First dual-vessel high-repeat GoM 4D shows development options at Holstein field

Hesham Ebaid, Ali Tura, Mosab Nasser , Paul Hatchell, Frans Smit, Nigel Payne, Shell Exploration and Production Co., Don Herron, Darrell Stanley, John Kaldy, Chuck Barousse, BP Americas Inc.*

Summary

In the Gulf of Mexico (GOM), loop and eddy currents can cause large 4D shot and receiver location errors between baseline and repeat streamer surveys. These large repeatability errors are seen as a hindrance to the application of 4D seismic technology in the GOM, as they invariably lead to poor 4D seismic data quality. In a recent 4D acquisition a new and novel dual-vessel 3-D acquisition method was used to address the repeatability problem and show reliable time-lapse measurements over the Holstein field. The time-lapse seismic data shows time-shifts up to 6ms over depleting sands and amplitude changes over swept and compacted sands. This 4D information has improved understanding of the field and can be used to support optimal placement of water injection and production wells.

Introduction to Holstein

The Holstein Field is located in the deepwater GOM (4300ft water depth). The field is operated by BP and jointly owned by Shell (50%). The field produces from stacked Pliocene turbiditie sands at depths of 11,000 to 14,000ft. The field started production in December 2004. Given that the majority of resources still remain to be produced, understanding reservoir compartmentalization is a key issue for future field development decisions.

4D Acquisition

The pre-production 2001 baseline survey for Holstein is a high-resolution survey with excellent image quality. A 4D seismic modeling study concluded that the best timing for a monitor survey would be just prior to water injection to separate depletion from water injection changes. Also, high-repeat far offsets would be important to allow 4D AVO inversion for separating pressure changes from water saturation changes (Tura and Lumley, 1999; Landro, 2001).

In late 2005, two high-repeat 2D lines using dual vessels configuration and short cables were acquired (see Tura et al, 2005; Hatchell and Bourne, 2005). The data showed small amplitude changes and time-shifts, consistent with limited production to date. At the end of the study, calibrated 4D seismic modeling and the 2D lines helped build the case for 4D acquisition over Holstein.

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 method, shot and receiver location errors between baseline and monitor acquisition ($\Delta s+\Delta r$) of less then 100m for over 90% of the survey were obtained for offsets up to 4500m. The whole survey has an average NRMS (normalized root-mean-square difference) value of 0.23 (Figure 1), a level of repeatability not seen before in the GOM. Furthermore, for the first time, both the NRMS and the $\Delta s+\Delta r$ values are consistent with repeatability values achieved in the North Sea, where time-lapse seismic is an established technology. In the undershoot area (green polygon Figure 1) the near offsets are missing in the monitor data. However, in the mid offsets the baseline and monitor data start to match with less than 100m $\Delta s+\Delta r$ location errors. As a result, only the mid-offset stack is used, with caution, for interpretation in the undershoot area.

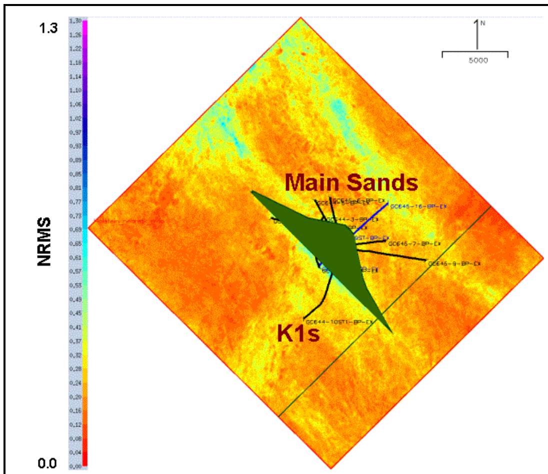

Figure 1: NRMS values from application of high-repeat acquisition over the Holstein field (undershoot polygon in green). NRMS is estimated in a 1s window centered at 2.5s. An average NRMS value of 0.23 on final migrated data and an average shot+receiver repeat error of 75m is achieved.

4D Processing

The 2001 baseline and 2006 monitor surveys were jointly processed in parallel through a 4D processing flow. Prior to merge, cold water and tidal statics, 3D SRME, and receiver motion correction were applied. The surveys were then merged and the following key steps were applied: global matching, 4D binning based on a combined $\Delta s+\Delta r$ and minimum NRMS criteria, regularization, Azimuthal move-out (AMO), high-frequency differential statics, radon multiple attenuation, and acquisition footprint removal. These steps were followed by PSTM and anisotropic PSDM. RMO, stack (full, near, mid, far), and residual matching of stacked cubes were applied.

Water sweep at K1s

The K1s reservoir is an isolated sand that is located southwest of the platform (see Figure 1). It is different from the 'Main Sands' in that it has good aquifer pressure support. Figure 2 is a seismic section through the K1s producing sand. The difference data suggests an aquifer sweep. The original oil-water contact appears to have moved up-dip towards the producing well. A clear 4D signal, with minimum residuals from other seismic events, is observed.

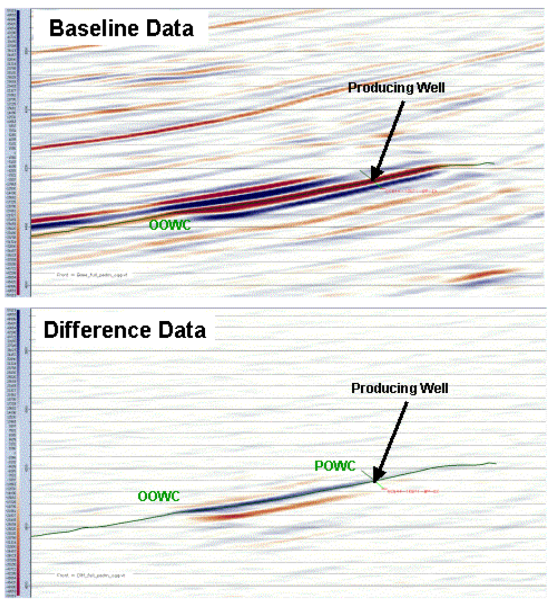

Figure 2: Baseline and difference data through K1s producing well . The difference data shows exceptional time-lapse data quality clearly showing up-dip water movement. The original oil-water contact (OOWC) has moved up-dip to the present oil-water contact (POWC) approaching the producing well. As of December 2007 water cut at this well has reached 80%.

The K1s sand top amplitude pick is shown in map view in Figure 3. The bright colors in the baseline data indicate gas and oil whereas the cool colors down dip of the original OWC indicate water. The white line represents the original oil-water contact. In the difference section, the oil-water contact has moved up-dip towards the producing well. At the time of the monitor survey this well had 70% water cut and has reached 80% water cut as of December 2007. A map view shows that a large portion of the hydrocarbons, outlined by the red polygon, have apparently not been produced offering potential access through sidetrack of the existing well.

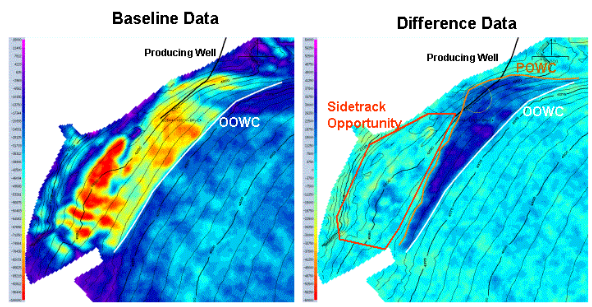

Figure 3: Map view of baseline and difference top sand amplitude at K1s. The original OWC (white line) and present OWC (brown line) based on 4D are indicated as well as the location of the producing well. The red polygon shows an area of by-passed hydrocarbons.

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 are under primary depletion without aquifer support. 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.

Compaction in the K2

The K2 is a 150ft thick sand that lies below the J sands. Figure 4 shows the top sand amplitude picks from the mid-offset stack (preferred in the undershoot area). Difference data suggests compaction-related impedance increase in a region around well 1 which is the largest producer with 4300psi pressure drop. Limited production and a rapid (2500psi) pressure drop suggests that well 2 is either in a relatively small compartment or has completion problem. Difference data shows a local 4D impedance increase at this location possibly supporting the limited production results. Well 3 was drilled after the 4D acquisition in a region with good amplitude support (as seen from the baseline data) and no 4D signal (as seen on the difference data). Well results are consistent with the lack of 4D signal indicating no depeltion.

Compaction and water injection in the J2

The J2 is a 70ft thick sand. Figure 5 shows wells 4 and 5 that are the best producers in this sand with approximately 2600psi depletion each. The difference data suggests that large area (yellow polygons in Figure 5) has compacted around these wells and the two areas could be connected which is consistent with production data. 4D data show that the area highlighted by the red circle is a compartment that is not being depleted by wells 4 or 5 and could be a future drilling target. Well 7 is in a compartment with limited production and a 2700psi pressure drop. The difference data suggests that well 7 is not connected to the main reservoir. Well 8 (in blue in Figure 5) is a water injector. 4D data from the mid-offset stack show a region of increased impedance around this well (blue polygon in Figure 5).

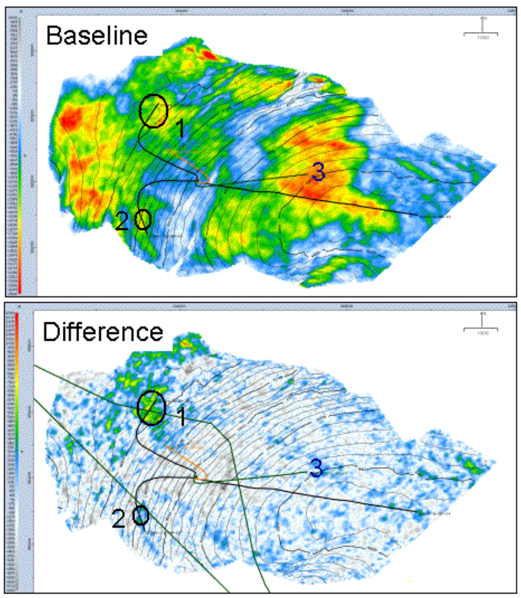

Figure 4: Baseline and difference amplitudes at K2. Black circles indicate amount of pressure drop up to the time of the monitor survey (4300psi at well 1, 2500psi at well 2). Green polygon indicates undershoot area. Difference data shows compaction (impedance increase) around well 1 and compartmentalization around well 2. Well 3 is a post 4D well with good production.

Compaction and water injection in the J3

The J3 is a 110ft thick sand just below the J2. Well 9 is the largest J3 producer followed by well 10 (Figure 6) and both wells show 2700psi depletion. The 4D difference data are consistent with production data and spatially identifies the potentially depleted area. Well 11 is an injector that was drilled during acqusition of the 4D survey. Well 12 is a water injector however, it is in the most poorly repeated part of the survey where 4D interpretation is not reliable.

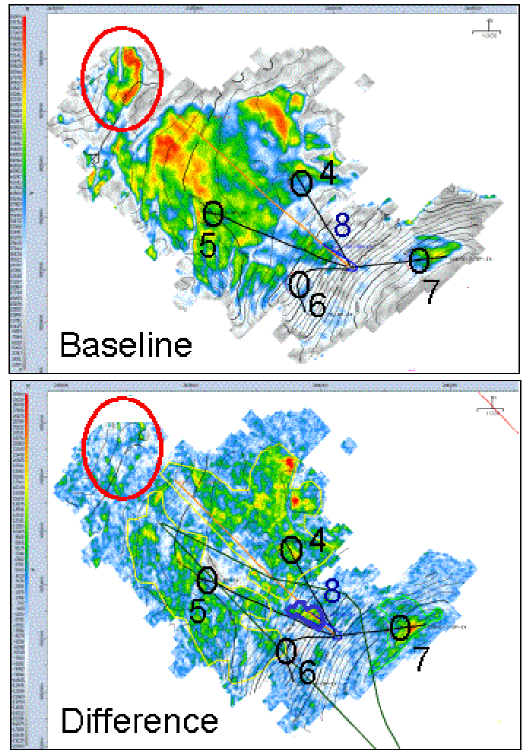

Figure 5: Baseline and difference amplitudes at J2. Black circles indicate amount of pressure drop up to the time of the monitor survey (around 2600psi at wells 4-7). Green polygon indicates undershoot area. Difference data shows impedance increase region around wells 4, 5, 7. Well 8 is a water injector and injection related impedance increase can be seen around this well (blue polygon).

Time-shifts from the Main Sands (J and K)

At Holstein apparent 4-D time-shifts up to 6ms are observed over the depleting sands (Figure 7). These time shift values are indicative of reservoir compaction. In map view (Figure 8) the time-shifts correlate well with the pressure decrease observed at wells over multiple depleting sands. The largest pressure decrease (largest black circle in Figure 8) corresponds to 4200psi where the largest time-shifts are observed. Modeled time-shifts generated from dynamic reservoir simulation are consistent with the time-shifts taken from field data after adjusting for pore compressibility. Further, the red circles in Figure 8 indicate areas of mis-match between the modeled time-shifts and field data. Pressure data from wells drilled after the 4D in the northern mis-match regions (outside the green undershoot polygon) show depletion, supporting accuracy of the field 4D time-shifts.

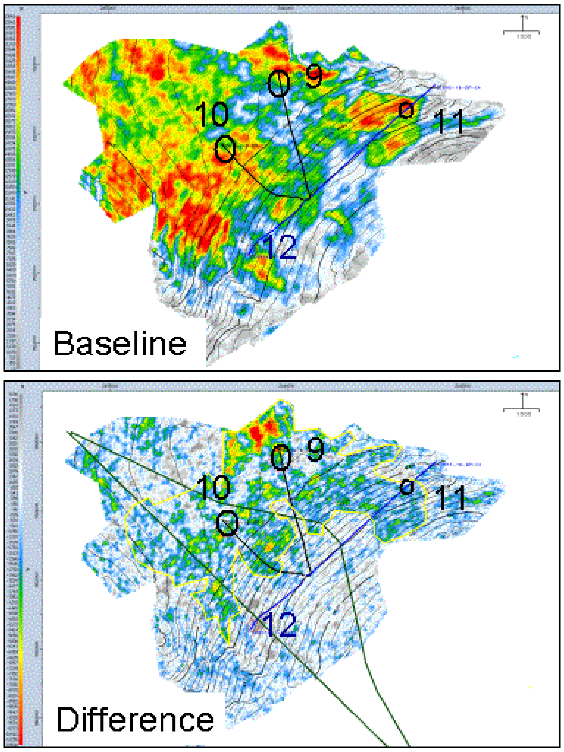

Figure 6: Baseline and difference amplitudes from base of J3 sand. Black circles indicate amount of pressure drop up to the time of the monitor survey (around 2700psi at wells 9 and 10). Green polygon indicates undershoot area. Difference data shows region of impedance increase around wells 9 and 10. Well 12 is a water injector in the undershoot area.

Conclusions

Successful acquisition of 4D towed-streamers data with high repeatability at Holstein in the deepwater GOM has shown that high quality 4D amplitudes and time-shifts can be obtained and used to support field development decisions. Time-lapse amplitudes show sweep and compaction of individual producing sands and time-lapse time-shifts suggest production-related effects of compaction of stacked sands. Seismic time-shifts, in conjunction with 4D amplitudes, can be used to support decisions to place production wells in virgin compartments and to place water injectors that will support existing producers. At Holstein, 4D is currently being used to place future production and injection wells, and a second monitor survey is being planned for 2009.

Acknowledgements

The authors would like to thank Shell and BP management for given us the permission to publish this work.

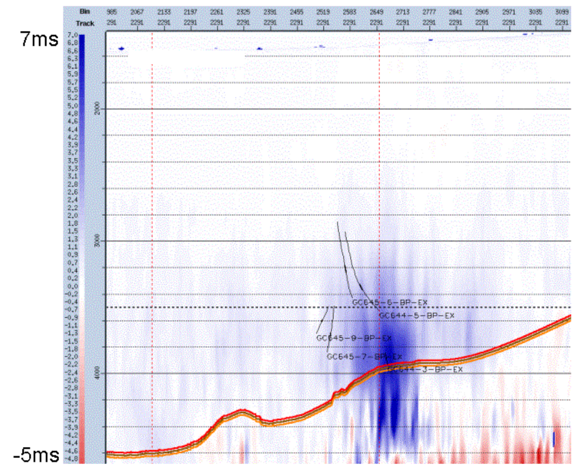

Figure 7: Cross-section of time-shifts over central part of depleting J and K sands.

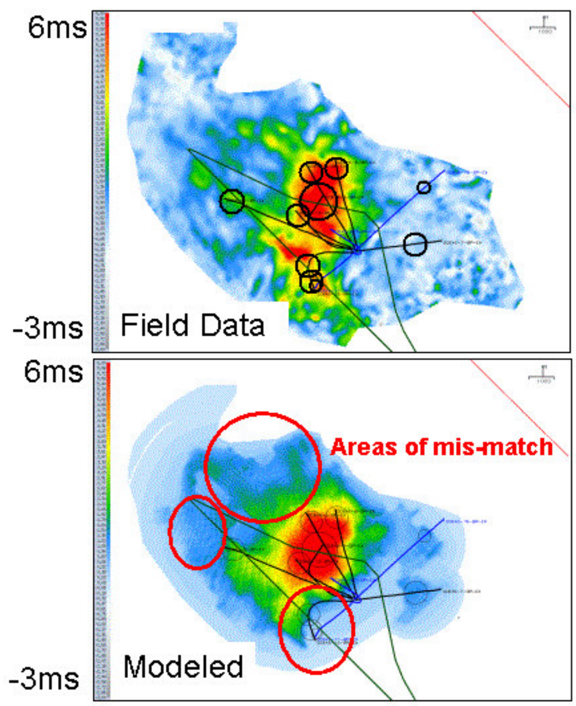

Figure 8: Field data time-shifts extracted above the J2 sands (top) and pressure depletion observed at wells in J and K sands (black circles). Modeled time-shifts above the J2 sands (bottom) indicate areas of mis-match (red circles) with the dynamic model.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2008 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Barousse, C., D. Herron, D. Stanley, and J. Kaldy, 2007, Concept systems: Shell EP Americas.

4D repeatability using dual vessel acquisition: Holstein Field, Gulf of MexicoDeriskinig of time-lapse monitoring at Mars with 2D data: The Mars/Europa Time-Lapse Study Team, EPJT, 2005.

Tura, A., S. Hany, C. Collins, K. Koster, M. Ligtendag, and C. Heldreth, 2007, 2D high-repeat lines over 12 fields and their impact on the future of 4D seismic in the Gulf of Mexico: EPJT 2007.