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PS Predictions of Gas Hydrates Using Pre-Stack Seismic Data, Deepwater GOM*

Dianna Shelander[1], Jianchun Dai[1], George Bunge[1], Timothy S. Collett[2], Ray Boswell[3], and Emrys Jones[4]

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Abstract

A seismic study was employed to predict and characterize gas hydrate accumulations at proposed sites that would be drilled in 2009 by the Chevron-led Joint Industry Project (JIP) in the deepwater Gulf of Mexico. In this phase of research, the JIP focused on finding favorable conditions for hydrate formation - primarily, high-quality sand reservoirs, and secondarily, the availability of methane source and migration pathways. Wells targeting various geologic models in both high and low predicted saturations of gas hydrates (Sgh) were selected, and thus, allowing the test of the seismic prediction techniques.

The methodology for predicting Sgh, using industry standard, 3D seismic data, involves an integrated workflow of seismic interpretation, rock model building, data conditioning, seismic data inversion, and conversion to Sgh. Seismic stratigraphic interpretation was used to identify sequences likely to contain sand reservoirs. Additional site studies also provide other aspects crucial to identifying hydrates, such as the base gas hydrate stability zone, migration pathways, and availability of gas for source. Rock models of elastic seismic responses of the clastic sediments were constructed using regional knowledge and principles of rock physics and compaction. Preconditioning the offset data is applied to increase the resolution and fidelity of the seismic offset data for subsequent AVO analysis. Inversion of the pre-stack data converts the seismic data to pseudo rock properties (P-impedance and S-impedance), which are compared to the initial rock model. The deviations of impedances from the model are then input for Sgh predictions.

Results of the drilled JIP wells are compared with the Sgh predictions. Initial findings indicate that the methodology works well for predicting relative saturations occurring in thick sand units. High gas hydrate concentrations were found consistently in the wells where high Sgh values were predicted. Accurately predicting low saturations is somewhat more challenging without nearby well control for calibration. In a well where relatively low concentrations were predicted, thin hydrate layers (below seismic resolution) are evident on the well logs. Intervals of hydrate-filled fractures were not readily apparent in the Sgh volume, probably due to the formation's overall low concentrations of gas hydrates. In general, the comparison of the drilled results with the predictions are very positive and show that this methodology can be used to estimate moderate to large accumulations of gas hydrates using pre-stack seismic data.

Selected References

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Predictions of Gas Hydrates Using Pre-stack Seismic Data, Deepwater GOM

CONTROL ID: 735179

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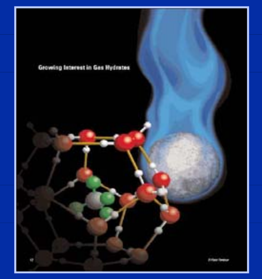

ABSTRACT: A seismic study was employed to predict and characterize gas hydrate (GH) accumulations at proposed sites that would be drilled in 2009 by the Chevron-led Joint Industry Project (JIP) in the deepwater Gulf of Mexico. In this phase of research, the JIP focused on finding favorable conditions for hydrate formation - primarily, high-quality sand reservoirs; and secondarily, the availability of methane source and migration pathways. Wells targeting various geologic models in both high and low predicted saturations of gas hydrates (Sgh) were selected, and thus, allowing the test of the seismic prediction techniques.

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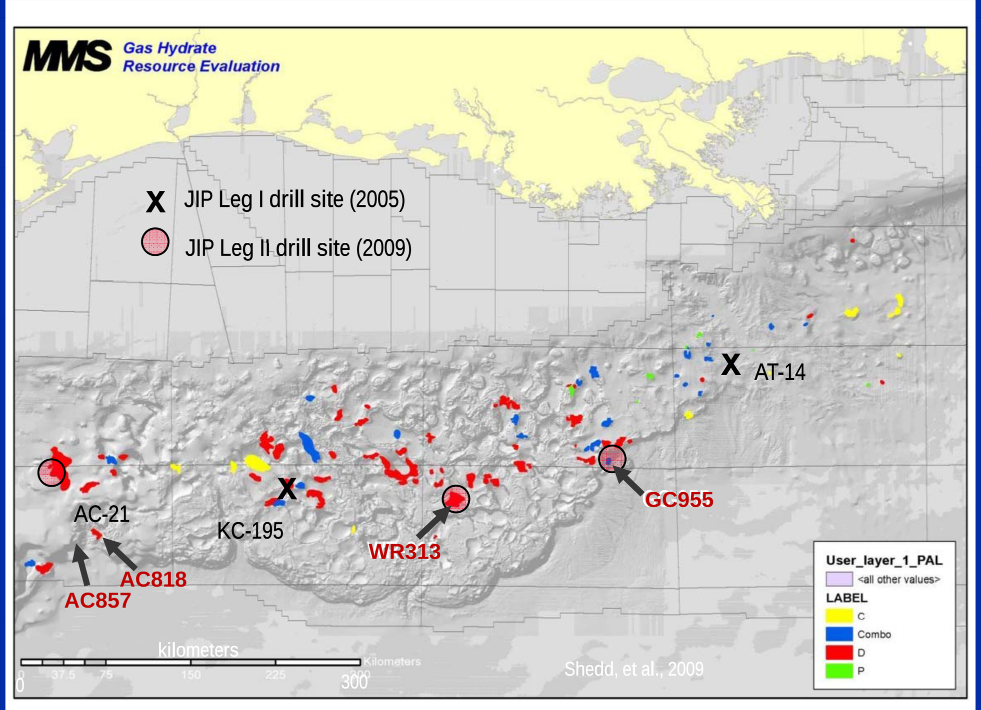
Seismic indicators of Hydrates in GoM

MMS has identified 100+ thus far

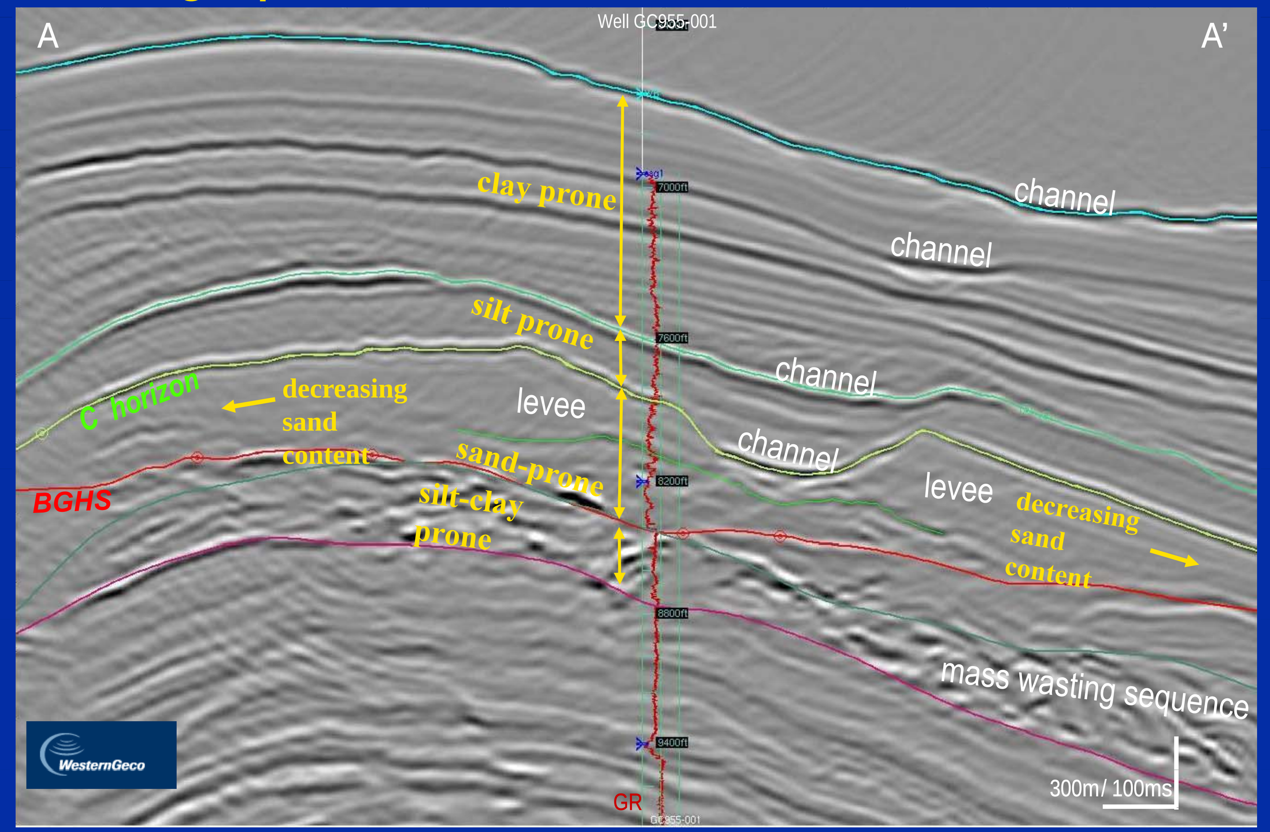


Gas hydrates occur in the GOM where water depths > 500m.
MMS has begun documenting where indications of GH on seismic data have been observed.
JIP Leg-1 wells targeted hydrates in clays.
JIP Leg-2 targeted hydrates in sands (sands have a greater reservoir potential).

Seafloor Relief Map —Green Canyon Sediment Flow

GC955 is in an excellent location for sand deposition as it lies at the mouth of the canyon where load bearing currents become unconfined and downslope gradients rapidly change.

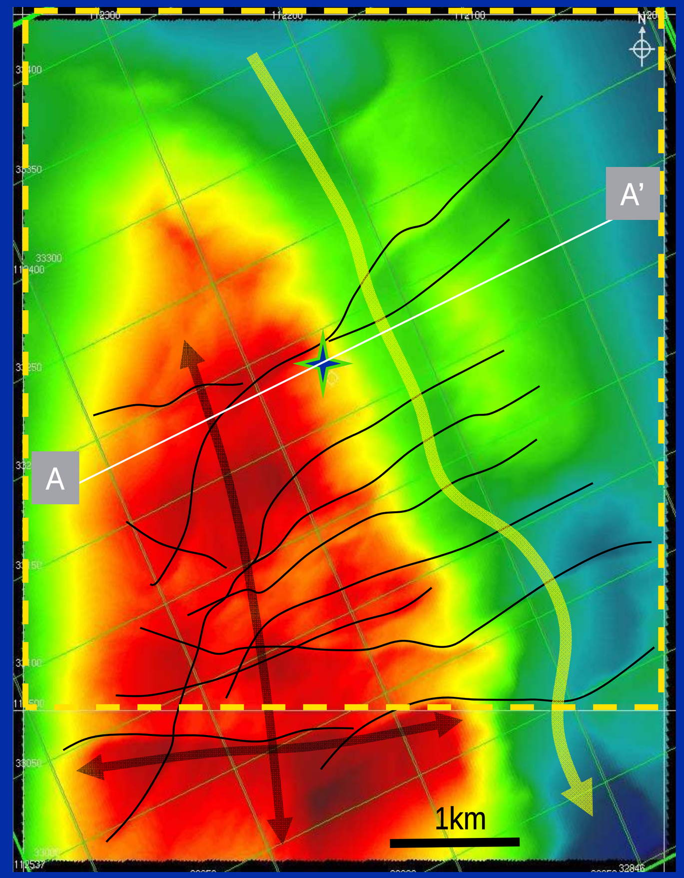
Stratigraphic Evaluation (GC955)



Sand prone facies are targeted for Leg-2 wells.
C horizon is interpreted at the top of levee sand sequence near the base gas hydrate stability (BGHS) zone.

C Horizon Structure (GC955)

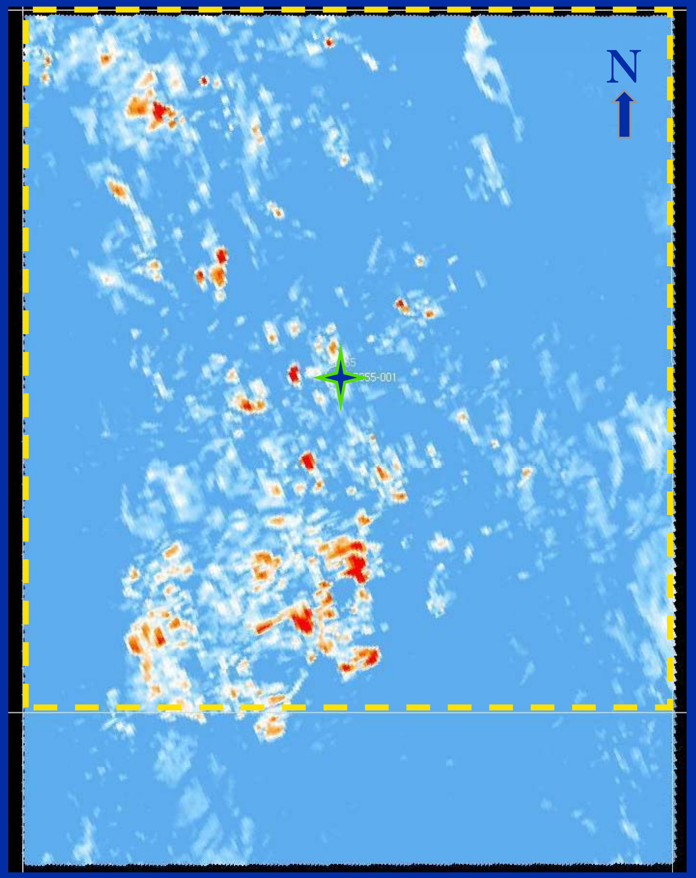
(time, reds are high and blues are low)



Four way closure with faults (black lines) which are important migration pathways to source hydrates.
(C Channel axis indicated by the yellow arrow. GC955 block boundaries are shown with the dashed yellow line.)

Bright Spot (gas indicator) Map

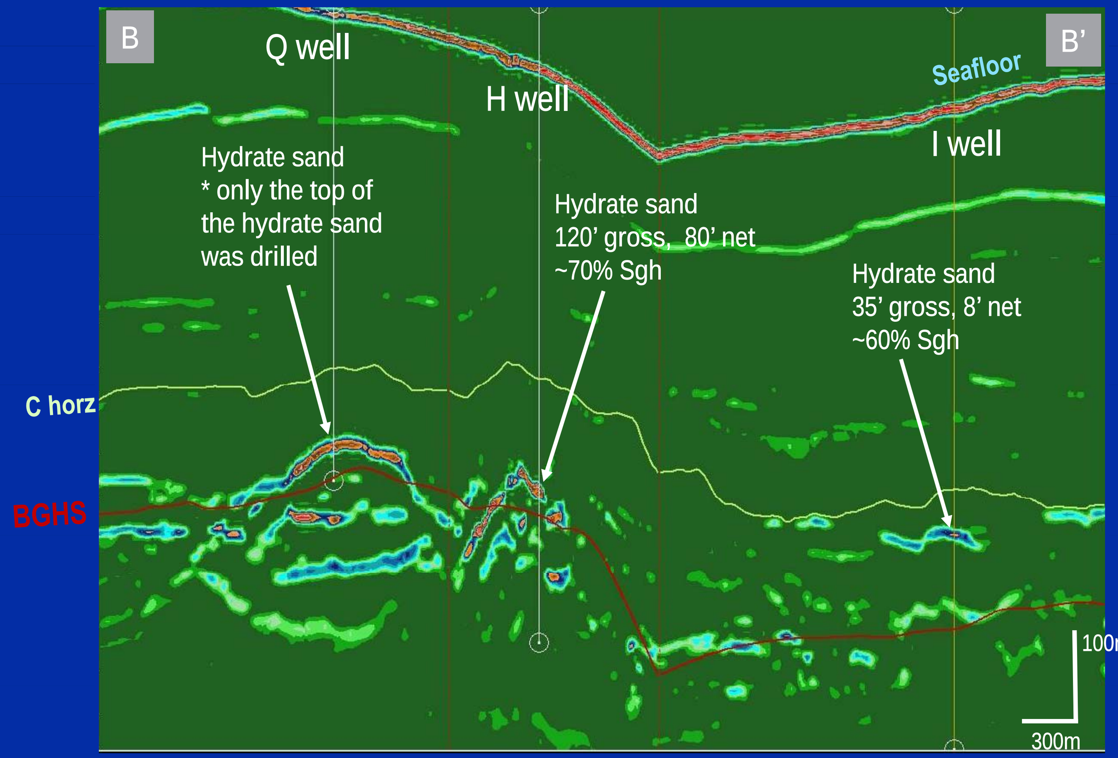
(Min Amp., 100ms window, below BGHS)



Bright spots (high amplitude troughs, in red) indicate gas accumulations beneath the hydrate stability zone. They roughly correspond to the faulted four way closure. The green star locates the existing conventional well.

Saturation of Gas Hydrates (Sgh)

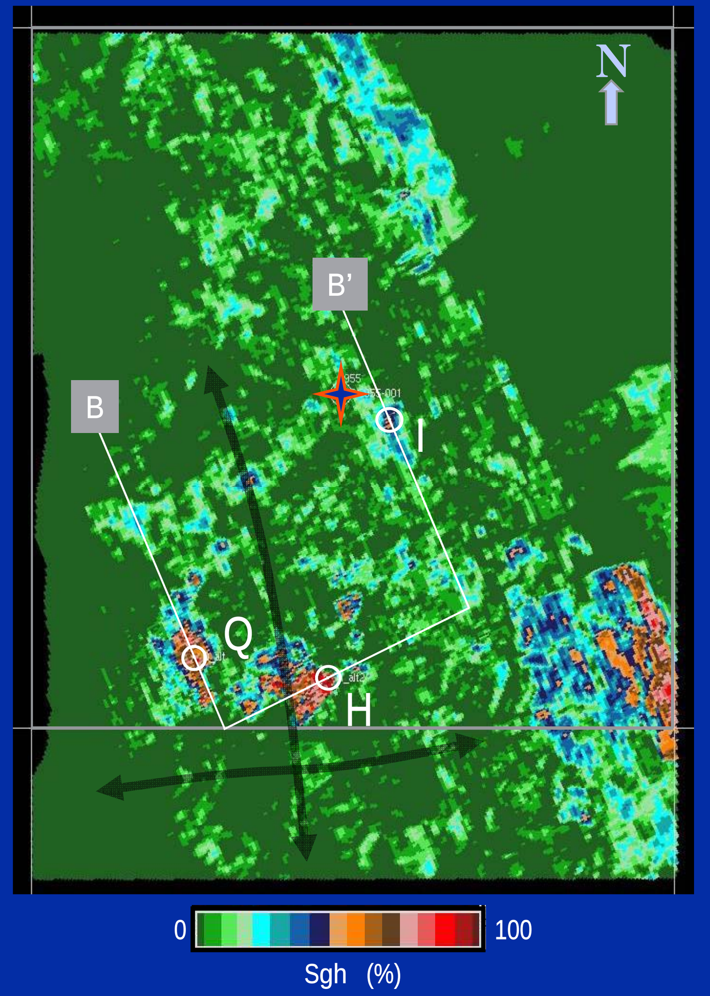
Random Line B-B' tying JIP Leg-2 wells Q, H, and I



Sgh volumes using inversion technique were generated in 2008; JIP Leg-2 wells were drilled in 2009.
A shale-sand rock physics model was used for this Sgh estimation.

Sgh GC955

(Max value, interval: C Horizon – BGHS)



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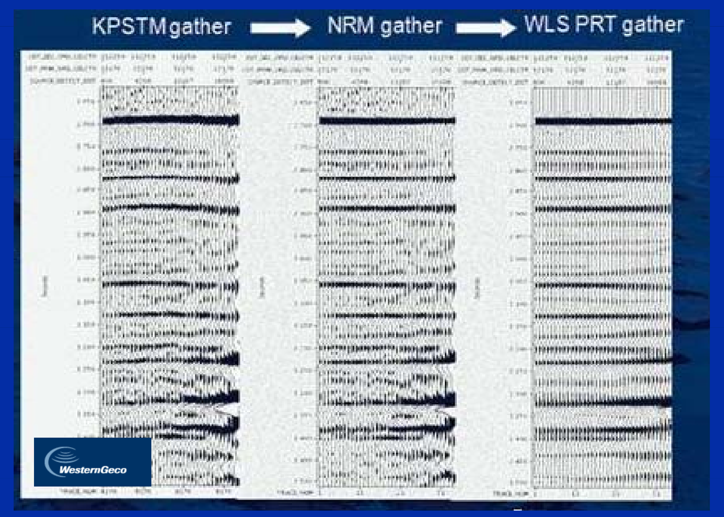
Methodology – Sgh estimation

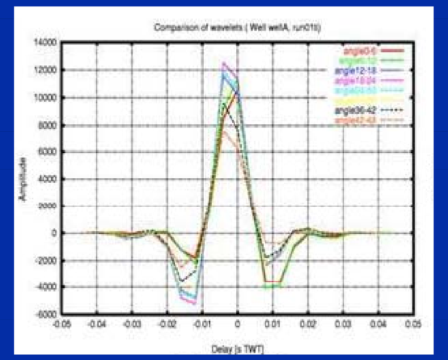
Conditioning pre-stack data

- optimize the signal-to-noise (statics, radon transform, etc.)
- provide the best quantitative measurement of the true AVO signature

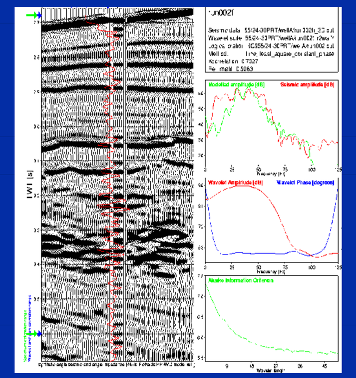


Wavelet analysis – on multiple angles

- wavelets are stable overall
- small wavelet differences expected between angle offsets

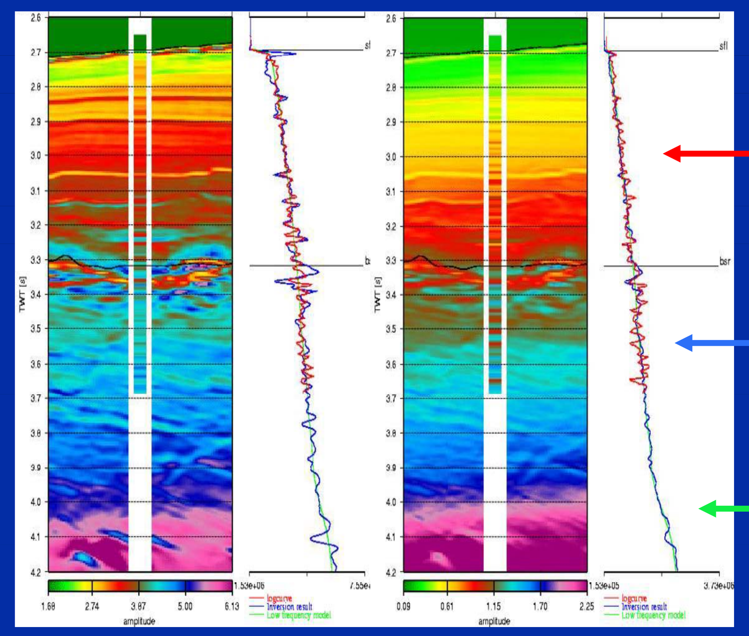


- QC- compare synthetic (middle) to seismic data



Simultaneous Inversion QC

- generate P-impedance and S-impedance



Red curves: PSWI pseudo logs for comparison only

Blue curves: inversion results at the well location

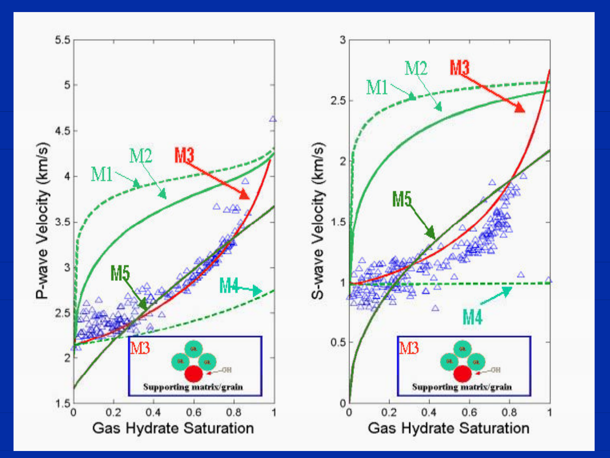
Smooth green curves: input model

P Impedance = P velocity x Density

S Impedance = S velocity x Density

Rock Models and Responses

Gas Hydrate Rock Models

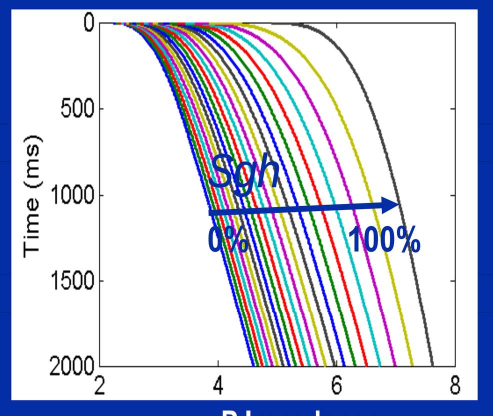


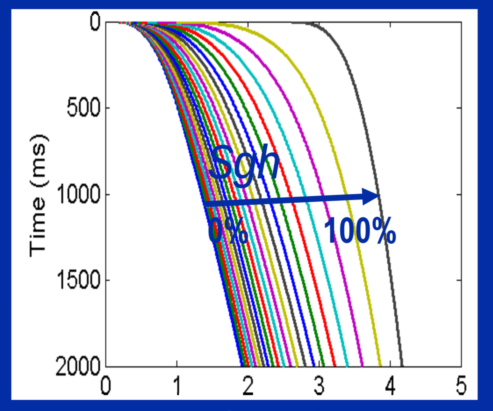
Model 3
Supporting matrix/grain model--hydrates grow in the interior of the porous frame and support the overburden together with the grains.

Data (blue triangles) are from Mallik 2L-38 well, Canada.

The M3 model matches hydrate sands in GOM and other locations.

Sgh Trend Curves





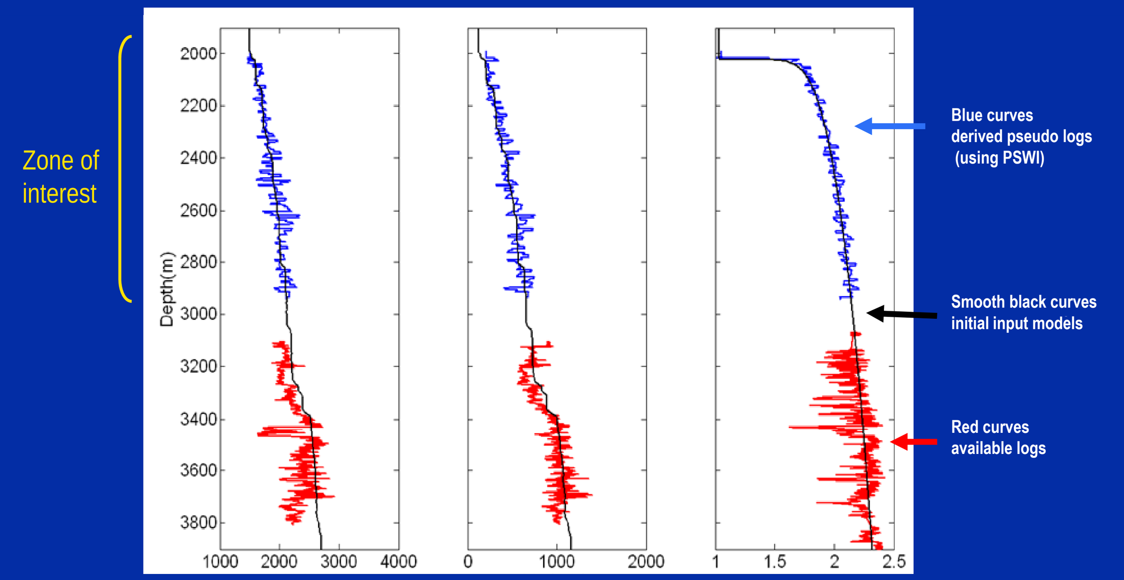
0% Sgh curve is based on:
- stratigraphic analysis and regional knowledge
- compaction trend
- tied to available logs below the zone of interest

METHODOLOGY SUMMARIZED

The seismic interpretation identifies reservoir quality sediments, migration pathways, and the availability of methane gas sources for hydrate formation, and establishes the BGHS. Models establish sediment trends through the zone of interest by applying principles of rock physics and shallow sediment compaction, constrained by regional geological knowledge. The seismic data conditioning provides higher resolution, and higher signal-to-noise data that preserves the relative amplitudes of events that are crucial for AVO inversion. Dense velocity analysis reveals the patchy horizon velocity structure of the shallow subsurface and is used as a low frequency background model to resolve potential gas hydrate accumulations. The solution of simultaneous pre-stack elastic inversion is optimal in a global sense. It yields the estimates not only for acoustic impedance, but also for Poisson's ratio and shear impedance. And, volume conversion to Sgh using regional knowledge enables the identification of significant concentrations of gas hydrates.

Pre-Stack Waveform Inversion (PSWI)

- generate control logs in the zone of interest



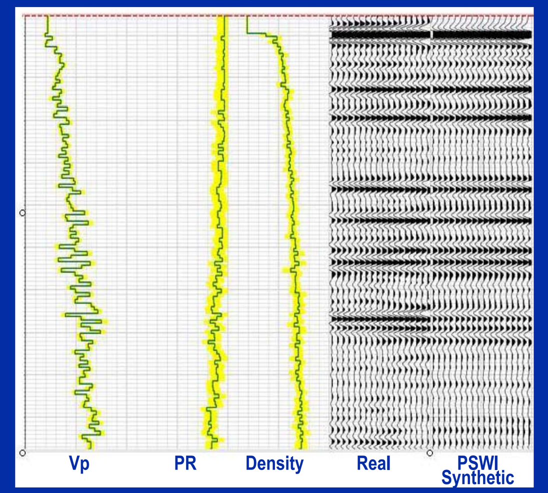
PSWI generates pseudo sonic, shear, and density logs for zone of interest. Initial models used (1) seismic velocity for *Vp*, (2) Castagna's (1985) type of mud rock relation for *Vs*, and (3) compaction trend for the density. A random population of elastic earth models - *Vp*, *Vs* (or PR), and density - is generated within specified search intervals from the initial model - "Monte Carlo Inversion".

Next - an iterative process that matches the computed synthetic common-midpoint (CMP) gather to the actual CMP gather. Subsequent modifications of the model are made until the best match between the synthetic and the actual data is achieved. The algorithm finds the best fit between the synthetic and the actual gather by following a biological evolution process, in which the elastic models (chromosomes) are coded in binary form, undergo genetic processes of selection, reproduction, crossover and mutation – "Genetic Algorithm".

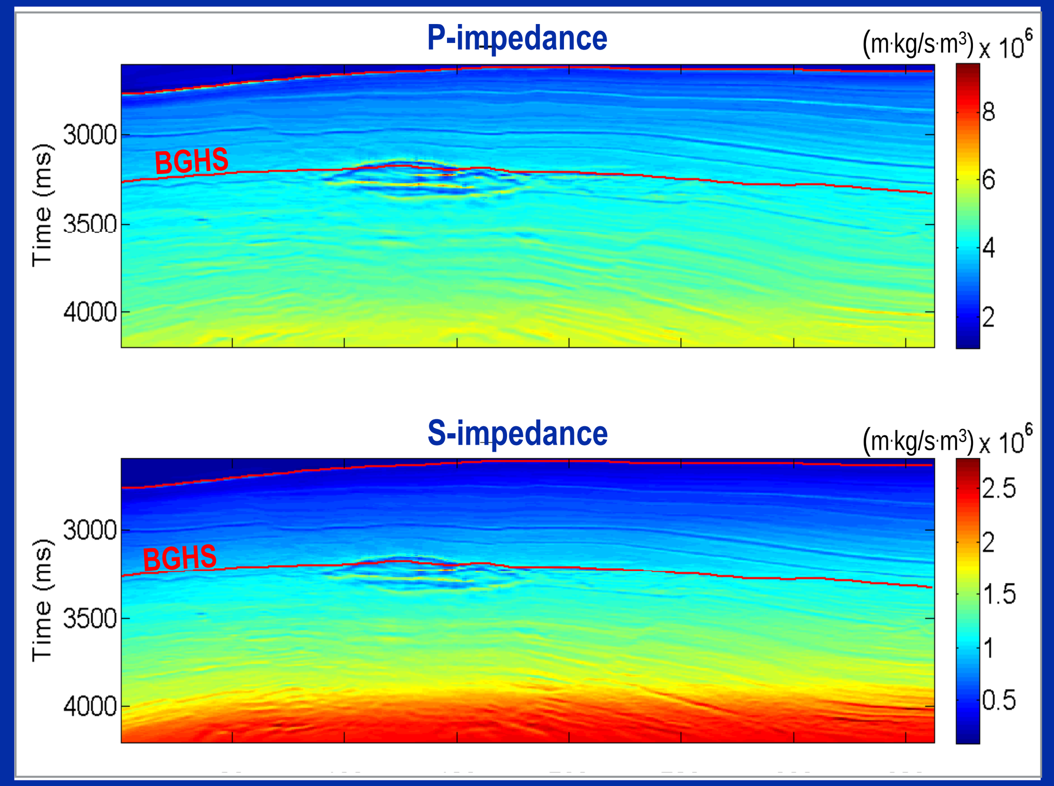
The primary advantage of PSWI is that it has the ability to use the full wave equation based forward modeling algorithm. This allows the inversion process to account for tuning effects, interference from multiples and converted waves, attenuation, and reflection and transmission effects in the presence of velocity gradients.

PSWI Quality Control

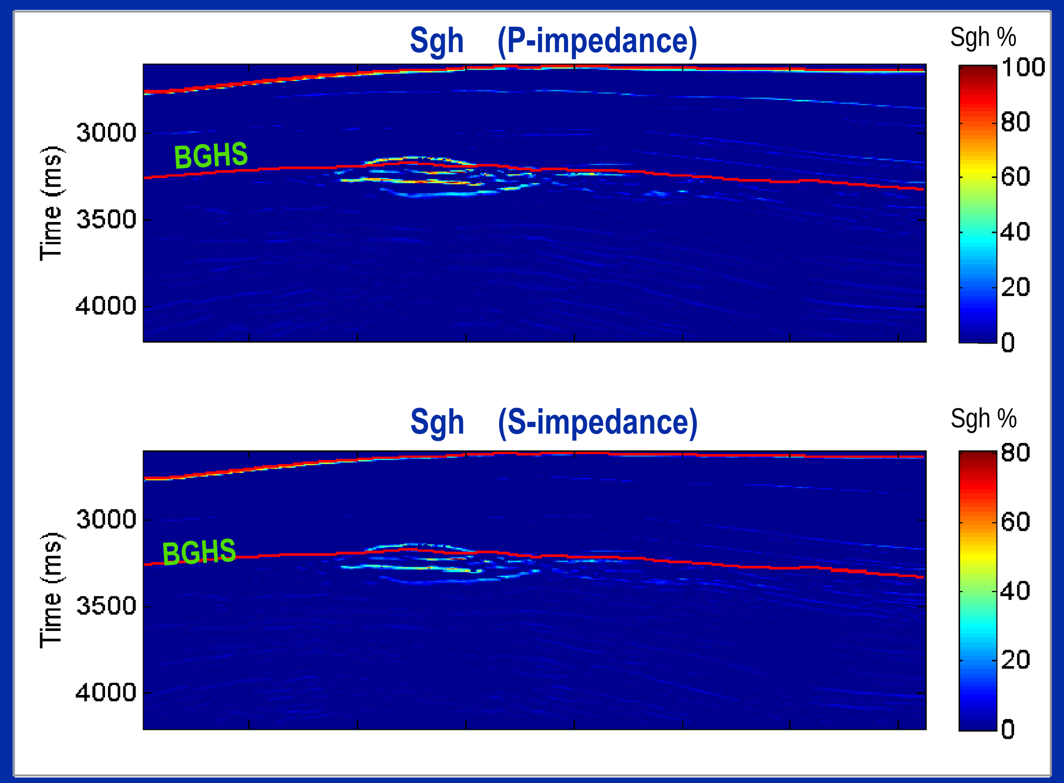
PSWI pseudo logs: *Vp*, Poisson's ratio, and density
(width of the yellow band corresponds to uncertainties)



Simultaneous Inversion - Impedance volumes



Sgh volumes – sand/shale model

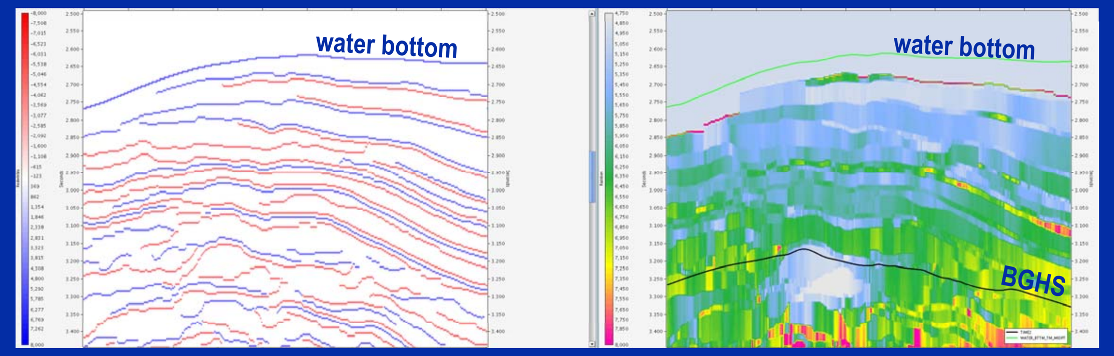


High resolution velocity analysis

- independent of amplitude analyses

Velocity analyses on spatially consistent horizons

High frequency interval velocity dataset



Analysis on virtually every event and every trace.

low velocities=blues
high velocities=pinks

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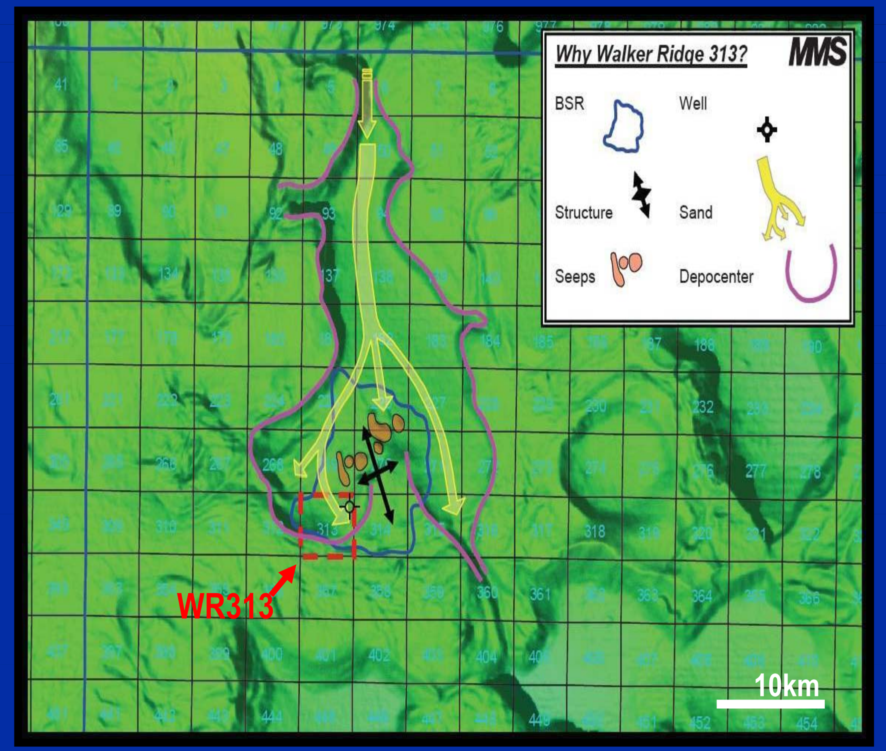
WR313 and Discussion

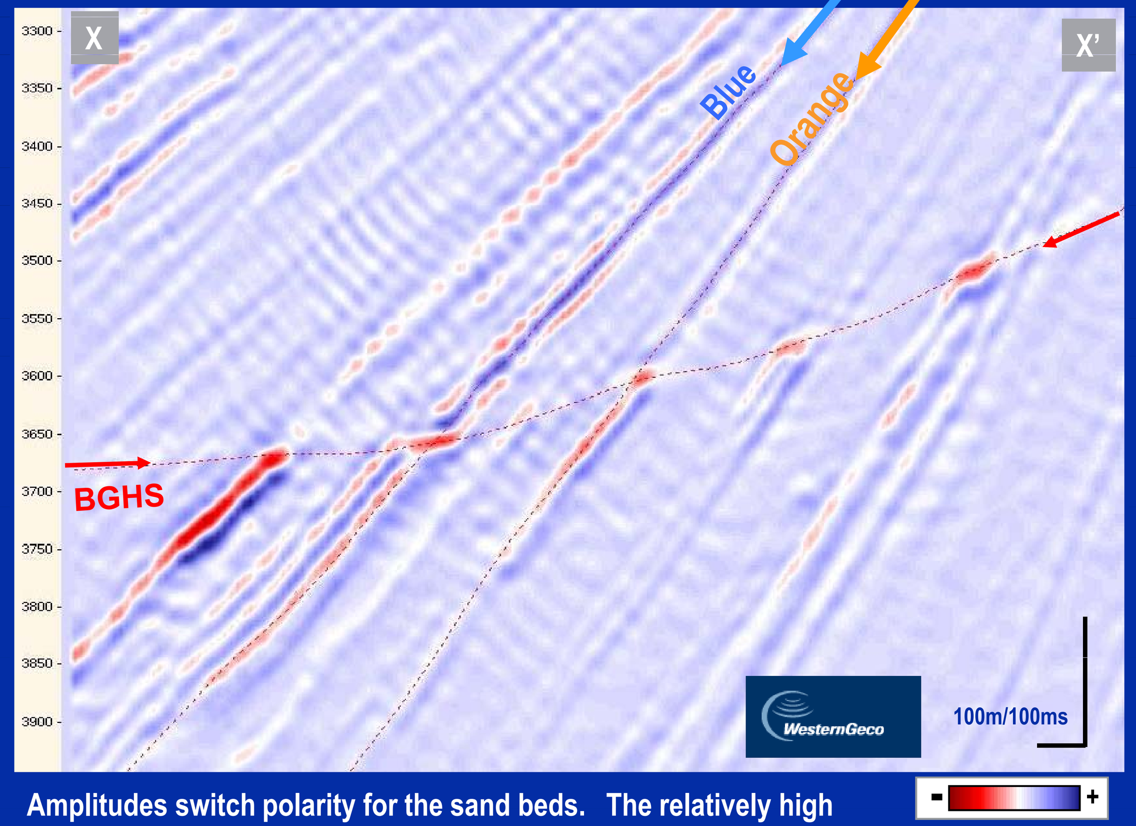
Seafloor Relief Map
— Terrebonne Basin Area (Purple Line)



(Map courtesy of W. Shedd, MMS)

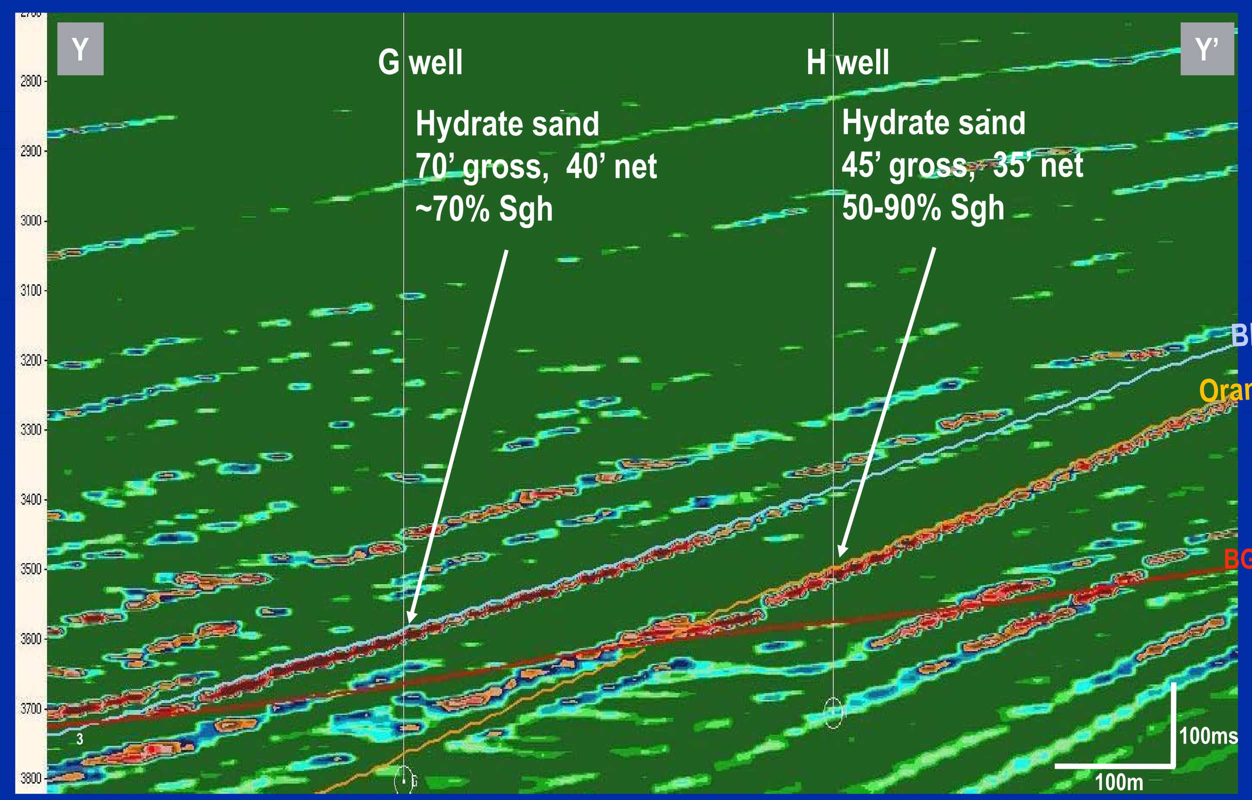
WR313 is in an excellent location for sand deposition as it lies at the termination of a sediment pathway.

WR313 Seismic Example – (dip section)



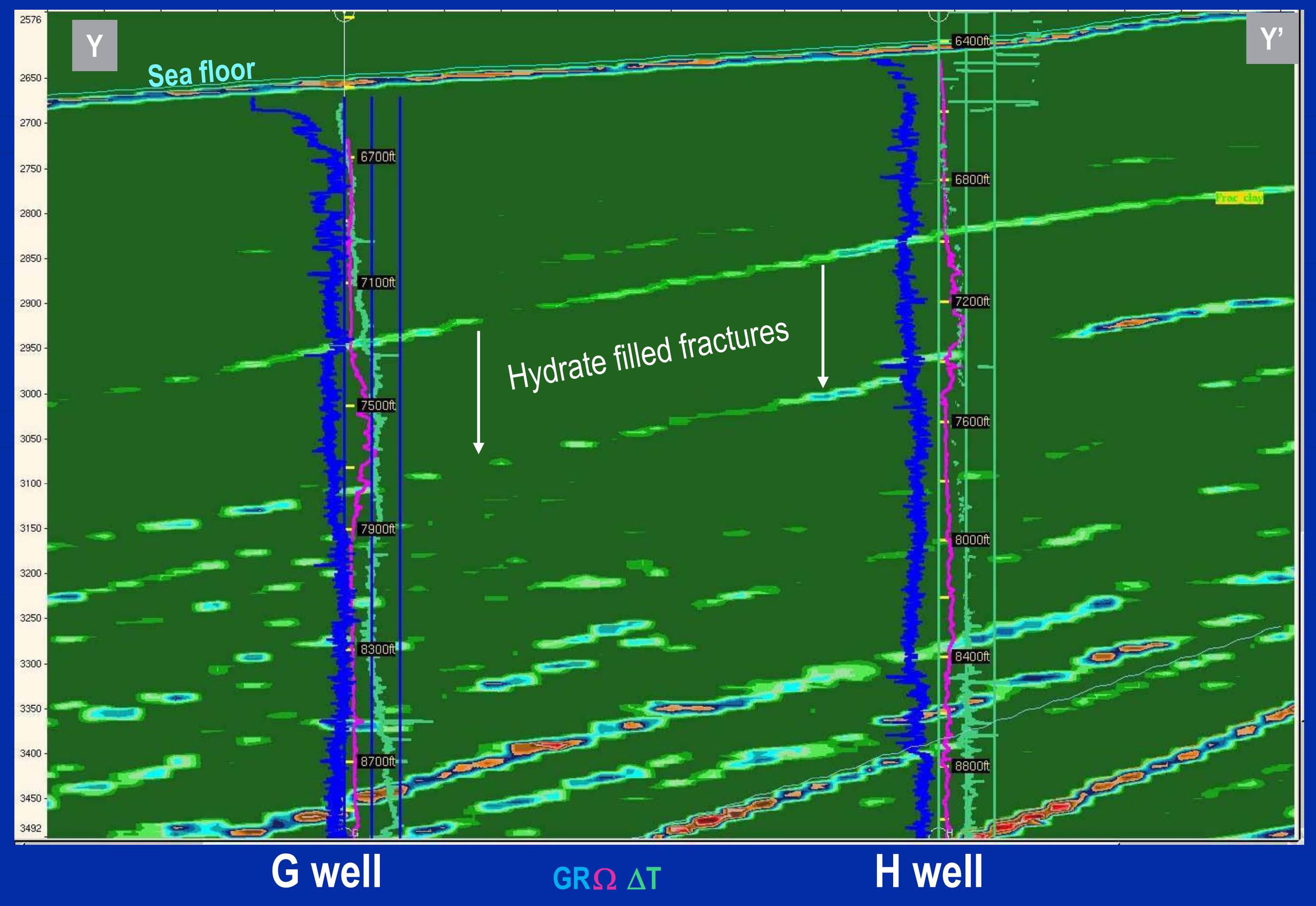
Amplitudes switch polarity for the sand beds. The relatively high velocity hydrate bearing sands are positive (blue) events while the low velocity gas bearing sands are negative (red) events.

Sgh - Random Line tying 2009 JIP wells (WR313)



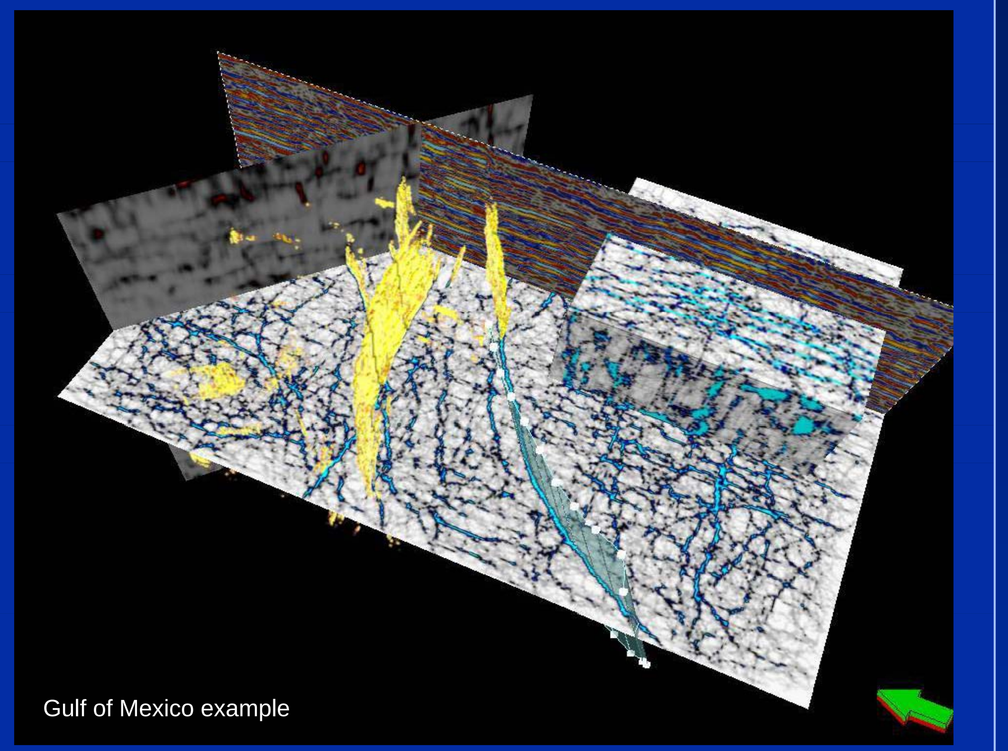
As predicted, Well G encountered thick sands with high saturations of hydrates in the Blue Horizon and thick gas sands in the Orange. Well H encountered thin (below seismic resolution) finer grained sands in the Blue and thick sands with high saturations of hydrates in the Orange.

Sgh - Random Line WR313



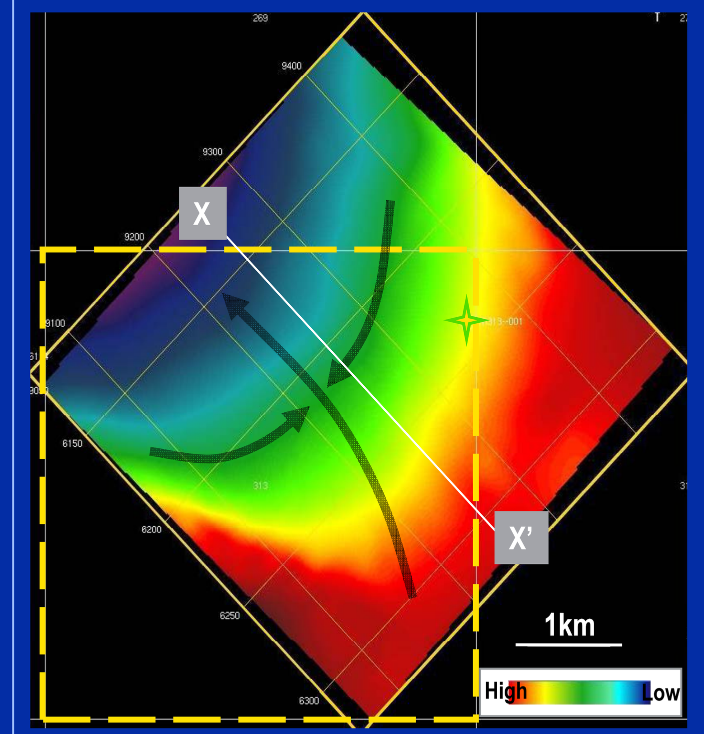
An unanticipated sequence with hydrate-filled fractures was found in the upper section of the stability zone in both G and H wells. A refined seismic inversion analysis using these 2009 LWD logs as control would likely indicate the areal extent of this zone.

Fault / Fracture analysis - Ant track



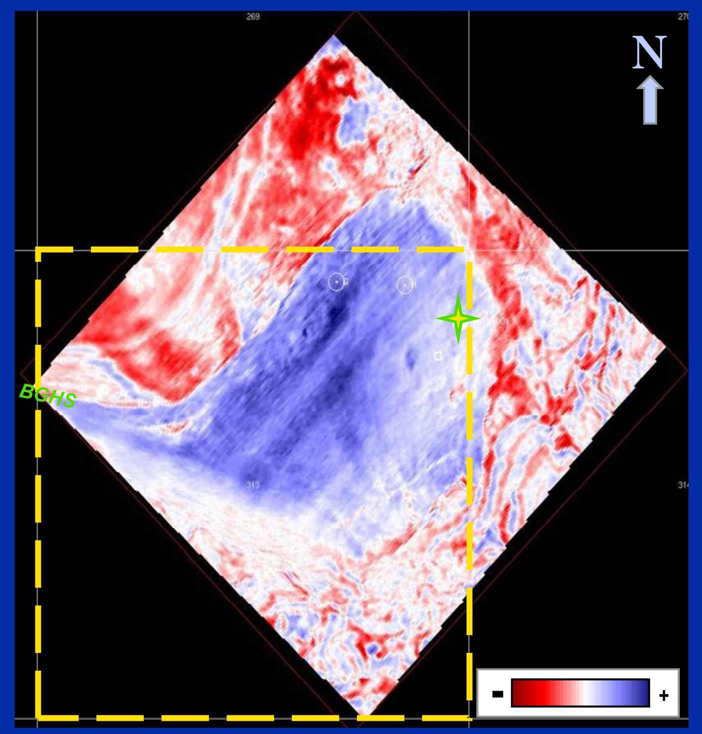
This technology may help define fracture orientations and concentration.

Structure Map (time)
Blue Horizon - WR313



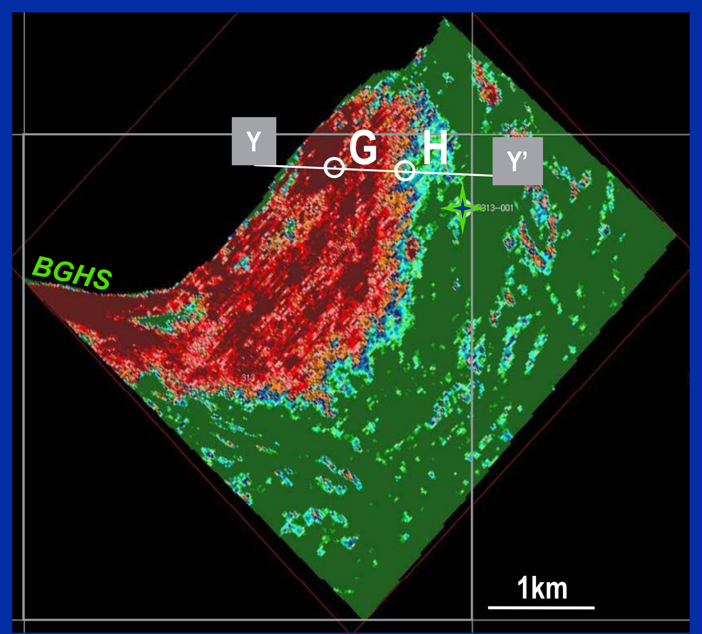
The Blue Horizon structure is a plunging syncline. The green star locates the pre-existing conventional well (WR313-001).

Amplitude Map
Blue Horizon

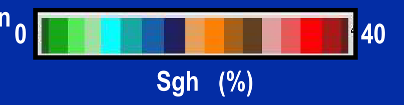


A sharp amplitude change from red (negatives) to blue (positives) occurs where the Blue Horizon crosses the BHGS.

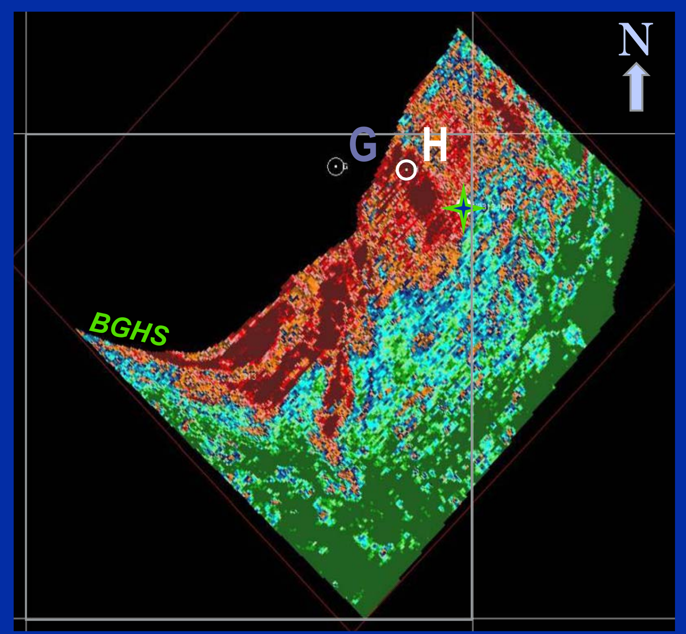
Sgh Map (max, 40ms window)
Blue Horizon - above BGHS



Wells G and H drilled through the Blue horizon above the BGHS. Well H drilled on the edge of the high predicted saturation zone.

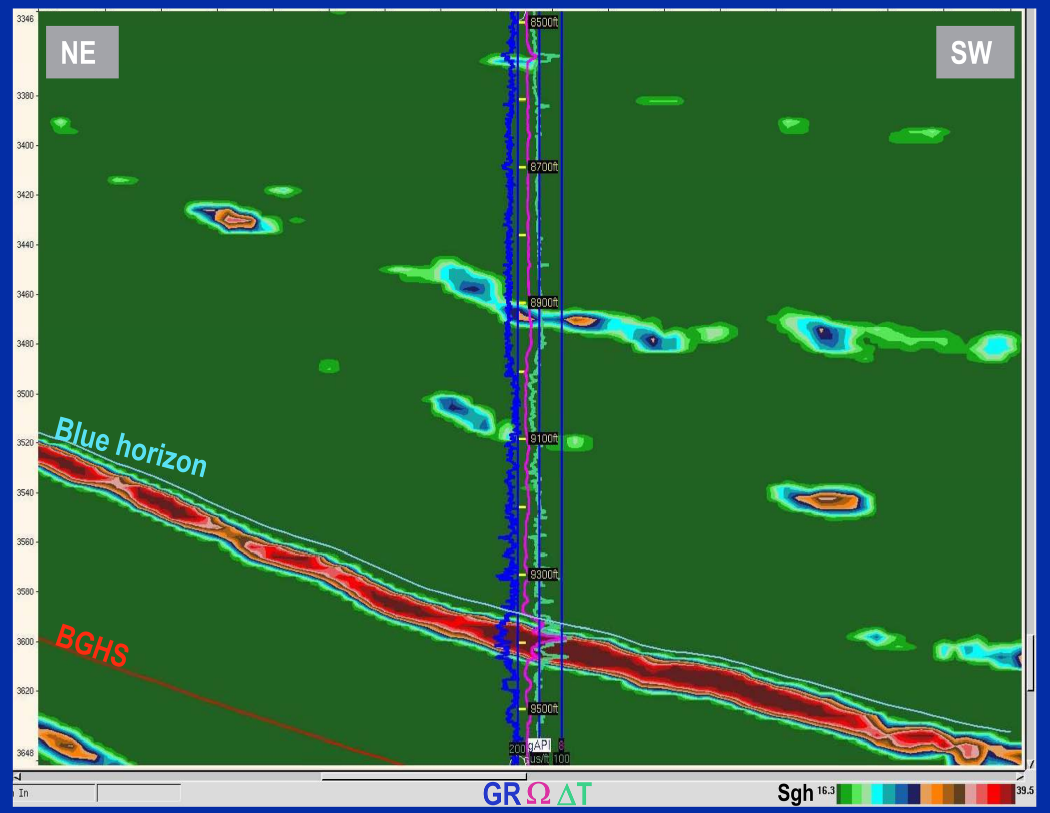


Sgh Map (max, 40ms window)
Orange Horizon - above BGHS

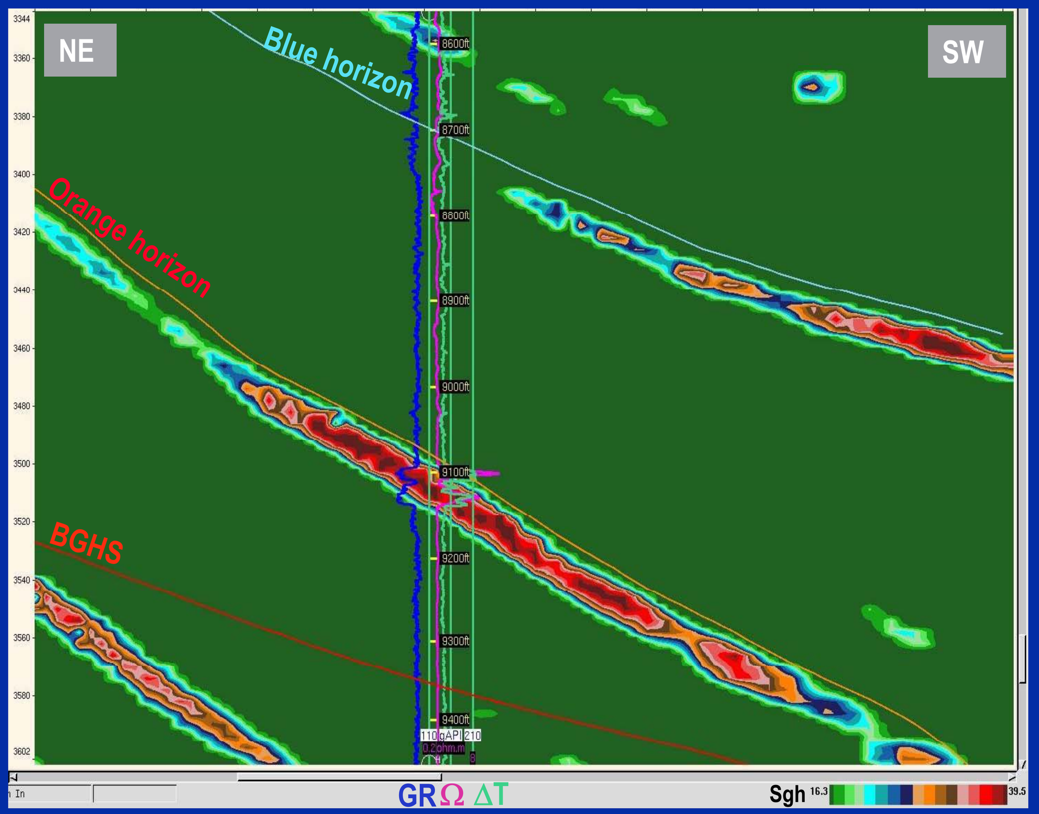


Well H drilled through the Orange horizon above the BGHS. Well G drilled below the BGHS and encountered gas/water.

Sgh – WR313 well G
(using shale-sand model)



Sgh – WR313 well H
(using shale-sand model)



Resistivity values (pink) increase and sonic values (green) decrease in hydrate zones.

DISCUSSION

The *Sgh* volumes were very useful for planning the 2009 JIP wells. The initial results from the 2009 JIP wells indicate this was a successful method of predicting the significant occurrences of hydrates. In four of the five wells drilled in WR313 and GC955 where relatively high *Sgh* values were predicted, significant gas hydrate-bearing sands were found at the target horizons. Gross interval thicknesses of the high hydrate concentrations range from 45ft to 115ft. Unanticipated zones of hydrate-filled fractures (current interpretation) were also encountered in the shallower section (Boswell et al., 2009). Most likely, hydrates forming in fractures do not change the overall impedance enough to create a significant seismic response.

Sgh estimation from pre-stack seismic data is quantitative in nature. However in this project the rock model for gas hydrates and resulting elastic inversion were not calibrated because sonic and density logs were not available in the zone of interest. Therefore, *Sgh* was used more in a relative sense rather than in absolute magnitude. With the 2009 JIP well data, the model and inversion can be updated and calibrated. With greater confidence in the *Sgh* values, gas hydrates resources can then be predicted with more accuracy in these areas.

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