Time-lapse seismic technology – PAST, PRESENT AND FUTURE
For many of us, the principal business driver today is to derive the maximum economic return from oil and gas fields. In today’s environment, making the most of what you have makes good business sense. This can be achieved through the effective use of technology to improve operational efficiency by means of fewer, better-placed and safer wells.

In doing so, we derive the economic benefit from operational excellence and capital efficiency.

Seismic technology has a proven track record in reducing reservoir risks and improving exploration and production performance. The development of 3-D seismic techniques in the 1970s resulted in unprecedented success in exploration, and reservoir characterization subsequently produced improved field development and oilfield economic performance. Now time-lapse or 4-D seismic surveys use the difference between surface seismic surveys to measure production and reservoir properties periodically during the life of the reservoir. Observed changes assist in the characterization of the reservoir. The differences between the surveys may be attributed to changes in saturation, pressure and, in many fields, overburden stress due to reservoir compaction. Time-lapse surveys may indicate the presence of barriers to reservoir connectivity, changes in reservoir saturation and pressure, and changes in overburden rock strength.

More than 220 time-lapse repeat surveys have been acquired to date over more than 180 oil and gas fields; some fields having multiple repeat surveys. Figure 1 shows that the majority of 4-D seismic surveys have been acquired in the marine environment. It also shows significant growth in time-lapse surveys from 1996 onwards, resulting from the development of seismic data acquisition and processing technologies designed to improve the imaging of the time-lapse seismic response.

The development of time-lapse seismic technology has focused on resolving the time-lapse signal through attenuating noise in the seismic record and increasing repeatability between surveys. In the mud-rich continental margins such as the North Sea, the time-lapse signal is often high due to the elastic nature of the usually clastic reservoirs. In this environment, early time-lapse studies were carried out during the 1990s. Back then, time-lapse seismic technology essentially meant that 3-D seismic surveys were differenced in data processing. The step-change in 4-D seismic data quality has come from 4-D seismic acquisition, resulting in significantly improved repeatability and signal-to-noise ratio. Technology developments such as Q-Marine single-sensor seismic acquisition with steerable streamers have contributed significantly to improving the resolution and repeatability of successive 4-D monitor surveys.

Time-lapse seismic technology in use
While many of the early surveys were in the North Sea, the technology has now spread globally, with recent surveys being successfully acquired offshore in the Gulf of Mexico, the Congo Basin of West Africa, the Campos Basin of Brazil, Australia and Southeast Asia, and onshore in the Middle East.

Applications of 4-D 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...
late-field life where the primary driver is identifying bypassed oil to extend economic recovery.

**Why use time-lapse surveys?**
The technical benefits include the ability to better place wells in the reservoir to maximize productivity and to avoid losses in the overburden. We can also use time-lapse seismic methods to look to the future, intervening in the reservoir to prevent catastrophic events such as early water breakthrough, and to proactively manage and monitor drainage strategies that increase ultimate recovery. Uniquely, time-lapse seismic technology provides information throughout the reservoir regarding fluid movements. Industry-wide market surveys identify time-lapse or 4-D seismic technology as having a major impact on ultimate recovery and drilling efficiency, and it provides more accurate predictions of future reservoir production.

**When should they be used?**
Many of us, when faced with choice, usually seek advice. Time-lapse seismic technology provides the most economic benefit when there is significant uncertainty or choice. When the outcome is certain, new subsurface information will rarely add value. Unfortunately, in many fields, understanding of the reservoir beyond the well bore is poor, and reservoir surprises are all too common. Time-lapse seismic surveys add the most value when there are multiple choices; for instance, when there are many more drilling targets than opportunities to drill, or when the prior probability of hydrocarbons is uncertain.

**Will it work for my reservoir?**
Many factors influence whether or not the time-lapse signal in the reservoir can be detected as well as the frequency with which 4-D surveys may be repeated. These include the reservoir rocks themselves and the nature and rate of change of fluids being produced from or injected into the reservoir. Together, these influence the relative strength of the time-lapse seismic signal. The ability to detect the seismic signal is also affected by the ability to exactly duplicate the previous survey. The first step in any time-lapse survey is a feasibility study, which will assess the ability to detect a signal, repeat the earlier survey and determine the optimum time interval between surveys.

**What is the future?**
Many of the world’s hydrocarbon reserves are to be found onshore, and equally important, many of the world’s reserves are located in carbonate reservoirs. Two factors inhibit the application of 4-D seismic methods in these geographic areas and geologic environments. First, the bulk strength of carbonate rocks is higher than most sandstones, resulting in a relatively weak time-lapse signal. Second, high-amplitude near surface-generated noise has historically masked signal but can now be attenuated through the implementations of single-sensor seismic acquisition techniques onshore such as Q-Land, enhancing our ability to detect weak low-amplitude time-lapse signals.

Offshore streamer steering improves operational safety in the congested environment around many oil fields, and new technologies are emerging that improve the industry’s ability to repeat monitor surveys in areas of very severe currents such as the Gulf of Mexico.

Finally, data delivery is important in seismic reservoir monitoring, as each seismic survey represents a snapshot of reservoir conditions at a moment in time. In-field or onboard processing is speeding the delivery of time-lapse seismic surveys, enabling time-lapse difference estimates of reservoir production or injection to be delivered within days of seismic survey completion.

**Reservoir needs drive development**
Reservoir management demands and economic benefits have been the drivers for development of the technology to detect time-lapse seismic signals from successive 3-D seismic surveys. The development of single-sensor recording with steerable streamers has resulted in superior signal-to-noise ratio, resolution and repeatability. Onshore, single-sensor technology improves the signal-to-noise ratio and intra-array statics, resulting in significantly improved time-lapse signal measurements. These developments have caused 4-D or time-lapse seismic reservoir monitoring to become an essential part of the global reservoir management strategy of many oil companies.