Introduction to this special section: 4D seismic

Mosab Nasser[1], Shuki Ronen[2], and Jan Stammeijer[3]

Time-lapse (4D) seismic is a well-established technology used to monitor production in oil and gas fields. This includes fluid replacements, pressure changes, and geomechanical effects. Using a variety of acquisition systems and techniques, 4D seismic is being used actively on fields around the world to optimize production, find bypassed oil, influence well-drilling decisions, and optimize development and production plans.

Over the years, 4D seismic has gained a front-row seat in the geophysical arena despite the skepticism and criticism it faced during its early lifetime in the 1990s. Since then, many case histories have shown that the value of information interpreted from 4D seismic data has greatly exceeded the cost. The value comes from better development decisions resulting in reduced drilling costs and increased recovery rates.

Time-lapse seismic has made the great leap from the testing phase to full-fledged deployment. Not only has the idea of 4D monitoring gained the industry's trust, oil and service companies have also been convinced to invest in a variety of monitoring systems and processing workflows dedicated for 4D seismic. The evolution of such systems and workflows was driven largely to maximize *repeatability*, a critical parameter for 4D seismic because, generally speaking, higher repeatability leads to lower noise levels. To put it simply, repeatability measures the degree of similarity between two or more seismic monitoring surveys. It can be influenced by many factors, including but not limited to acquisition method, acquisition geometries, overburden complexity, and background noise.

Offshore, 4D programs were initially conducted using streamer data from legacy surveys that had not been designed nor dedicated for monitoring purposes, hence producing what we now consider poor repeatability. Nevertheless, such legacy 4D surveys sometimes provided surprisingly high value. Since those early days, we have witnessed great progress in improving repeatability. The first permanent-reservoir-monitoring (PRM) system was deployed in Foinaven in 1995. Since then, PRM improvements include four-component recording, fiber-optical telemetry, and fiber-optical sensors. Improvements in nonpermanent seismic technology include better streamer positioning, shooting in tide cycle, steerable streamers, improved source repeatability, and ocean-bottom systems (cables and nodes). Further data-quality improvements are associated with lowering noise levels, such as those coming from solid streamers, 24-bit recording, broader band, and higher fold. These different technologies and methods have their individual cost characteristics. Coupling the technology palette and cost structures with the specific reservoir-monitoring requirements and overburden complexity of each case, it seems that all of these systems have their place in the market. This is clearly illustrated also by the range of contributions in this special section of *The Leading Edge*.

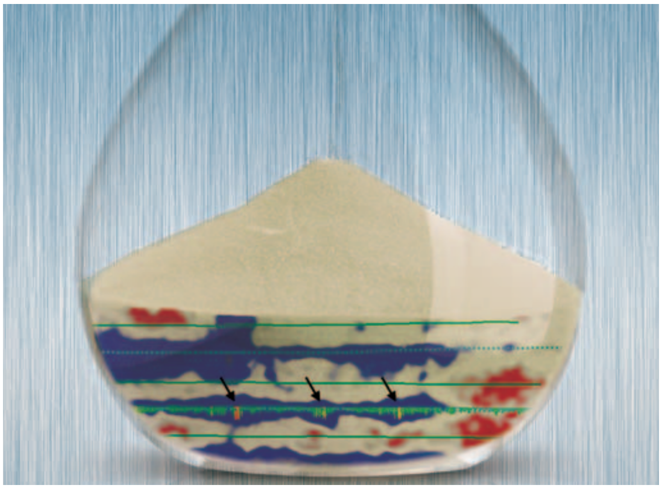

Image adapted from Figure 10, Calvert et al., pages 840–848, this issue.

The diversity of recovery processes that engineers employ in combination with intricate geology and variations in rock properties often leads to complex and sometimes nonintuitive 4D signatures. The aforementioned continuous improvements in data quality with every new survey allow operators to unravel complex production effects with far greater details, leading to derisking of subtle infill targets or well optimization and work-over opportunities. In addition, improved data quality and lower cost of seismic acquisition and processing motivates and enables operators to acquire more 4D surveys with shorter intervals, hence shortening the cycle of business impact.

To lead off this issue's special section, Byerley et al. interpret resaturation of previously produced compartments, thus possibly extending drilling targets from bypassed oil to resaturated reservoir compartments. Calvert et al. then show a great example of monitoring a chalk field in the Danish North Sea using 4D seismic, which was used to update the seismic interpretation model, provide evidence that some faults serve as potential pathways for formation-water entry into the reservoir, and identify numerous well-intervention opportunities.

Permanently installed receiver systems open up more possibilities. Hicks et al. explore new 4D attributes (using full-waveform inversion) to help decouple various 4D effects, while Chalenski et al. investigate source modifications that lower per-survey cost while maintaining data quality.

Data quality by itself does not create value unless information is interpreted from the data in a timely manner and then used to make decisions. Quantitative 4D seismic interpretation, in general, and rock physics, in particular, are essential to decouple the often-competing effects embedded in a 4D signal. The rock-physics work by Avseth et al. models stress sensitivity and time shifts in

[1]Hess Corporation.
[2]Totum Geophysical Solutions and Low Impact Seismic Sources.
[3]Petroleum Development Oman.

http://dx.doi.org/10.1190/tle35100828.1.

patchy cemented sandstone. Moreover, an interesting quantitative assessment of various sources of nonrepeatability on 4D seismic data quality and noise levels is presented in a synthetic data study by Gherasim et al., while the stability of various 4D time-shift attributes is assessed in the article by Kanu et al. The last contribution in this special section sits on the interface between 4D monitoring and seismic acquisition. Eggenberger et al. investigate under what conditions simultaneous shooting can be applicable in a 4D context, aiming to lower acquisition costs without compromising data quality.

It is interesting to see this set of 4D trends and themes illustrated by different authors from different companies in different reservoir settings. This uniformity stands in contrast to the dis-similarity exhibited in the various figures the different authors use, even though they sometimes illustrate the same types of 4D attributes. A discussion on this topic in a previous *TLE* special section (Volume 32, no. 2, February 2014) apparently must have drawn little attention. But the editors of this special section are convinced that the high quality of papers presented here will make this issue's special section a keeper!

With every technology comes opportunities but also challenges. Over the years, geophysicists have struggled to justify the cost of acquiring a 4D survey, or the acquisition of more frequent 4D surveys, due to their limited ability to determine and effectively communicate the value prior to, and even sometimes after, data acquisition. The value often comes from the surprise factor — the "unknown unknowns" that were not accounted for during field development. Moreover, even in cases where 4D seismic has demonstrated the ability to make significant business impact, most geophysicists tend to (or maybe are only allowed to) externally communicate the technical challenges and solutions their 4D survey has brought forward but not its business impact — or, in other words, the associated dollar value. That is why *The Leading Edge* is creating more space for geophysicists and reservoir engineers to communicate the business value of 4D seismic projects, in the form of a dedicated special section planned for May 2017. TLE