Lessons Learnt in Time-Lapse Seismic Reservoir Monitoring

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Summary

In this paper, we look at the business growth of 4D seismic technology and briefly examine the following issues:

- The historic global development of 4D seismic applications
- Identify the critical challenges for the future, especially regarding deepwater, onshore repeatability and weak signals
- Review the techno-economic feasibility of 4D seismic surveys, and present a method for predicting the economic value.

Introduction

Today, over 220 4D surface seismic repeat or monitor surveys have been acquired over 180 fields; the number of surveys acquired is currently about 40 per year, representing a growth rate of almost 20 percent (Figure 1). While the majority of these surveys are in the North Sea, the technology has spread globally, with successful surveys acquired in the Gulf of Mexico, West Africa, Brazil, the Middle East, and the Far East.

Applications for 4D seismic technology now span the life of the reservoir, from initial production to identify pressure cells through mid-field life monitoring of waterflood fronts, to eventually late field life where the primary driver is identifying bypassed oil.

The economic benefits of 4D seismic technology include improvements to the reservoir model, the ability to intercede in the reservoir to prevent catastrophic events such as water breakthrough, and improved economic outcomes. Independent studies indicate the economic benefits include NPV increases, reduced drilling costs, and increased production.

The reservoir needs and economic benefits have been the drivers for the development of the technology to enable 4D signal detection from successive 3D seismic surveys. Today, 4D or time-lapse seismic programs are an essential part of the global reservoir management strategy for many companies.

Developments in 4D seismic technology

Two principal factors influence whether we can successfully detect the 4D signal in the reservoir and the frequency with which 4D surveys may be repeated:

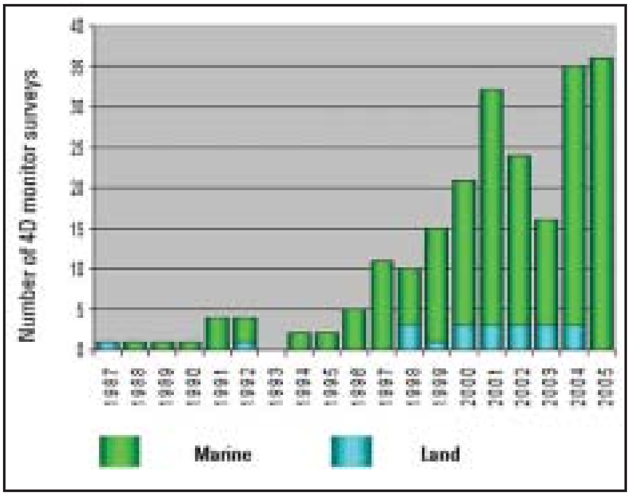

Fig. 1: The historic development of 4D seismic reservoir monitoring from 1987 to 2005.

1. The relative strength of the 4D signal, which, in turn, is influenced by the amount and rate of the change in the reservoir (Figure 2).

The strength of the noise, which is, in turn, influenced by the repeatability of the seismic acquisition.

In the mud-rich passive continental margins such as the North Sea, the Gulf of Mexico and West Africa, the 4D signal is high due to the elastic nature of the reservoir. During the 1990s, 4D seismic technology essentially meant that 3D seismic surveys were differenced in data processing. The step change in 4D seismic quality has come about since the turn of the century from 4D seismic acquisition, which has resulted in significantly improved repeatability and signal-to-noise ratio. Technology developments such as Q-Marine[f&] seismic acquisition have significantly contributed to the repeatability of successive 4D monitor surveys

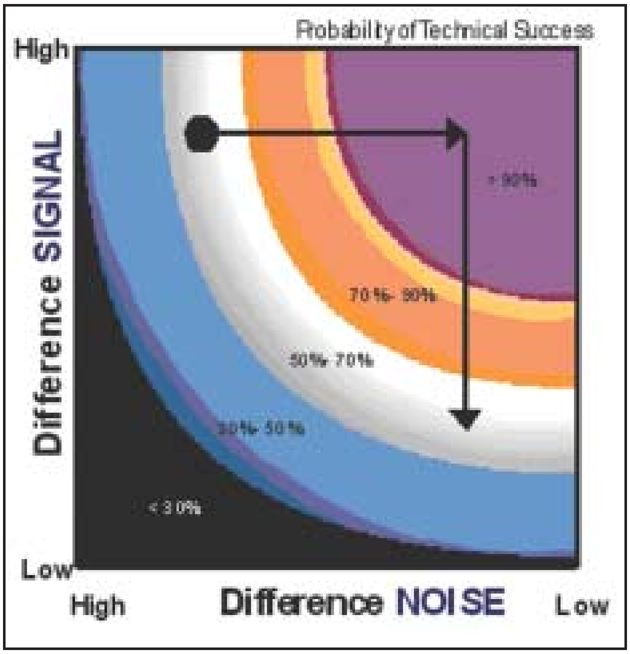

Fig. 2: Determining probability of technical success of 4D seismic.

through accurate positioning, streamer steering, calibrated sources, and single-sensor acquisition.

Future challenges for 4D seismic technology

Many of the world's primary reserves are to be found onshore, and equally important, many reserves are located in carbonate reservoirs. Three factors have inhibited the development of 4D seismic in these geographic and geologic environments because;

1. The bulk strength of carbonates is inherently higher than sandstone reservoirs, even with similar poroperm characteristics.
2. The onshore environment is inherently noisier due to variations in the near surface.
3. Onshore, the ratio of drilling cost to seismic cost is very low relative to offshore; especially in deepwater environments where drilling costs may significantly higher than seismic surveys.

Some of the future challenges to the continued development of 4D seismic technology may be summarised as:

- Repeatability in high current regimes
- High surface-generated noise onshore
- Low 4D signal fields
- Economic justification of 4D seismic surveys

High surface-generated noise can now be attenuated through the implementations of single-sensor acquisition onshore. Unlike conventional onshore seismic systems, single-sensor recording systems, such as Q-Land[f&], attenuate noise and near-surface errors prior to summation (array forming), thus improving the signal-to-noise ratio.

Low 4D signal reservoirs generally include carbonates; however, recent publications include reference to successful 4D seismic surveys acquired in carbonates in both the Middle East and the Far East. It is obvious that not all carbonate reservoirs behave the same, at least in terms of their 4D response. Unlike clastic reservoirs, a variety of mechanisms exist in carbonates for the storage and transmission of hydrocarbons. In some carbonates with high inter-particle pore spaces, bulk strength is weak, whilst, in others such as carbonates with intraparticle pore spaces and vugs the bulk strength is high.

The justification for 4D seismic programs in a carbonate reservoir must include a three-stage approach.

1. Feasibility, including rock physics modeling and signal-to-noise ratio modeling.
2. Survey design involving resolution analysis, acquisition parameter, and data processing sequence.
3. Economic justification – value of information analysis.

Economic justification

Even though it is difficult to measure (and predict) economic impact quantitatively and to relate the cost of 4D seismic programs to improvements in the value of the asset, it is clear that the 4D objective must be to generate economic value. Predicting economic value is an essential part of the 4D planning process.

Decision-tree analysis is a well-established methodology for predicting the value of information, as well as for incorporating prior perceptions of project risk and uncertainty. This approach can be used to quantify the value of 4D seismic data in drilling a new infill well.

In Figure 3, the value of the 4D information has been calculated for a field in the Norwegian sector of the North Sea.

In this instance, the 4D seismic program cost US $4.6 million. In the decision tree, Bayes' theorem is used to modify the chance of drilling success without 4D tools (Cs) and to estimate the value of drilling success with 4D

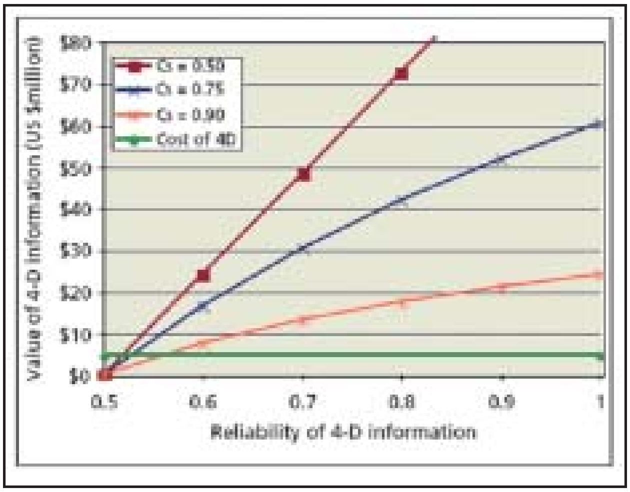

Fig.3: Value of information relative prior probability of success and to quality of seismic information.

technology. Note that the 4D value exceeds the 4D cost over a wide range of 4D reliability, suggesting that 4D programs will almost always add economic value. It can also be seen that when the operator's knowledge is low (Cs=0.5) and 4D seismic reliability is high, maximum value is created. Obviously, if the operator had "perfect information" (Cs=1.0) with respect to the reservoir, there would be no requirement for new information; however, this is rarely the case.

Finding where you are on the graph is simple. Past drilling performance can be used as a measure of the operator's knowledge, and geophysical performance measurements based on resolution and repeatability can indicate 4D reliability. Advanced 4D seismic technologies are more reliable and result in operators achieving better value from the investment in time-lapse information and their asset. Using these measures as a guide, it is easy to estimate the potential value addition attributable to time-lapse surveys.

Conclusions

In this paper, we have attempted to review the current status of the development of 4D seismic technology. The application of 4D seismic methods to new basins such as offshore and onshore India will require the application of appropriate technology and a detailed understanding of the rock physics response of the reservoirs.

The successful technical application of 4D seismic methods will depend upon the project design, including both feasibility and survey design.

The successful economic application of 4D seismic technology depends upon the level of uncertainty in the operator's reservoir knowledge and the quality of the seismic information.

References

Pickering, S., and Waggoner, J., 2003, Time-lapse has multiple impacts, Hart's E&P, March.