur in a limited area at the structural crest. The pressure decline of 1000 psi is relatively uniform across the field although there is approximately a 150 psi greater reduction at the crest compared to the field's flanks.

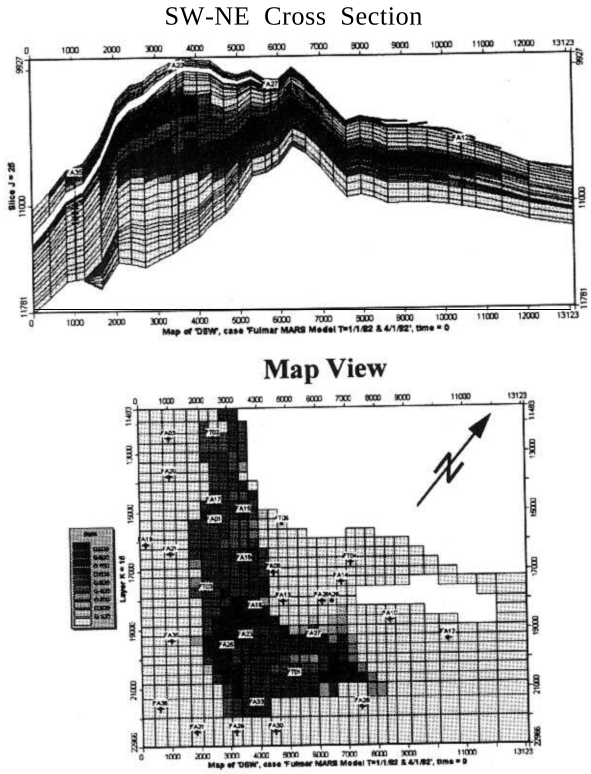

Figure 5. Water saturation changes between two flow simulation time steps, one at the beginning of producfion, the other in 1992.

Petrophysics

Gassmann fluid substitution calculations suggest a 4 to 5% increase in impedance as a result of water displacing oil at the saturations predicted by the flow simulation. A 4% decrease in impedance is expected as a result of secondary gas cap formation. No core measurements are available to directly determine the effect of pressure decline on impedance. However, as reported by Watts et al. (1996), a pressure decline of about 2000 psi in Upper Jurrasic sands at the Magnus Field results in an impedance increase of 12%. Well log data at Fulmar suggest an even greater pressure effect on impedance but these data are influenced by compaction and diagenesis. As a result, we conclude that pressure changes probably have a greater impact on impedance changes than do fluid saturation effects. At the crest of the reservoir, pressure decline is expected to counter the effect of gas cap formation on the impedance.

Comparison to Model

Using petrophysical relationships derived from well logs and fluid substitution from Gassmann's equation, we can estimate the average reservoir impedance changes from the flow simulation model. This predicted impedance change is illustrated in Figure 6. There is general agreement with the measured impedance changes shown in Figure 4 suggesting that the observed changes are associated with water influx and pressure decline.

Areas that are predicted to have changed from the model but have not changed in the data may represent bypassed oil. One such example is the area in the southwest comer of the field. Other potential bypassed areas may occur near faults. However, the seismic data quality is not sufficient to serve as the sole basis for drilling decisions. Many of the smaller-scale features seen on the data may be influenced by artifacts such as fault shadowing, unrelated to production changes. Had the field tapes for the 1977 survey been available, pre- and/or post-stack reprocessing of the data to improve repeatability would have been advantageous.

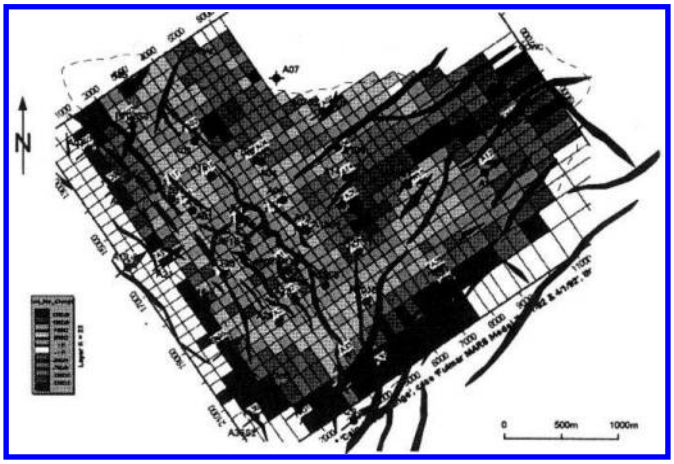

Figure 6. Calculated impedance changes from the reservoir flow simulation.

Conclusions

Seismic differences at Fulmar are related to saturation and pressure changes. The interpretation of impedance changes in terms of potential bypassed areas requires integration with the reservoir flow model. However, the data quality is not sufficient to conclusively demonstrate that small-scale features on the seismic difference map are related to production processes.

Acknowledgements

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Reference:

Watts, G. F. T., D. Jizba, D. E. Gawith, and P. Guttcridge, 1996, Reservoir monitoring of the Magnus Field through 4D time-lapse seismic analysis: Petroleum Geoscience, v. 2, pp 361-372.

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