Business Drivers and Technology Advances in 4D Seismic Monitoring

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This paper will discuss the business drivers and technology advances that are rapidly improving the state-of-the-art in 4D seismology today, drawing from selected reservoir monitoring case study examples around the world.

Time-lapse “4D” seismic technology was pioneered in the late 1980's and early 1990's as a series of EOR field pilot studies, and has today become a well-accepted reservoir management tool for monitoring many types of hydrocarbon production. The technology first gained major commercial success in the North Sea during the late 1990's, and evolving business forces are now expanding the application of 4D seismic to new geographies, reservoir geologies and production mechanisms, as will be shown in the examples.

4D seismic advances are also being driven by an increased interaction with the petroleum engineering community to become more quantitative and accurate in our ability to monitor reservoir processes. Qualitative interpretations of colorful time-lapse anomalies are being replaced by quantitative inversions of the 4D seismic data to produce accurate maps of fluid saturations, pore pressure, temperature etc. in physical engineering units with uncertainty analysis, as the examples will show. These 4D technology advances are improving engineering work flows for reservoir model updating, history matching, estimating the inter-well distribution of oil and injectants (water, gas, steam, CO2…), delineating reservoir compartments, flow paths/barriers, and the sealing properties of faults.

A Decade of 4D Seismic Monitoring in the N Sea

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In the mid 1990's 4D (time lapse) seismic was being used as a research tool in the N Sea. It was rapidly developed when it was demonstrated to be able to identify the presence of swept zones, major pressure changes, intra-reservoir barriers and by inference infill drilling targets.

There have been a few significant surprises over the last decade: 1) the level of definition of fluid change, 2) the number of fields that are 4D potential candidates and 3) the integration with field monitoring performance.

4D was originally envisaged as being for identification of infill well targeting on a very small selection of particularly benign environments. In fact it has developed to become a routine field surveillance tool with many of BP's North Sea portfolio being re-acquired on a regular (2 year) basis. Some fields now have 3 or more repeat surveys.

This presentation will describe the level of reservoir integration, surveillance and 4D impact by drawing on a range of examples. It will touch on some of the interpretation, integration and organisational issues which can provide valuable field management description or provide generate costly mistakes for the unwary.

Is Repeatable Noise Acceptable in 4D Seismic?

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A reasonable understanding now exists of the quantitative relationship between errors in source and receiver position and the effect of various noise sources at different depths upon repeatability. It is only partially true that coherent noise repeated within reasonable thresholds will effectively cancel during data differencing of baseline and monitor surveys. It is not true that all noise types are acceptable for 4D – even if they are repeatable. Noise that can be accurately modelled from the recorded seismic data can be removed for the stand-alone analysis and interpretation of baseline or monitor surveys, and can be accurately removed during the differencing step. In contrast, noise that cannot be accurately modelled from the recorded seismic data is not acceptable for either stand-alone or differencing purposes – even if it is repeatable. Case examples from the North Sea and Australasia demonstrate how a detailed analysis of the important noise mechanisms in a particular 4D survey location is critical during the feasibility study stages, and how such an understanding is necessary when managing the expectations of data repeatability. Accurate data regularisation and wavefield reconstruction are potentially significant processing tools that must also be factored into any consideration of noise issues when pursuing 4D seismic.

Design and Acquisition of a 4D base survey: A case study from the Pyrenees Oil Development, Exmouth Sub-basin, Western Australia

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The Pyrenees Oil development is a multi-field cluster development located in the Exmouth sub-basin, Western Australia. The three fields that make up the Pyrenees development have excellent direct hydrocarbon indicator (DHI) support, including seismic flat-spots coincident with fluid contacts and elevated seismic amplitudes associated with hydrocarbons. Based on this strong DHI support it was recognised that these fields may be candidates for 4D reservoir monitoring over the predicted 20 year field life. Rock physics modelling using oil saturations predicted from reservoir simulation, showed that after 5 years of production you would expect to detect changes in seismic properties caused by oil and gas production.

Prior to this survey the Pyrenees fields were covered by three different seismic surveys. These surveys were re-processed in 2005 to produce a single seismic volume that has a relatively seamless merge between the surveys and improved data quality. Differences related to the original acquisition parameters remain and portions of the seismic were deemed sub-optimal for the development of these fields. The decision was made to acquire a new survey, primarily to assist in the field development drilling but also to act as a base survey for 4D reservoir monitoring.

As it is not possible to achieve receiver co-location in marine environments due to feathering, the Pyrenees 4D base survey acquisition strategy was to acquire for source position with a small streamer separation and streamer redundancy. This approach is relatively cost effective as the streamer redundancy is partially balanced by a smaller infill requirement. In January 2006 a seismic survey capable of acting as a 4D base survey was acquired. This high resolution 4D base survey has provided those working on the fields potentially another tool to help understand these fields and identify further opportunities.

Vertical Seismic Profile (VSP): Beyond Time-to-Depth

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The talk will focus on Borehole Geophysics and primarily on VSP (Vertical Seismic Profile, or Borehole Seismic). Our prime attention is on applications beyond the standard time-to-depth application and focuses on 3D imaging and inversion using geophones temporarily deployed in newly drilled wells. We discuss the state of the art of the technology, what technologies are appropriate for different settings, and what the future may bring. Results will be shown from deepwater Gulf of Mexico prospects and we will discuss how these results have impacted our understanding of the reservoir and reduced risk on development well placement. On imaging algorithms we will examine some exciting new developments, imaging using multiples and "single well" salt flank imaging using interferometry. Imaging with free-surface multiples has the potential to greatly increase the fold and coverage of the VSP image, with additional benefit of being able to image above the receiver array up to the surface.