Time-lapse seismic makes a significant business impact at Holstein

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Summary

A successful 4D survey using a dual-vessel acquisition method was acquired over Holstein in 2006. The dual-vessel acquisition was designed to overcome the repeatability challenges in the GoM caused by the loop and eddy currents, which could significantly alter the source and receiver positions between the baseline and monitor surveys. Time-lapse amplitude hardening and time-lapse timeshifts as large as 6ms are observed after production primarily through pressure depletion. Besides the overall understanding of the subsurface as a result of the 4D survey, specific business decisions have been made which directly impacted the field development plan. This includes providing an alternative injector location in the J2 sand as well as increasing the probability of success (POS) and advancing the drilling of the K1 south sidetrack. The clear business impact made by the 2006 monitor have prompted the Holstein JV to plan for a second monitor in 2010, for which a 4D feasibility study was completed late in 2008. Parameters such as the R factor as well as the pore compressibility for the different sands have been calibrated as part of the 4D Close-the-Loop (CtL) using the baseline and 2006 monitor.

Introduction to Holstein

The Holstein field is an oil and gas development located 200 miles South of New Orleans in the Green Canyon protraction area. It was discovered in 1999 by a partnership of BP (50%, operator) and Shell (50%). Water depth is about 4,300 feet and the field produces from stacked Pliocene turbidities sands at depths of 11,000 to 14,000ft. As part of the asset surveillance strategy, time-lapse seismic was considered in the reservoir management technology portfolio in order to enable the asset to monitor pressure and fluid saturation changes in the reservoir, map flow baffles and pressure compartments, and update the static and dynamic models based on fluid sweep and pressure propagation patterns. These results would help make operational decisions and de-risk positioning of future injector and producer wells, thereby optimizing production and enhancing recovery.

4D Acquisition

A high-repeat 4D survey combining single-vessel (for near offsets) and dual-vessel (for mid and far offsets) was acquired at Holstein in August-September 2006 (Barousse et al., 2007). The second boat was ready for operation in dual-vessel mode from the start of the survey, and high repeatability would not have been achieved without the two-boat acquisition.

With this two-boat application method, shot and receiver location errors between baseline and monitor surveys were less than 100m for over 90% of the survey for offsets up to 4500m. The whole survey has an average NRMS (normalized root-mean-square difference) value of 0.23 (Figure 1). Such a level of repeatability is considered excellent in the deepwater GOM environment. Both the NRMS and the repeatability ($\delta s+\delta r$) values are consistent with values achieved in the North Sea reported by Smit et al. (2005) where time-lapse seismic is an established technology. In the undershoot area (green polygon in Figure 1), the near offsets are missing in the monitor data and there are larger differences at the far offsets, so that in this area only the mid-offset stack is used with caution.

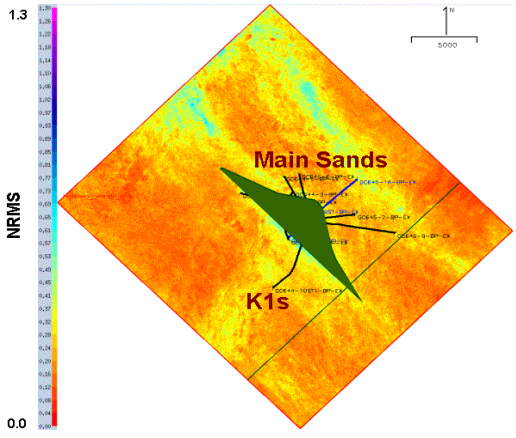

Figure 1: NRMS values from application of high-repeat acquisition over the Holstein field (undershoot polygon in green). NRMS is estimated in a 1s window centered at 2.5s. An average NRMS value of 0.23 on final migrated data and an average shot+receiver repeat error of 75m is achieved.

Introduction to the 'Main Sands': J2, J3, and K2

The 'Main pay Sands' are a vertical sequence of stacked sands in which the progressively deeper J2, J3 and K2 are currently producing. The J and K sands were under primary depletion without aquifer support at the time of the 2006 monitor survey. Water injection was initiated in May 2006 to offset pressure decline and provide pressure support to the J2 and J3 reservoirs. 4D interpretation of the main sands is more complex due to poor repeatability in the undershoot area and time-lapse changes of several stacked reservoirs. Figure 2 shows both the RFC amplitude and Timeshifts difference maps at the top of K2. Difference amplitudes suggest a compaction-related impedance increase in a region around well 1, which is the largest K2 producer with 4300psi pressure drop. Limited production and a rapid pressure drop (2500psi) suggest that well 2 is either in a relatively small compartment or has a completion problem, which is consistent with the lack of 4D changes observed near this well location. A third well was drilled after the 2006 monitor acquisition in a region with good amplitude support (on baseline data) and no 4D signal (on difference data). Well results verify that this region is not depleted and validates the lack of 4D signal in this location.

Compaction and water injection in the J2

The J2 is 70 ft thick sand with a depletion drive. Figure 3 shows wells 4 and 5 that are the best producers in this sand with approximately 2600psi depletion each. The difference amplitudes suggest that large area (yellow polygons in Figure 3A) have compacted around these wells and the two areas could be connected. This amplitude interpretation is consistent with the observed Timeshifts, which also agree with the production data. Combined Timeshifts up to 6ms as a result of the J and K2 sand compaction due to pressure depletion is seen in Figure 4.

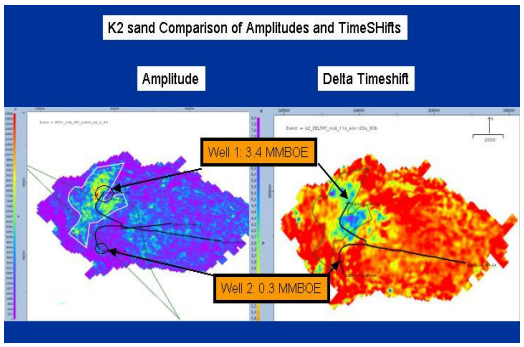

Figure 2: Comparison of amplitude (left) and timeshift (right) changes calculated at the K2 sand level.

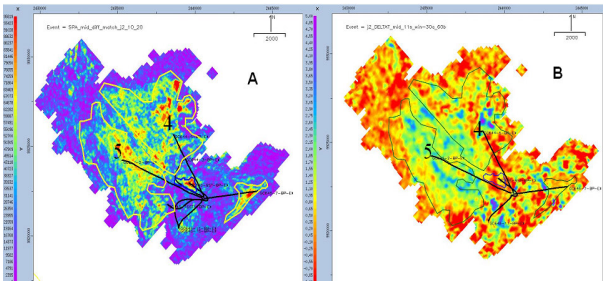

Figure 3: Map view of the 4D amplitude difference (A) and Timeshifts (B) at the top of J2 sand.

Holstein 4D Business impact

The Holstein 2006 4D monitor survey has impacted the field development decisions in many ways. Some of the decisions to which the 4D has contributed to are:

- Provided alternative injector location for J2 well 6-ST
- Increased the probability of success and advanced the drilling of the 10-ST
- Avoided drilling an injector well in the K2 sand
- Highlighted new target locations in Water flooded Sand "J3"

In this paper we will only discuss points 1 and 2 in more detail:

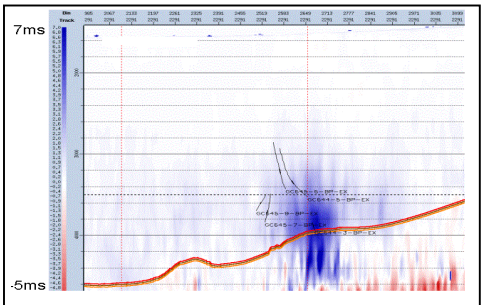

Figure 4: Cross-section of time-shifts over central part of depleting J's and K sands.

1-Provided alternative injector location for J2 well 6-ST

A sidetrack water injector well, to provide pressure support to the nearby producing wells, was to be drilled to a new J2 target after abandoning the existing well 6 completions. Based on an area identified as depleted from 4D seismic interpretation, the injector well 6-ST was drilled 350ft away from original A6 well. The well was drilled early 2008, as shown in figure 5, and as a result the production in well 5 increased right away with well 6-ST injection. Well 5 down-hole pressure also increased as Well 6ST injector was put online.

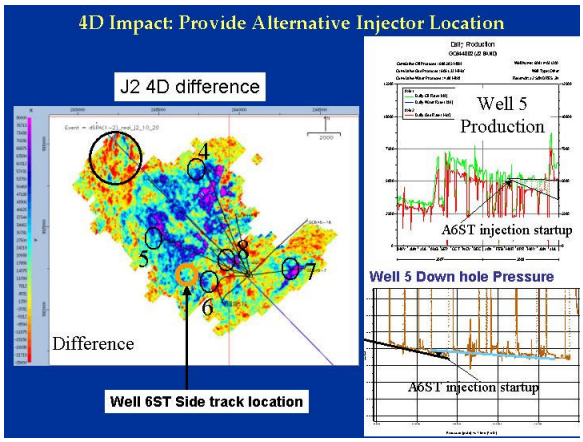

Figure 5: 4D provided alternative injector location for the well 6.

2-Increased the Probability of Success and advanced the drilling of the well 10-ST

The south area has access to a relatively large mapped aquifer, which has shown very strong support in K1 South reservoir as evidenced in well 10 performance and delineated clearly from 4D seismic. The new well (10-ST) was drilled in November 2008 and found unique reserves. Figure 6 shows the location of the new well on the 4D difference map.

Second monitor survey feasibility study

This forward-looking 4D feasibility study investigated whether a time-lapse signal due to water flood related saturation changes would be observed in 2009-2010 and how the pressure depletion signal might override it given the current reservoir simulation models. In this feasibility study we generate expected time-lapse seismic response from dynamic reservoir models and calibrate our model using the 2006 monitor survey results. Synthetic seismic volumes were created for several time-steps (2004, 2006 & 2009), based on the reservoir model using rock and fluid property relations derived from appropriate well logs and core measurement.

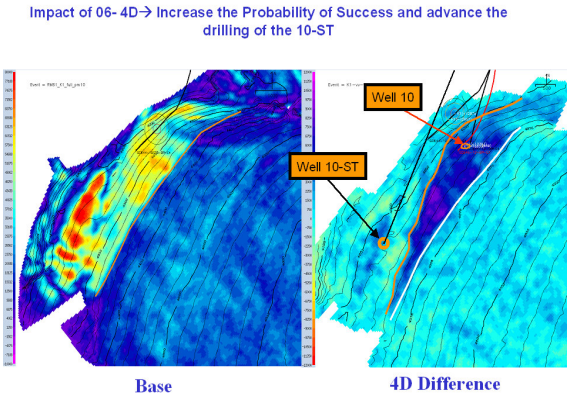

Figure 6: 4D Impact: Highlighted new targets at the K1-S sand

Figure (7) shows maps of predicted time-lapse responses observed for 2006 and 2009. By comparing the observed depletion amplitudes with the actual response in Figure 5 we determined the R-factor that best accounts for the amplitude change is ~ 1.3 inside the sandstone reservoirs. This was also found to be consistent with observed timeshift change across this reservoir. Based on this calibrated R-factor and comparing the responses from the area undergoing water injection and depletion drive it was determined that it was possible to track the additional water a 2010 monitor survey.

Conclusions

Successful streamer acquisition of high repeatability time-lapse seismic data at Holstein in the deepwater GoM, has produced high quality 4D data with clear amplitude changes and measurable Timeshifts of top reservoir times. The observed Timeshifts were due to subtle overlying shale velocity changes caused by

the depletion of the reservoirs in early field life. These two attributes as well as others have significantly improved the overall subsurface understanding, reduced uncertainties, and influenced important business decisions.

The amplitude changes and Timeshifts have highlighted both sweep patterns and areas of compaction respectively, due to production from the different stacked sands. The time-lapse data have also highlighted un-swept areas, isolated compartments and sealing faults, which have influenced decisions of well placement whether its a producer or injector.

Parameters such as the R factor for the sand, the reservoirs pore compressibility's and the lateral rock properties variations were possible to calibrate using the time-lapse seismic data. The value gained form the 2006 monitor survey has encouraged the Holstein partners (BP & Shell) to plan for a second survey in 2010, for which the 4D feasibility study described above has been completed.

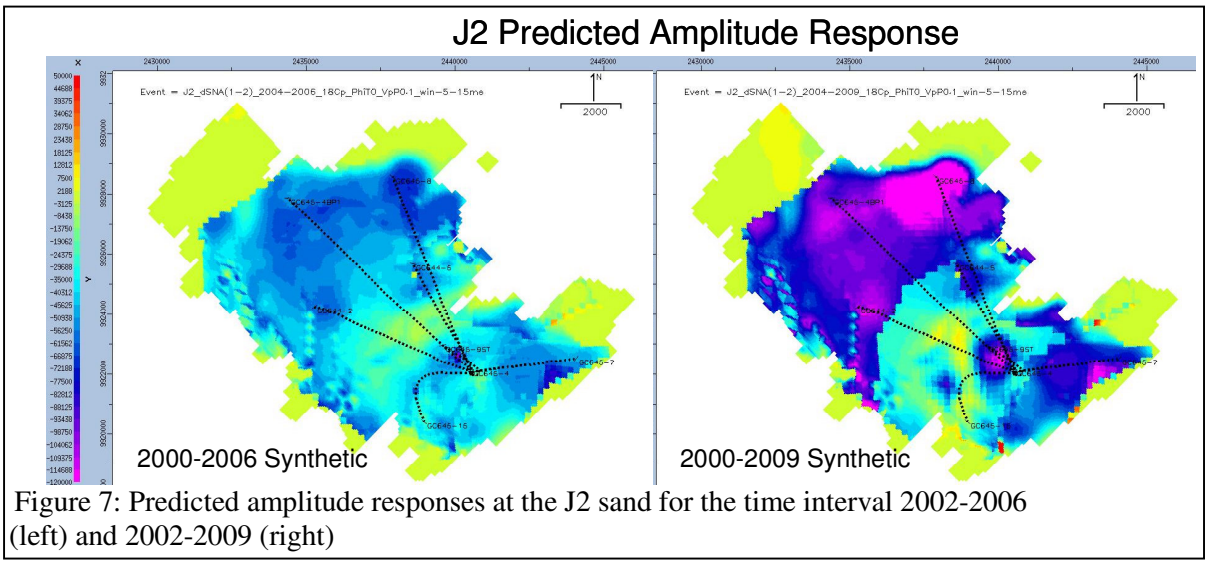

Figure 7: Predicted amplitude responses at the J2 sand for the time interval 2002-2006 (left) and 2002-2009 (right)

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