[AV]Seismic Technologies for Unconventional Reservoir Characterization: Wamsutter Field Case Study

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Abstract

As part of a significant seismic technology effort, the BP Wamsutter Seismic Integration team conducted two extensive field trials during 2006 and 2007- a surface seismic field trial and a borehole seismic field trial.

The surface seismic field trial consisted of the world's-first deployment of cableless full-wavefield single-sensors in a 3D onshore survey. This acquisition delivered a unique high density, full azimuth, 3-component dataset for analysis. Very careful processing was applied to the full wavefield data to optimize resolution and retain robust amplitude and azimuthal information. In addition to conventional full stack seismic attributes, analysis of velocity anisotropy, AVO (Amplitude with Offset) and AVOAz (AVO with Azimuth) attributes calibrated to well data have greatly increased our understanding of this tight gas sandstone reservoir.

The borehole seismic field trial consisted of a 3D VSP (Vertical Seismic Profile), as well as a four-well crosswell seismic campaign. The 3D VSP was acquired to further our understanding of seismic technical limits within the field, demonstrate the value of enhanced temporal resolution to reservoir characterization, and to test the viability of borehole seismic as a development tool for infill planning. Pre-acquisition modeling allowed theoretical limits of vertical seismic resolution to be compared to existing seismic data. Processing of the field data demonstrated that significantly higher frequencies (double the bandwidth) were achieved with the 3D VSP, as compared to existing and newly acquired surface seismic data. Prestack depth migration of the 3D VSP yielded high quality imaging results, which have allowed enhanced stratigraphic description of a very complex, heterogeneous reservoir.

Analysis, interpretation, and integration of the surface seismic and borehole seismic data have greatly progressed our understanding of the potential increase in the value of "designer" or fit-for-purpose seismic across the Wamsutter Field and beyond. Learnings from the field trial are already impacting the onshore seismic strategy both within the Wamsutter field and across BP's tight gas business.

Reference

Sinha, S., and R. Ramkhelawan, 2008, P-wave azimuthal anisotropy from a full-wave seismic field trial in Wamsutter: SEG Expanded Abstracts, v. 27, p. 198-201,
http://dx.doi.org/10.1190/1.3054787

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Seismic Technologies for Unconventional Reservoir Characterization: Wamsutter Field Case Study

BP America
Rosemarie Geetan*, Brian Hornby and Ricko Wardhana

Talk Outline

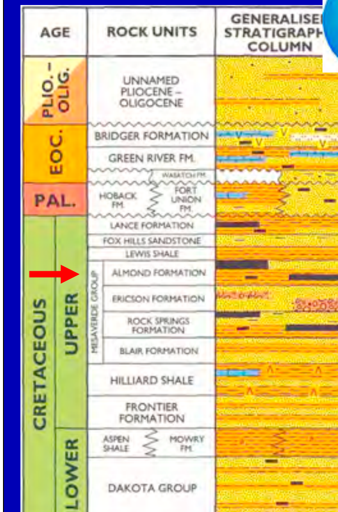
Location and Geologic Setting

The 2006/ 2007 Seismic Program

Interpretation and Analysis

Integration and Summary

Wamsutter Field Context



- Located in Eastern Green River Basin, WY
- 'Wamsutter Development Area' covers >1600 sq miles
- > 50 TCF GIIP, of which 2TCF produced & >30TCF YTF
- 2 major tight gas fairways under development (Almond, Lewis), multiple others with additional potential
- Almond reservoir is 500ft thick at depth of 10,000ft
- 2007 regulatory approval for 40 acre infill
- Hydraulically fractured completions yield 800mscfd IP, recover ~2bcf

Presenter's Notes:

-Wamsutter is a tight gas field located in the Eastern Green River Basin in Wyoming, one of the largest in the US

-Estimated more than 50 TCF in place of which only 2 been produced

-Been in development since the 1970s and is currently at 80 acre spacing, Completed by hydraulic fracs

-Now moving to 40acre spacing and pad development – becoming more challenging as move outwards into more complex geology – transition from shoreface-dominated system to more heterogeneous coastal plain environment

-To date, well placement has been dominated by production and well correlation with only a few operators seeking to incorporate seismic

-Production predominantly from the Cretaceous Almond section with 10% from overlying Lewis

-Target horizon is at ~10,000 ft and approx 500ft though low N:G (~20%)

-Almond is thinbedded heterogeneous

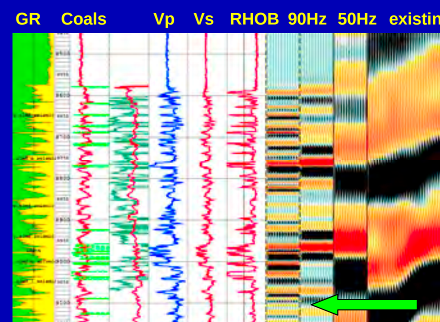
-Also worth noting is the extremely sensitive environmental conditions of the Wamsutter region – a number of species are listed as endangered and the state imposes strict guidelines on both drilling and seismic activities. The future development will be largely controlled by our ability to minimise our impact.

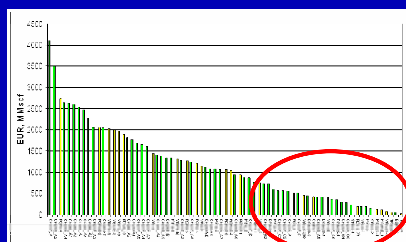
The Imaging Challenge

- Field development becoming more complex
- Existing seismic not optimal for development needs
- Need for simpler more integrated seismic workflow

Field Trial Objectives:

- Explore new technologies with the potential to transform land seismic capability
- Can seismic deliver a step change in ability to **high grade well locations**?





-***Presenter's Notes:***

-**Why here and why the field trial?**

-Geology very complex and challenging

  -Coals in reservoir section mask sand response

  -Thinly bedded stratigraphy of lower coastal plain

-Field development becoming more complex – economics depend on need to improve average well outcome in outer field areas. Not able to resolve with well correlation.

-Existing data limited – azimuth, offset, fold, different vintages, resolution (see figure)

  -Merge of different vintages

  -Highly layered stratigraphy characterised by essentially 2 seismic cycles

  -1D modeling suggested that higher bandwidth data would have potential to resolve more reservoir character

-Gap between existing data quality and today's capabilities

-Current workflows based on geostatistical attribute approach and in need of rigorous calibration to subsurface properties

Field Trial has 2 objectives:

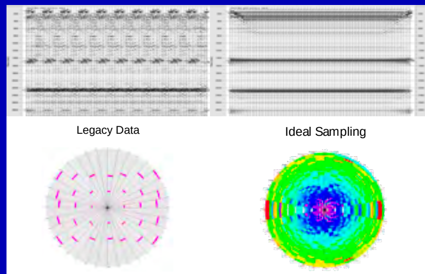
-Explore potential of new techs to move land seismic to a different place

  -Operational safety and efficiency

  -Imaging capability from advanced attributes

-Test ability to use seismic to high grade well locations and change statistical outcomes.

Survey Design: Surface Seismic



Equipment
- First production scale field test of ION Firefly acquisition system
- Cableless receivers - operational & HSE benefits (10,000 nodes)
- Full-wavefield recording captures more data from the subsurface
- Dynamite source

Design
- Orthogonal source & receivers deliver good bin sampling for offset and azimuth
- Static receiver patch records every shot
- Long offsets, full azimuth
- High density enables leading edge processing techniques

Presenter's Notes:

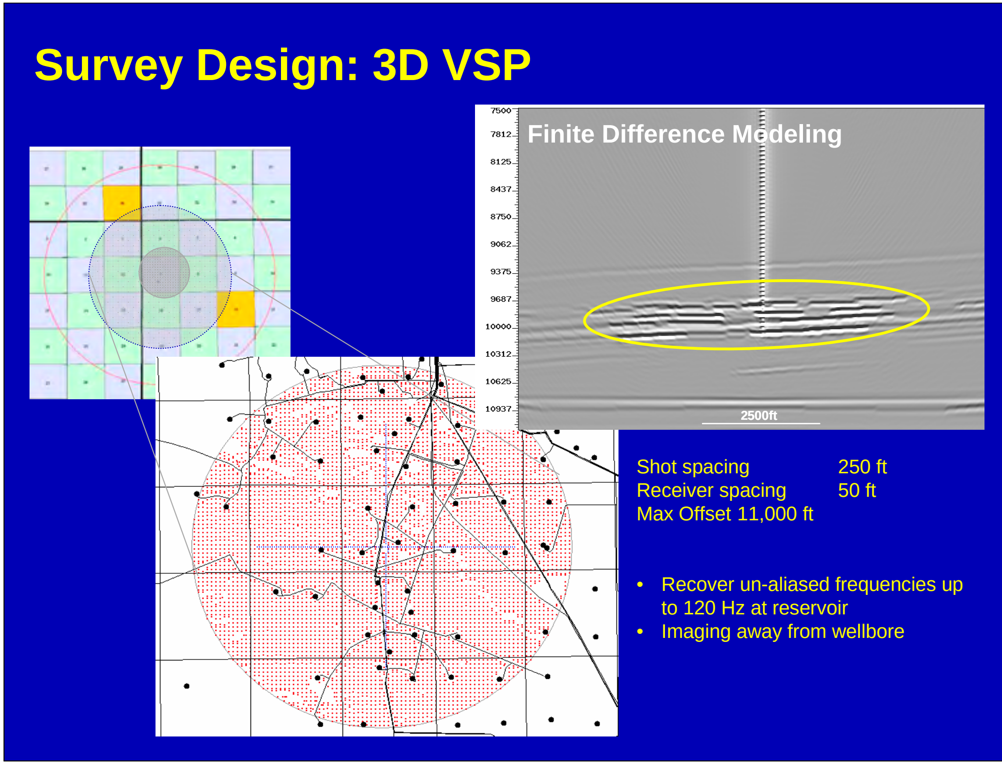
-The seismic survey was acquired in 2006-7 as part of a larger technology program, combined with a 3D VSP and crosswell tomography (see earlier presentations)

Equipment:

-The world's first production scale deployment of the Firefly acquisition system
-Shot over 25 sq miles in the center of the Wamsutter field, focused on Section 7 at the center
-Number of elements being trialled:
    -Cableless kits aimed to test capability to improve efficiency and safety of onshore shoots aligned to BP's development strategy
    -Full wavefield recording aimed to capture more data from the subsurface
-The first generation kit was not yet vibroseis capable so dynamite source was chosen based on field tests for size and depth
-As a side note, future shoots will move to vibroseis for both system efficiencies and potentially greater bandwidth outcomes

Design:

-Designed to enhance bandwidth (>40Hz), wide azimuth, long and uniform offset multicomponent
-2D Finite modeling was used to design optimal layout for desired offsets and azimuths
-Tx and Rx layed out orthogonally to retain good bin sampling of offset and azimuth
-Dense sampling – shots every 125ft, line spacing 750ft
-Offsets ranged from 625 to 24,000ft
-Static receivers so every Rx recorded every shot – final survey design included >8000 Rx and >7000 shots

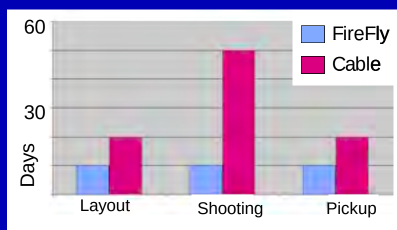


Presenter's Notes: From the finite difference modeling, the "perfect design" would have shots at 200 ft spacing out to an offset of 14,000 ft. This in effect would mean a source effort of approximately 15,000 vibe points. High frequency aliasing was expected at frequencies of 145 Hz or higher for source spacing of greater than 300 ft. The final design selected has a shot spacing of 250 ft, out to an offset of 11,000 ft, with wellbore 3C receivers every 50 ft. The selected grid slotted into the surface seismic field trial acquisition grid, which allowed synergies in the field execution aspects of the acquisition. This design was expected to recover unaliased frequencies of up to 120 Hz for the target depth of the Almond Formation. WEM PSDM imaging of the modeled data are in Figure 3. The image quality, extent, and resolution predicted by this result were more than adequate to justify going forward with this survey.

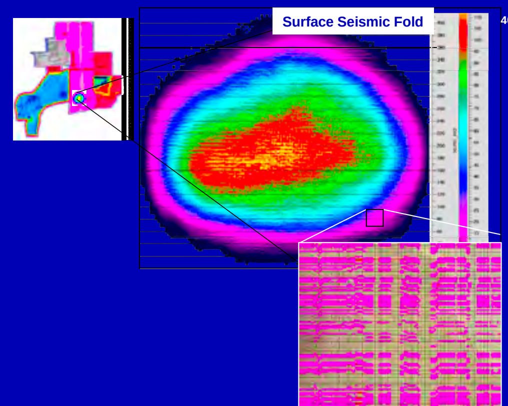
A previous multi-well survey had 4 wells with 80 levels in each well (Sullivan et al., 2002) – doubling the number of receivers in the well has the potential to significantly increase image quality and velocity control.

Acquisition: Surface Seismic

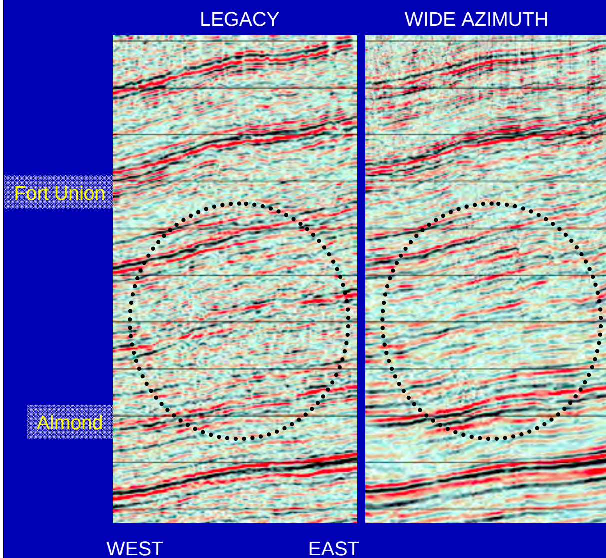
- Fast deployment and shooting rates (700 shots/day)
- Reduced manpower in field (no redeployment)
- High trace density 566,000 traces/sq mile (vs 39,000 traces/sq mile conventional)
- 4-6 times more fold at target than existing surveys
- Negligible environmental impact – animals ignored equipment

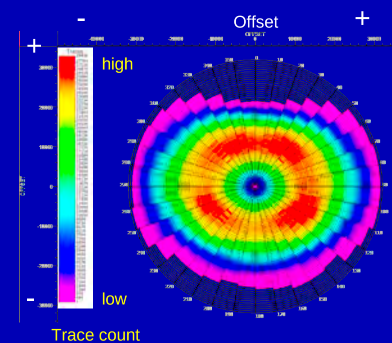


- Accelerated timeline
- Manufacturing delays
- Power management
- Weather
- Significantly less traces recorded than designed

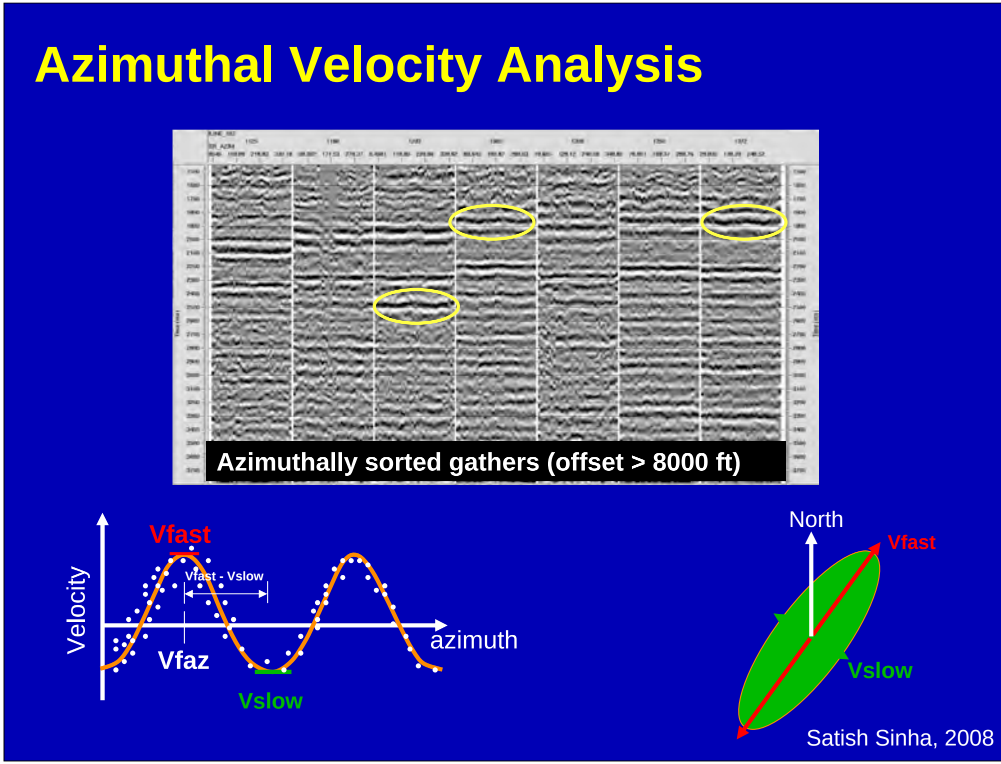


Legacy and wide-azimuth data surface seismic comparison





Offset/ Azimuth Distribution



Presenter's Notes: Offset sorted CMP after isotropic NMO<-> Resort these offsets by azimuth 0-360 degrees sinusoidal variation slow fast slow fast

Exceptional azimuthal coverage of FireFly seismic has enabled us to increase our confidence in azimuthal anisotropy analysis

Seismic velocity anisotropy correlates with the current day stress as well as paleo-stress conditions

Dipole sonic based anisotropy correlates with azimuthal AVO

Within FireFly area Almond reservoirs have seen two phases of tectonic deformations

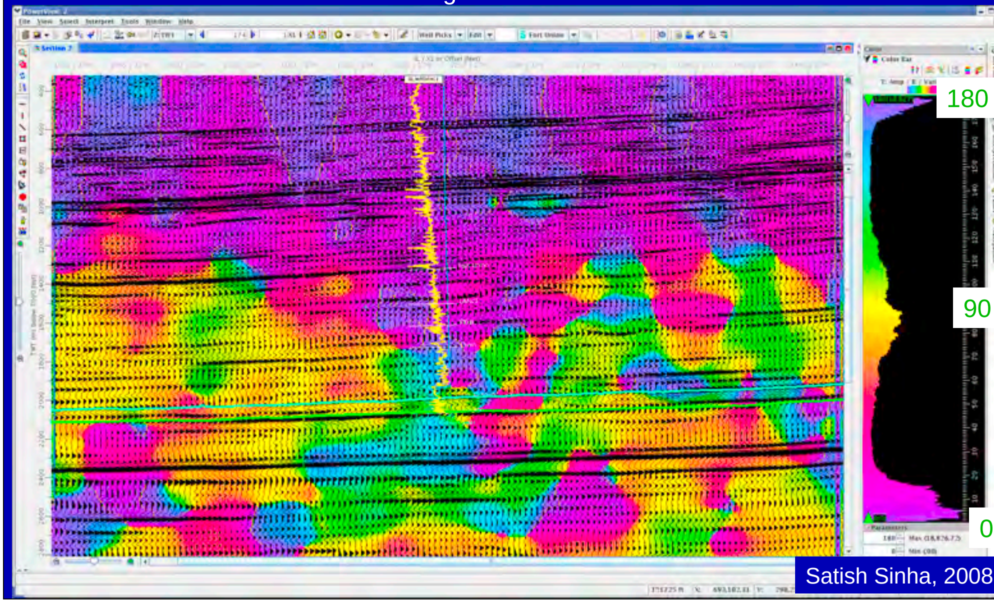
Current day maximum horizontal stress orientation in the area is N15-20 whereas paleostress is ENE-WSW

Current day stress orientation in WDA changes spatially from South to North

Numerous realizations of modeling for velocity anisotropy falls within the observed anisotropy from surface seismic

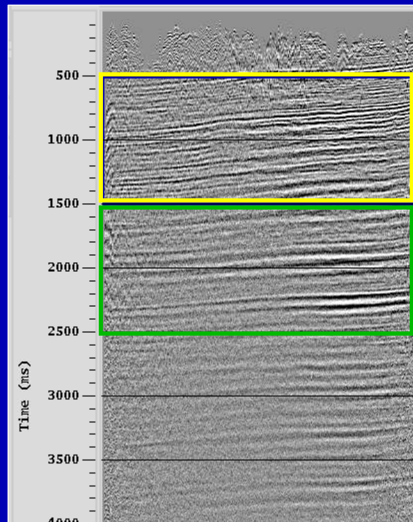
Azimuth of Fast Interval Velocity

E-W Line through calibration well

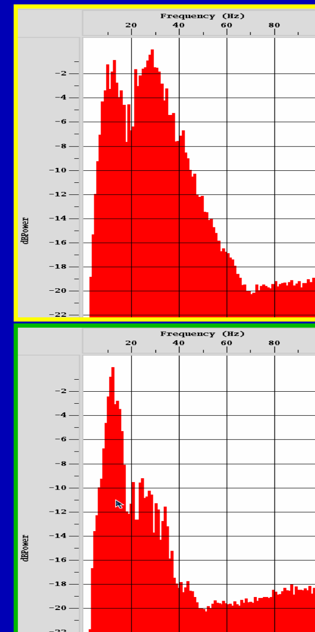


Satish Sinha, 2008

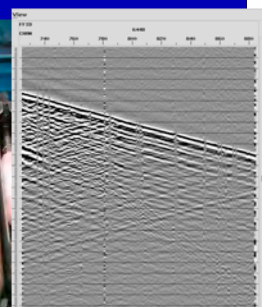
Rapid Overburden Attenuation

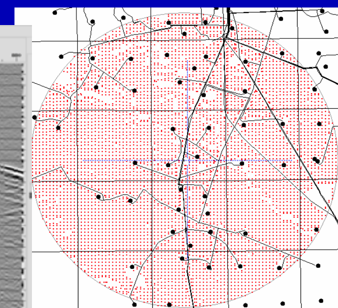


Shallow coals



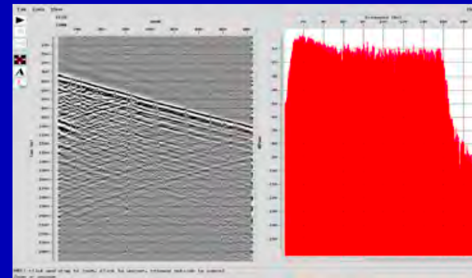
“Massive” 160 level 3D VSP at Wamsutter





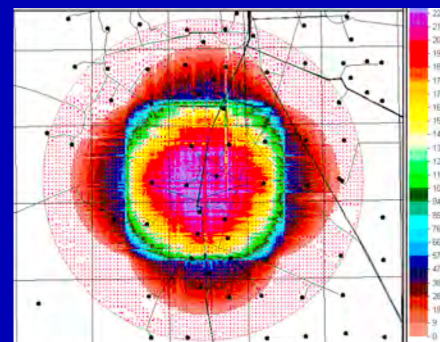
Circle is 11000 ft diameter

Acquisition: 3D VSP

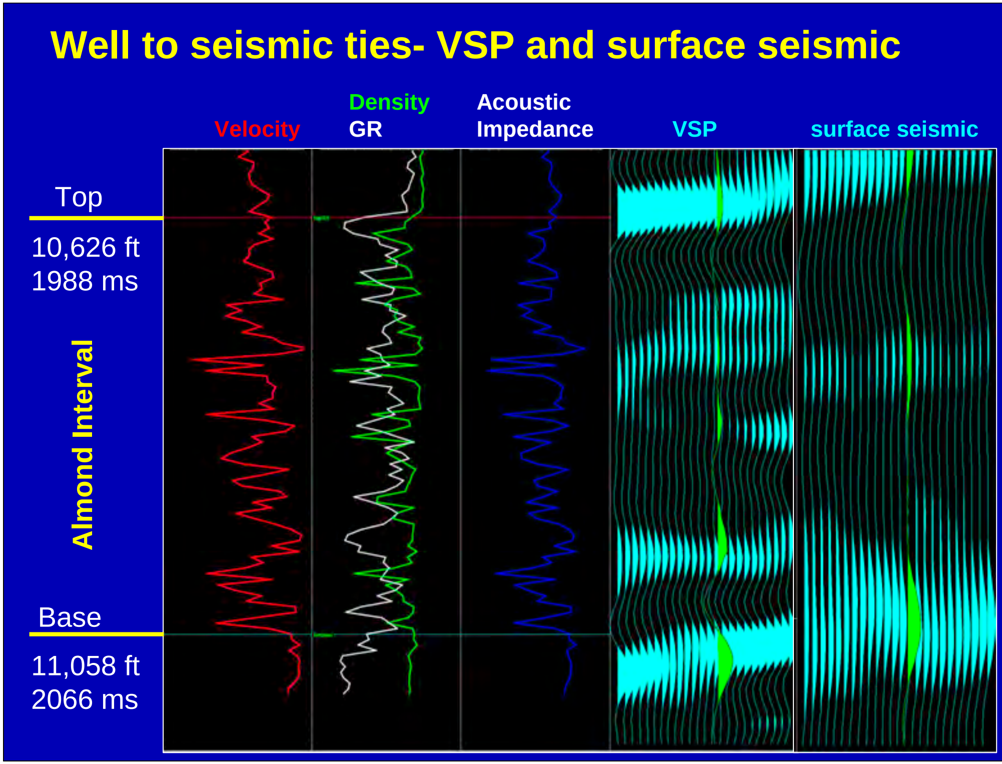


Recording:
- 8000 ft geophone tool string
- 160 3C geophones 50 ft apart
- 8 seconds recording

Source:
- Vibroseis single source
- 5630 vibe points
- 250 ft source grid
- 11,000 ft offset
- 2 sweeps, 14 s, 6-160 Hz

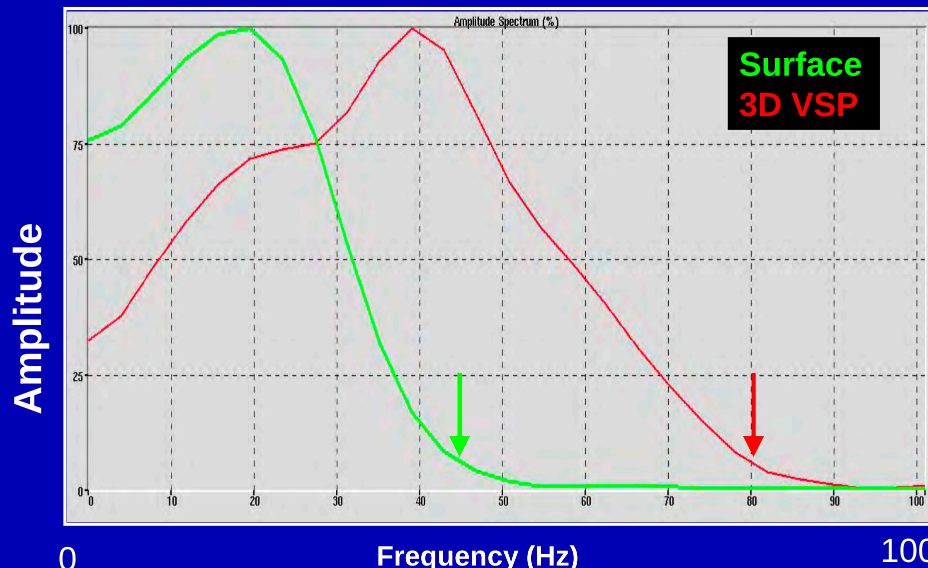


- 2,500-10,000ft depth
- **Largest array ever deployed in single borehole** – increased image quality & velocity control
- >90% pre-plot shots acquired over 6 days

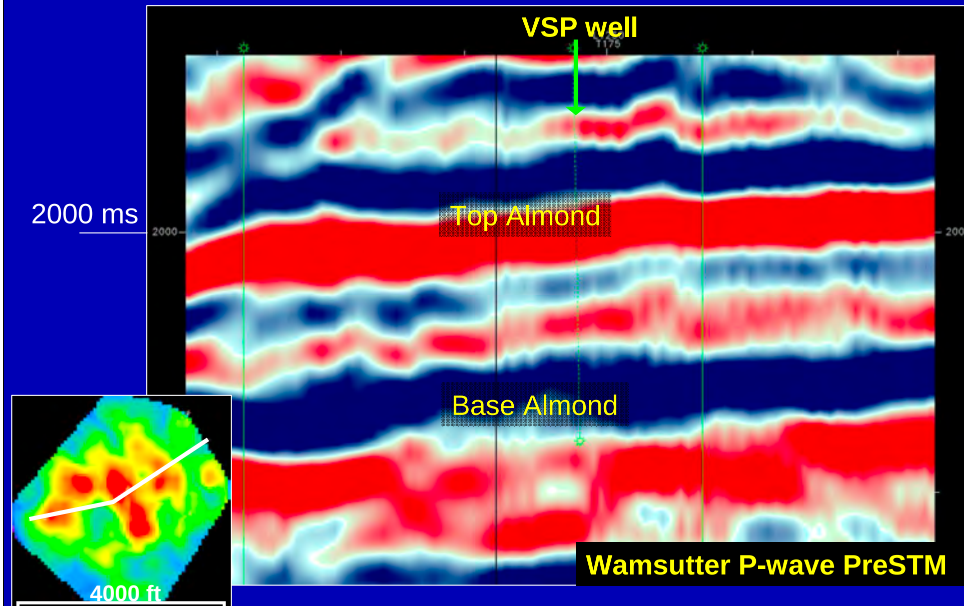


Presenter's Notes: As part of the data integration and interpretation process, well to seismic calibration was carried out for all the wells within the footprint of the VSP image. An example of the well tie to surface seismic and to the VSP data for the VSP well is illustrated. The higher resolution image from the VSP data hints at the internal complexity of the Almond Interval.

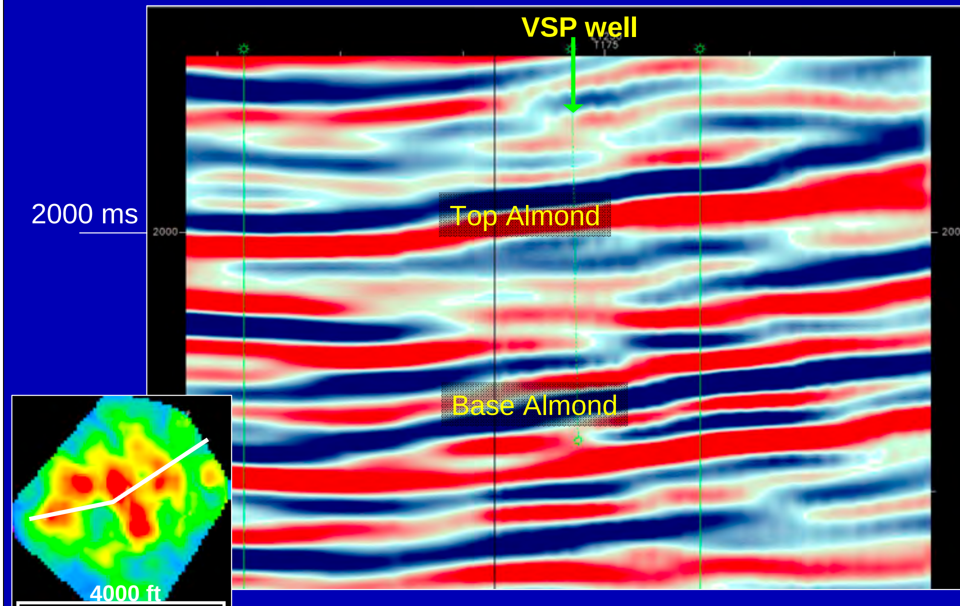
Bandwidth comparison-
Surface seismic and VSP data



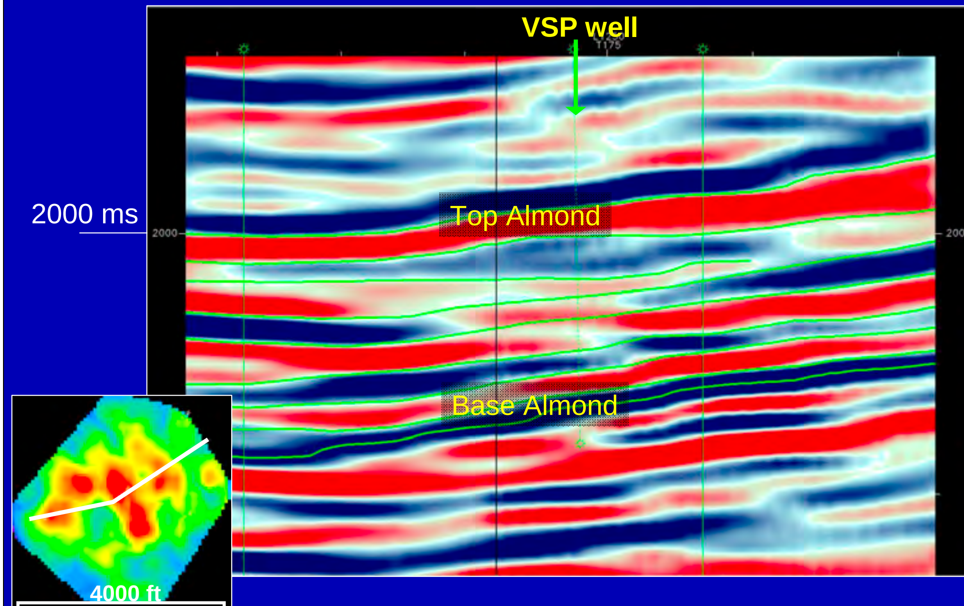
A look at the data-
comparison to surface seismic data



VSP data-
comparison to surface seismic data

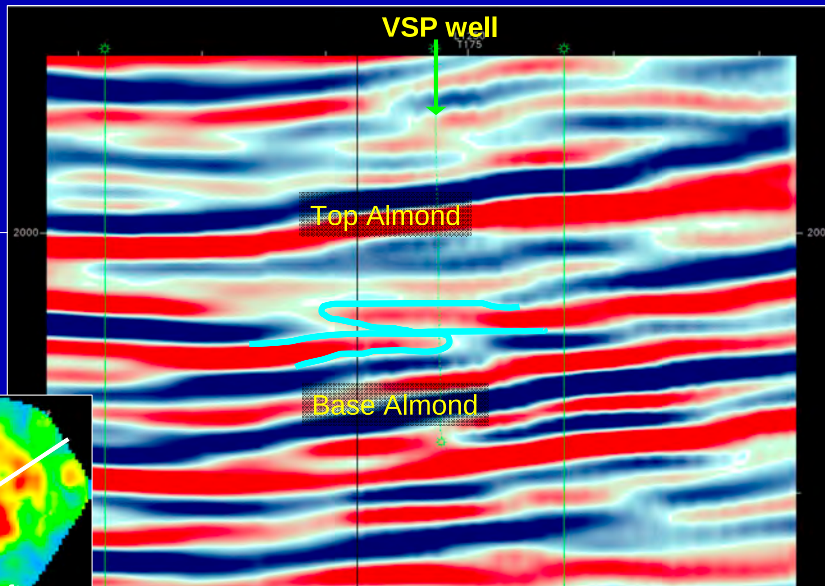


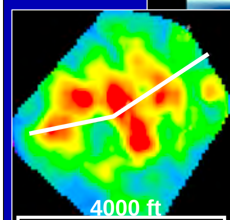
VSP data with interpreted surfaces



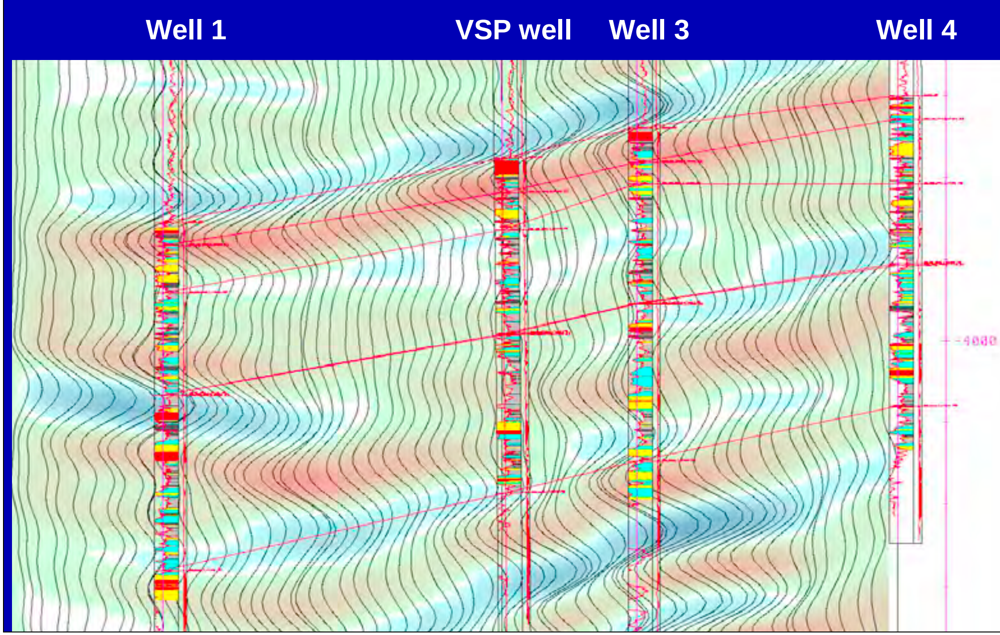
VSP Data

clearly visible terminations that tie into the depositional framework

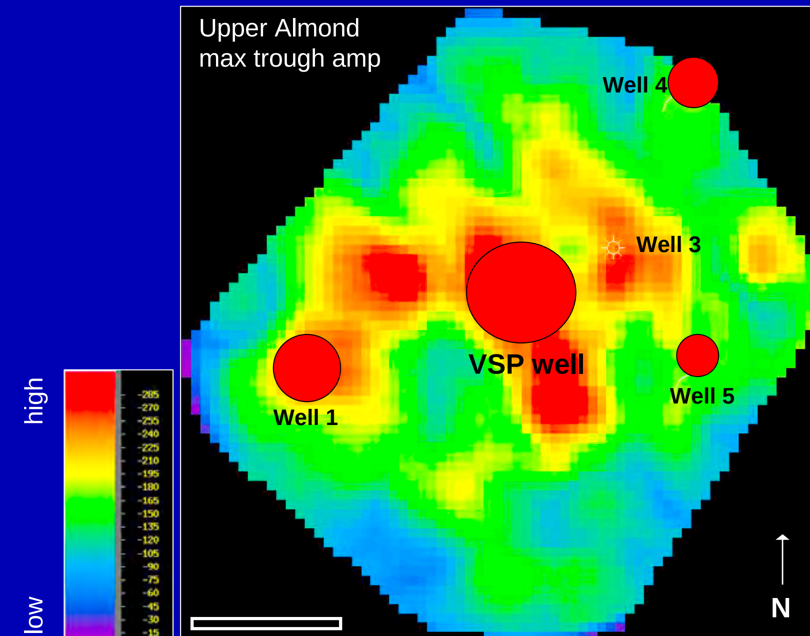




Line of section through VSP well
gamma ray curve displayed



Almond reservoir 3D VSP and Production overlay



Presenter's Notes: EURs shown (estimated ultimate recovery in BCF)

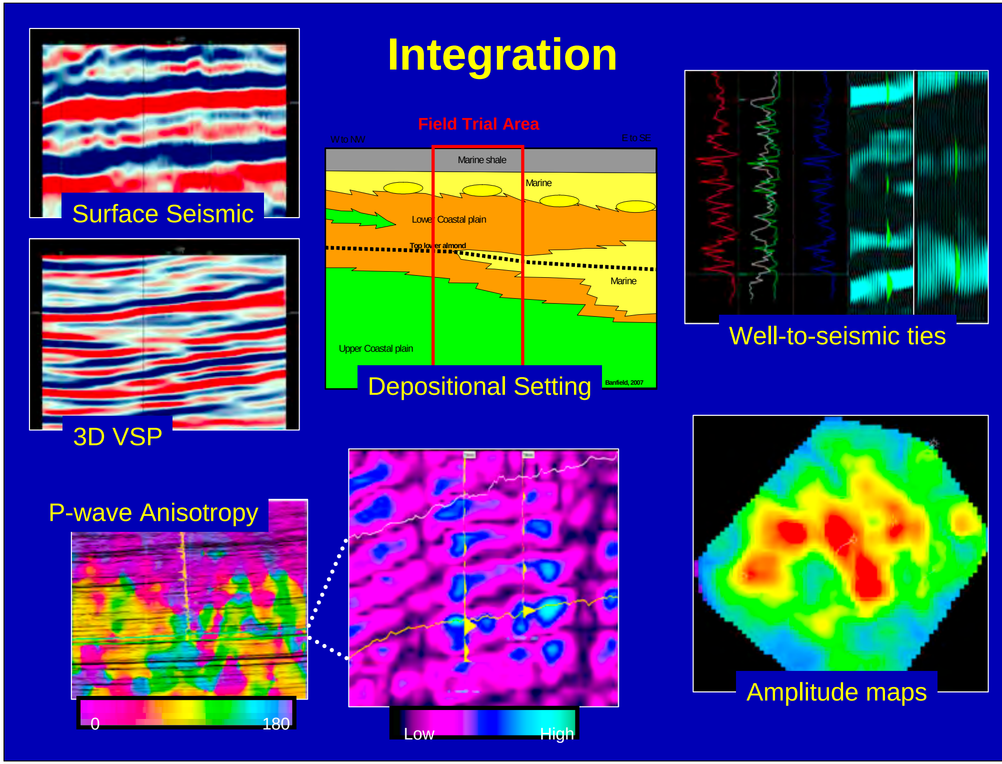
Well 1- not a BP well- estimated at 0.6 BCF

VSP well- EUR 1.5 BCF

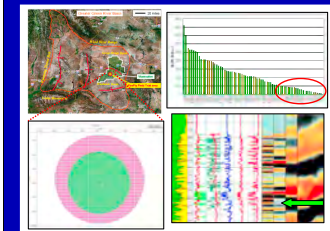
Well 3- deep well-multiple targets, not only Almond- numbers not shown (not consistent)- significantly higher EUR >4 BCF- multiple targets- not Almond level only

Well 4- EUR 0.4 BCF

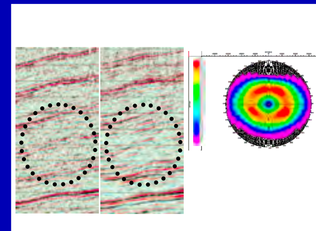
Well 5- not a BP well- estimated at 0.3 BCF


Integration
Surface Seismic
3D VSP
Field Trial Area
W to NW
E to SE
Marine shale
Marine
Lower Coastal plain
Top lower almond
Marine
Upper Coastal plain
Banfield, 2007
Depositional Setting
Well-to-seismic ties
P-wave Anisotropy
0
180
Low
High
Amplitude maps

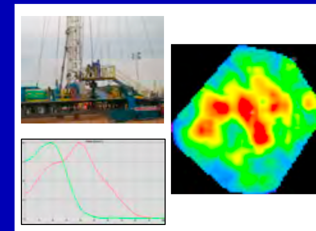
Summary



- Explore new technologies with the potential to transform land seismic capability
- Can seismic deliver a step change in ability to **high grade well locations and eliminate the tail?**
- Simpler more integrated seismic workflows



- Increased bandwidth with additional lows
- Spatial resolution improved with denser sampling and wide azimuth acquisition
- Azimuthal anisotropy
  - Velocity anisotropy correlates with the current day stress as well as paleo-stress conditions
  - Appears consistent with borehole anisotropy



- Safe, efficient operations
- Double bandwidth of existing surface seismic
- More detailed mapping of internal character
- Correlation of seismic amplitude to sand thickness and production metrics
- Integration of multiple seismic technologies

Acknowledgements

- BP and Anadarko Petroleum Corporation
- Numerous BP Colleagues
- Cableless seismic data was acquired by ION Geophysical Corporation
- 3D VSP data was acquired by Paulsson/GSI using their 160 level 3C geophone string
- Vibrator sources and surface recording were provided by Veritas DGC Land
- VSP navigation QC and pre-processing were provided by CGGVeritas Calgary and Open Geo Solutions respectively