Seismic Modeling, Migration and Velocity Inversion

BP-Shell Holstein in GOM

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Outline

1. **Holstein (see Calvert et.al. TLE 2003)**
   - Background and Seismic Problem
   - Reservoir Development
   - Sampling Requirements
   - Bandwidth
   - The Test Lines
   - Processing Issues
   - Acquisition
   - Velocity Model Building
   - Common Azimuth and Kirchhoff Migrations
   - Reflectivity and Acoustic Impedance
   - Development Timeline

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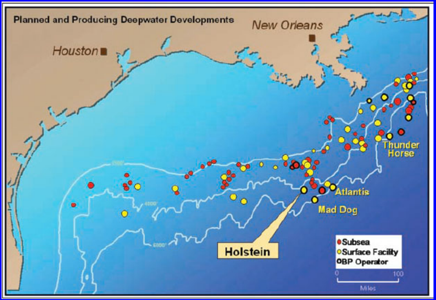
Location and Summary

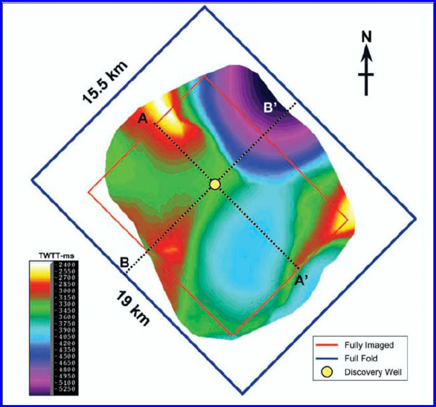
- 200 miles So. of New Orleans
- 4300 ft water depth
- Discovered in 1999
  - Exploration DMO-Time survey
  - Appraised at 350 MM BOE
- Challenging development
  - High costs — deep water
  - Complex reservoir



Basin Structure and Key Lines

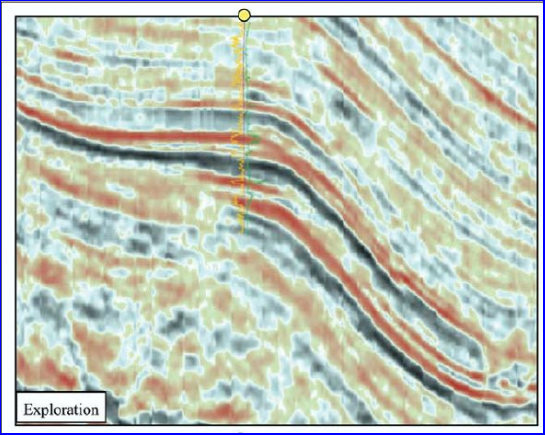
Representative structural map of Holstein Basin. AA′ and BB′ indicate location of two test lines used to verify acquisition parameters and assess the degree of expected multiple contamination. Yellow dot indicates discovery well.

Area in red is the full fold and fully imaged boundaries of a high resolution survey survey acquired to address reservoir characterization issues. AA′ and BB′ also are the locations of subsequent inlines and crosslines from the new high resolution survey acquired to address reservoir characterization issues.



Discovery Seismic

Exploration AA′ line extracted from the original 3D exploration DMO-Stack-PostStack-Time migration volume. Assessment and production wells used to provide reservoir description. Note the structural ramp to the right in this figure.



Reservoir Characteristics

- Stacked sheet sands 15 - 150 ft thick
- Separated by shale layers of similar thickness
- Compensation geometry
  - Net thickness of adjacent gross units remain almost constant
  - Relative proportions vary significantly
- Sands act as independent reservoirs
  - Different pressures
  - Hydrocarbon heights of 2500 ft
  - Description of the structural ramp critical to design of successful water flood
- Strong lateral velocity variations ($\approx$ 15 %)
- Limited AVO response
- Zero-offset reflectivity sensitive to water saturation.
- Oil-bearing sands have low reflectivity
- New survey required to characterize reservoir

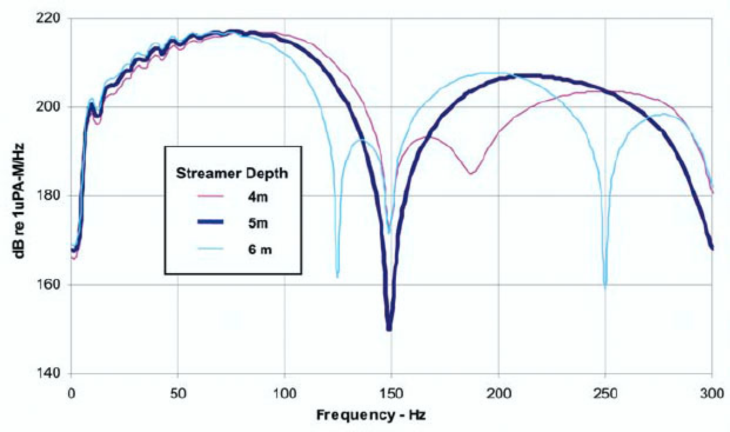
Reservoir Characterization Objectives

- Resolve a 25 ft thick sand package
  - Requires 75 HZ and 7,500 ft/sec sand velocity
  - Implies fine sampling during acquisition
- Reservoir description of 30 degree structural ramp
- Provide basis for subsequent water-flood
- Estimate local pressures
- Accurate development well placement
- Provide basis for 4D time-lapse

Achieving Theoretically Optimum Imaging

- Two-samples per wavelength for common-offset migration
  - Max $(\Delta x, \Delta y) \approx \frac{V_{min}}{4f}$
  - With $f = 75$ and $V_{min} = 5280$, Max$(\Delta x, \Delta y) \approx 17.5$ ft (5m)
- For migrations that mix offsets (WEM, RTM)
  - Max $\Delta offset \approx \frac{V_{min}}{2f}$
  - With $f = 75$ and $V_{min} = 5380$, Max $\Delta offset \approx 35$ ft (10m)
- Alternatives to reduce cost
  - Interpolate beyond aliasing in processing
  - Limit dip range
    - At 45 degrees the numbers above become 10m and 20m respectively
- Economic threshold
  - 12.5m crossline bin
- Closer one gets to the ideal the less likely assumptions will be violated

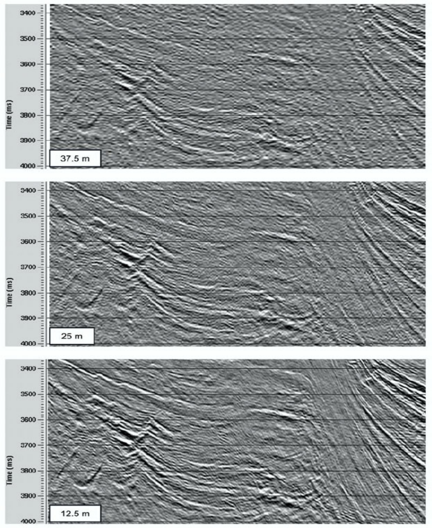
Cable Tow Depth and Bandwidth



Effect of cable tow depth on the signal spectrum for a 3000 in^3 source array towed at 5m. Note that all the graphs have notches at 150 HZ and 300 HZ owing to a consistent source depth of 5m with additional notches due to cable tow depth.

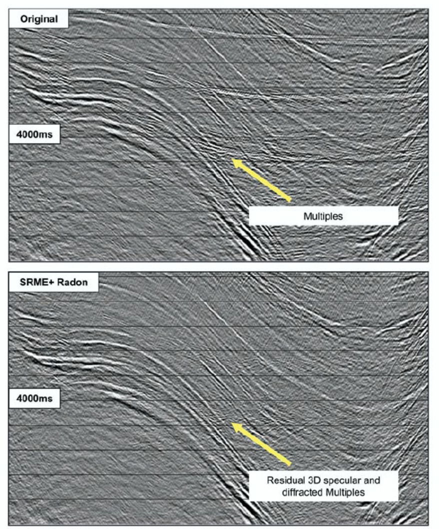
Test line BB′ Sampling

Portion of test line BB′ DMO-poststack-time migration with bin sizes of 37.5m, 25m, and 12.5m to investigate impact of crossline sampling on resolution. Note the progressive increase of lateral resolution with decreasing bin size.

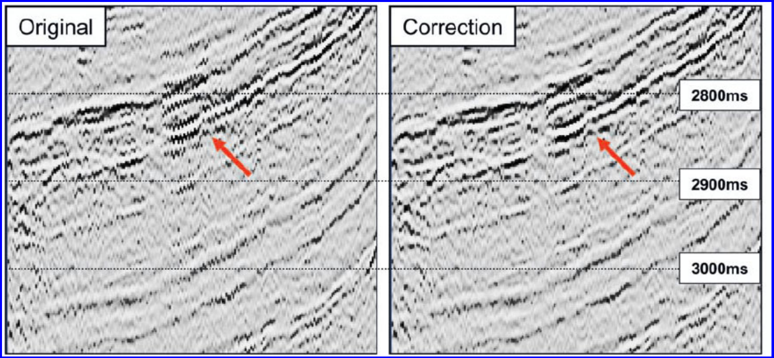


Short Stacks and Multiple Elimination

AA′ 0-800m stack illustrating effectiveness of a combined 2D SRME and high-resolution Radon approach to multiple attenuation. The strong 2D multiples are significantly attenuated; however, specular and diffracted multiples from out of the plane are not attenuated as effectively.

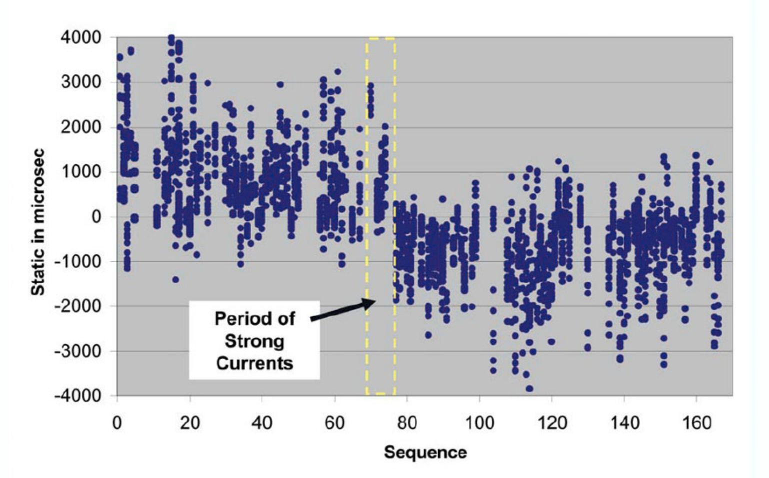


Holstein



Example crossline through a common offset cube before and after application of a correction for water column statics.

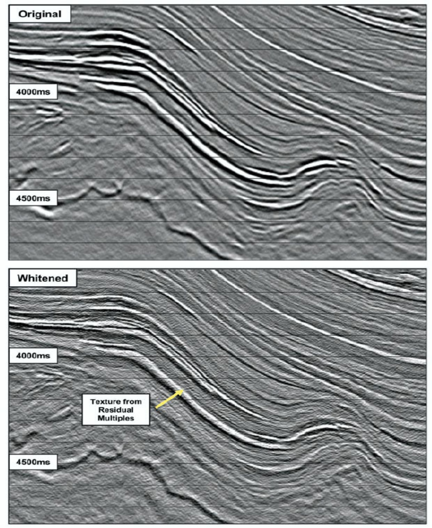
Holstein



Calculated water column static versus sequence number showing possible correlation of a change in water velocity with a period of strong loop currents.

Holstein

Inline before (top) and after (bottom) spectral whitening. This illustrates the presence of residual multiple energy at high frequencies after spectral whitening.



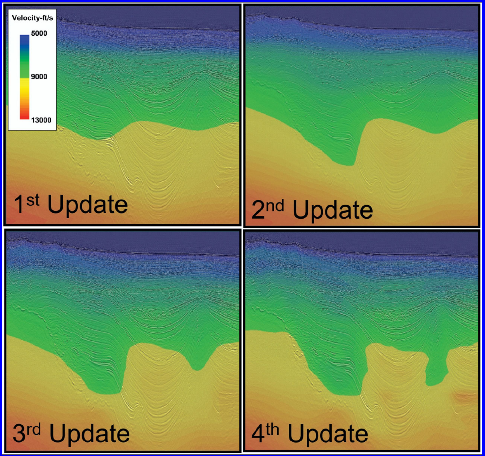
Acquisition Summary

Table 1. *Acquisition parameters for exploration survey (WesternGeco's Green Canyon Ultra Survey, Phase 11), 2D test lines and new 3D*

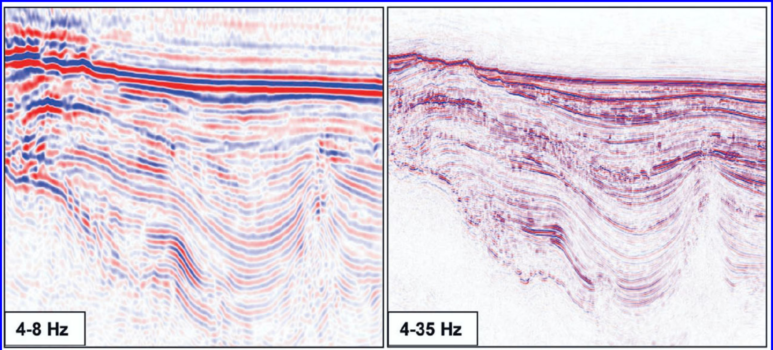
	Exploration	2D Test Lines	New 3D
Inline bin (m)	12.5	3.125	6.25
Crossline bin (m)	40	-	12.5 (via interleave)
Number of sources	2	1	2
Shotpoint interval (m)	75	25	37.5
Source depth (m)	7	5	5
Source volume (cu.in.)	6000	2958	3000
Number of streamers	3	1	6
Streamer length (m)	8000	8000	6400
Streamer depth (m)	10	6	5
Group interval (m)	25	3.125 summed to 6.25	12.5
Nominal fold	53	160	85
Streamer type	Conventional	Conventional/Q	Solid
Record length (s)	13	12	6.5

Common Azimuth Velocity Updates

Evolution of the depth velocity model during iterative velocity model building. Each iteration consisted of a full volume Kirchhoff PSDM on a 25 X 25 m grid followed by tomography. Note the progressive increase in detail with each iteration and the non-conformance of the velocity with stratigraphy. Variations in velocity are believed to result from presence of hydrocarbons and overpressure.

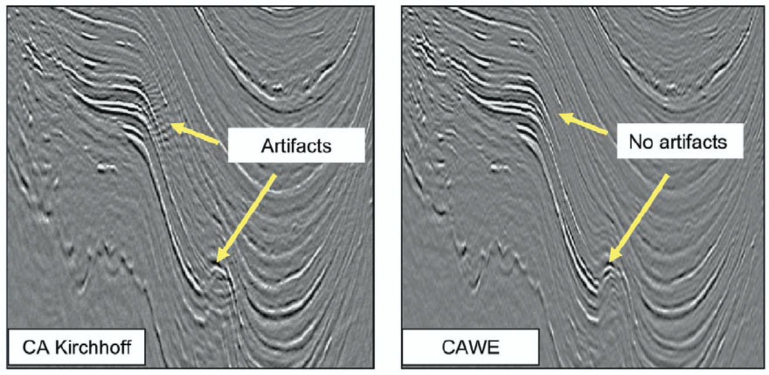


Holstein



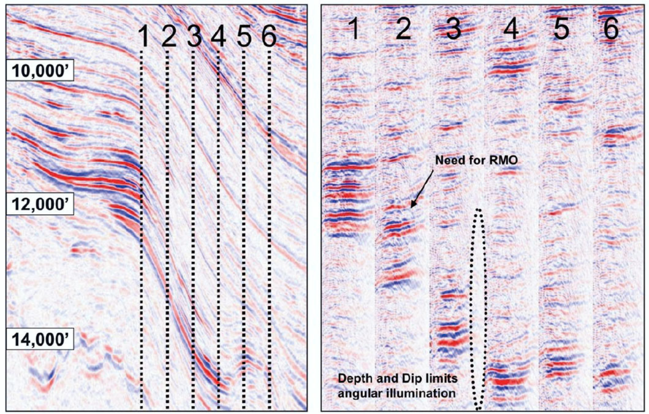
CAWE stacks generated from 4-8 Hz and 4-35 Hz bands. Note the interpretable features in the 4-8 Hz band despite shallow tow and narrow bandwidth. In 2003 migrating 300 km^2 at 100 Hz was a massive computational task. CAWE migration done in 4 frequency bands in 10 weeks. Today an RTM could be done in just two weeks.

Kirchhoff vs Common Azimuth Migrations



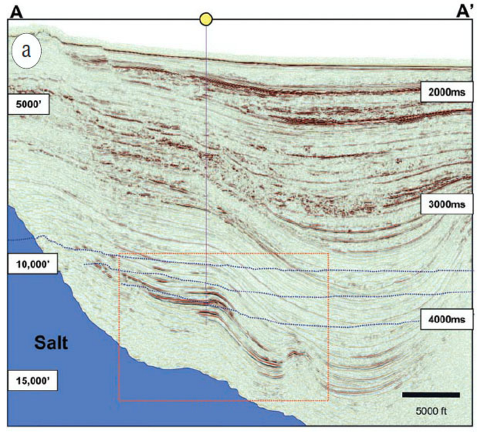
Comparison of common azimuth (CA) Kirchhoff and common azimuth wave equation (CAWE) migration with same data and velocity model illustrating artifacts resulting from approximations (tiling of operator) made in Kirchhoff for speed. Shows Kirchhoff velocity sensitivity.

Holstein



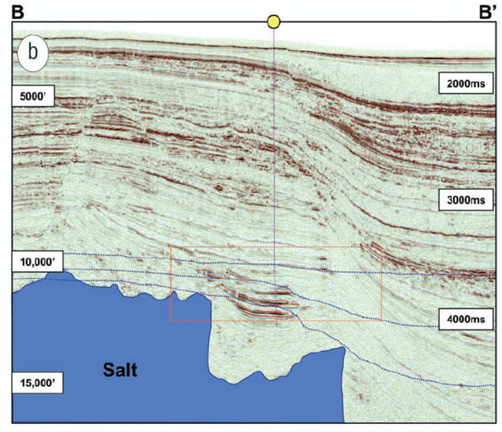
Example angle gathers ($0 - 40^o$) showing need for residual moveout on dipping sections despite four iterations of velocity model building (perhaps related to anisotropy). Note also the limits placed on angular illumination by a nonzero minimum offset, dip and depth.

AA′ Reflectivity (Depth)



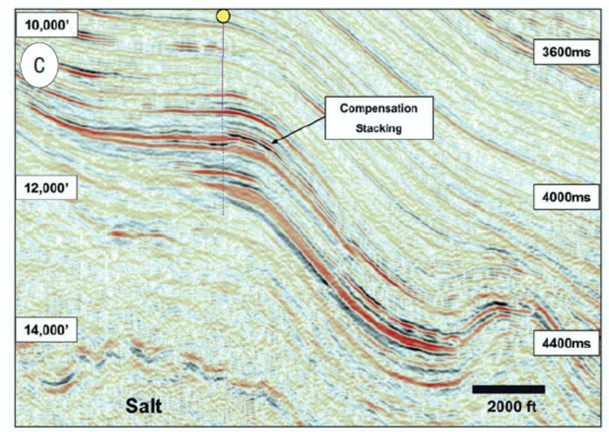
Reflectivity section from high resolution survey along AA′ showing supra salt location and exploratory well. The stacked sands are apparent. Dashed blue lines indicate the approximate location of free-surface multiples form water bottom and two shallow reflective horizons.

BB′ Reflectivity (Depth)



Reflectivity section from high resolution survey along BB′ showing Holstein's structure along strike. The stack sands are very clear. Blue lines indicate approximate location of water bottom free-surface multiples and two shallow reflective horizons.

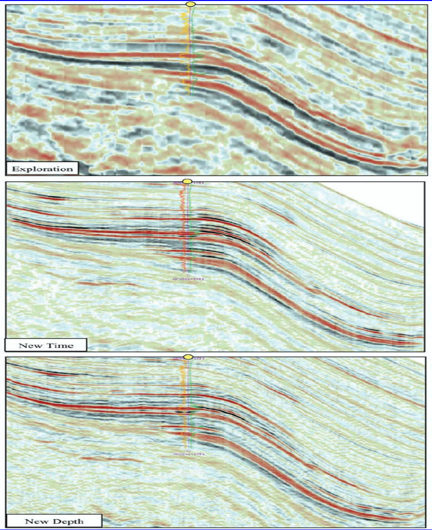
AA′ Acoustic Impedance ZOOM (Depth)



Acoustic impedance (AI) section generated from the high resolution survey showing a zoom of the red box area in Holstein slide (a) above. Note compensation stacking of reservoir sands (red) within gross packages.

Holstein

Inline comparison of AI volumes generated from the exploration, new time, and new depth data sets. Note the significantly improved vertical resolution in the new survey and the high resolution that can be obtained from a suitably parametrized depth migration.



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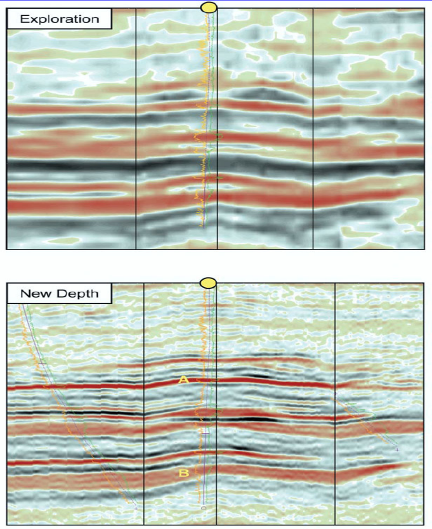
Arbitrary well-tie line (discovery and two development wells) from exploration and depth AI volumes. Note the significant improvement in vertical resolution and excellent correlation of low acoustic impedance zones with pay sand. Sand thicknesses penetrated at locations A and B are 20 ft and 70 ft respectively.



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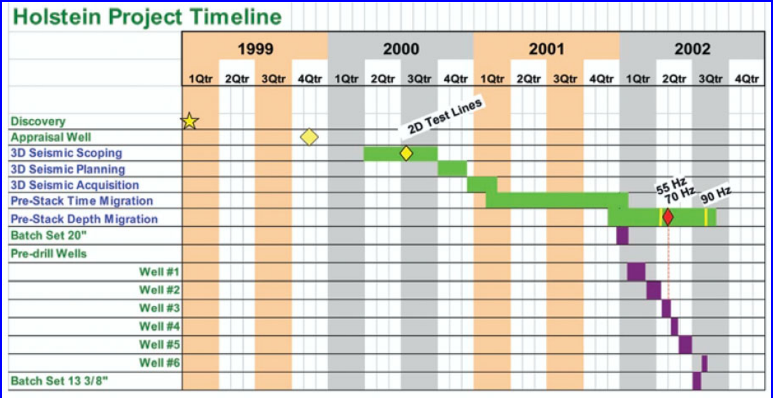
Holstein Project Timeline
1999
2000
2001
2002
1Qtr 2Qtr 3Qtr 4Qtr
Discovery
Appraisal Well
3D Seismic Scoping
3D Seismic Planning
3D Seismic Acquisition
Pre-Stack Time Migration
Pre-Stack Depth Migration
Batch Set 20"
Pre-drill Wells
Well #1
Well #2
Well #3
Well #4
Well #5
Well #6
Batch Set 13 3/8"
2D Test Lines
55 Hz
70 Hz
90 Hz

Questions?