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Understanding the Time-Lapse Seismic Response of a Compacting Carbonate Field, Offshore Sarawak, Malaysia

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Abstract

The M4 field, a reefal carbonate buildup offshore Sarawak, was discovered in 1980. It has an average porosity of 32% with a 170 ft condensate-rich gas column. The field came on-stream in 2002, producing through two subsea, near-horizontal wells drilled about 25 ft below the top of the reservoir. Similar to other fields in the area, a strong aquifer provides the main drive mechanism, although there has been a pressure decrease of about 650 psi after 3 years of production.

The original 3D seismic data over the field was acquired in 2001. In 2005 a time-lapse monitor 3D seismic survey was acquired with the objective of imaging the producing gas-water contact (PGWC) to determine its movement. Evident in the time-lapse data are amplitude changes, caused by aquifer influx into the gas column, and time-shifts, related to compaction of the reservoir.

The results immediately showed that a faster than expected movement of the PGWC had caused the increased water production observed in the producing wells. To gain further insight, several technologies were applied to the 3D time-lapse seismic dataset. Single volume sparse spike inversion was applied to the base and monitor surveys to highlight the acoustic impedance change to aid interpretation of original and producing gas-water contact for mass-balance estimates of remaining volumes. Simultaneous multi-volume inversion was applied to estimate the residual gas saturation and remaining volumes. Geomechanical models, calibrated to core data, were built to estimate the amount of compaction from the observed time-shifts. These studies highlighted that the compaction effect was more complex than expected. This resulted in challenges in defining an elastic rock property model that properly combined the effects of compaction and saturation changes to describe the observed seismic response.

The time-lapse seismic was a convincing success and provides a world-class example of monitoring production in a carbonate reservoir. It has yielded valuable insight into field-scale, production related compaction and saturation effects.

Introduction

In recent years, time-lapse seismic data has been widely used to monitor production effects in clastic reservoirs, to the extent that the seismic response in these reservoirs to saturation and pressure changes has become reasonably well understood. It is perhaps surprising however, given that carbonate reservoirs account for approximately half of the world's oil and gas reserves, that the use of time-lapse seismic data to monitor production in carbonate reservoirs has received less attention.

The Central Luconia gas province in offshore Sarawak (Figure 1) contains numerous Miocene carbonate buildups. The seismic response in the Central Luconia carbonates is dominated by changes in porosity that ranges from 5% to 40%. While the presence of gas is expected to have a significant effect on the seismic data, especially in the higher porosity zones, the identification of a GWC is very difficult due to the porosity overprint on the seismic amplitudes. In addition, the horizontal stratigraphy makes it difficult to identify the flat GWC reflection.

As a common practice, most of these fields use observation wells to monitor the movement of the gas-water contact (GWC). But this method only provides information at a few points. Full-field information can only be provided by time-lapse seismic. Since 2001, Sarawak Shell has been gaining experience in using time-lapse seismic as a reservoir surveillance tool for carbonate fields.

Time-lapse 2D seismic (2001)

The M3 gas field came on production in October 1995. In mid-1998 four producers suddenly experienced unexpected water breakthrough. Subsequent monitoring of the producing GWC (PGWC) in observation wells indicated that the water had