Seismic-Scale Rock Physics of Methane Hydrate

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GOAL

Establish rock physics models that will lead to improved seismic detection and quantification of offshore and onshore methane hydrate accumulations.

APPROACH

One approach to natural methane hydrate quantification is by generating synthetic seismic traces and comparing them to real data: if they match, the reservoir properties and conditions used in synthetic modeling might be the same as in-situ.

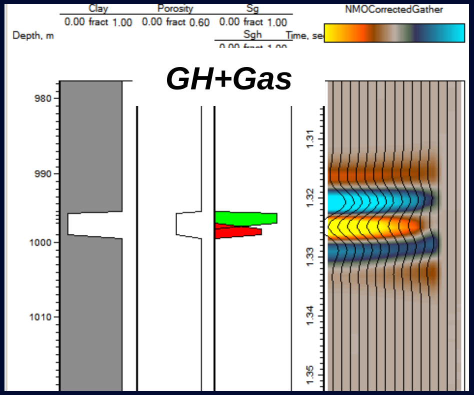
Such methodology has to be based upon a link between the porosity and mineralogy of the host sediment, pressure, and hydrate saturation and the resulting elastic-wave velocity and density.

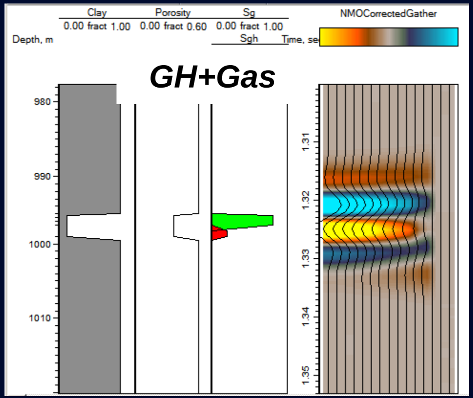
This link can be provided by a rock physics model for unconsolidated sediment where the hydrate acts as part of the mineral frame.

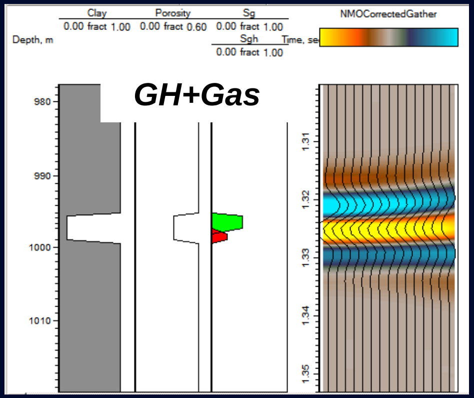
This rock physics transform, combined with simple geologically-plausible earth models, produces synthetic seismic reflections of gas hydrate that can be matched to real data and thus guide exploration and hydrate reservoir characterization.

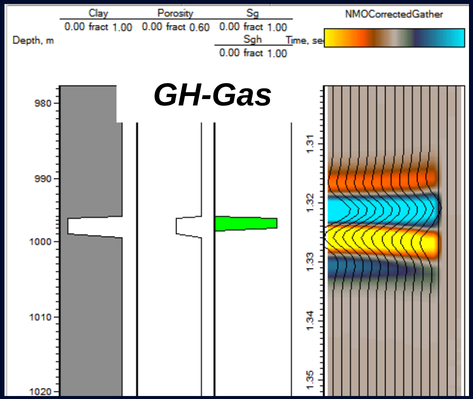
SEISMIC REFLECTIONS OF GH -- SYNTHETIC

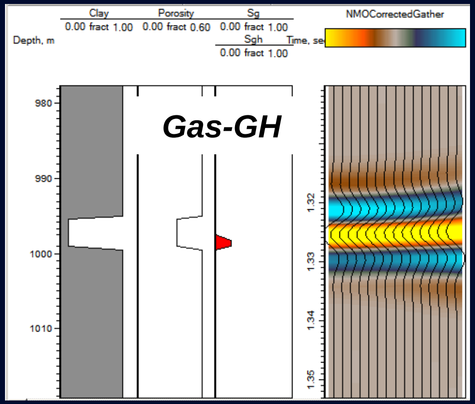
Catalogue



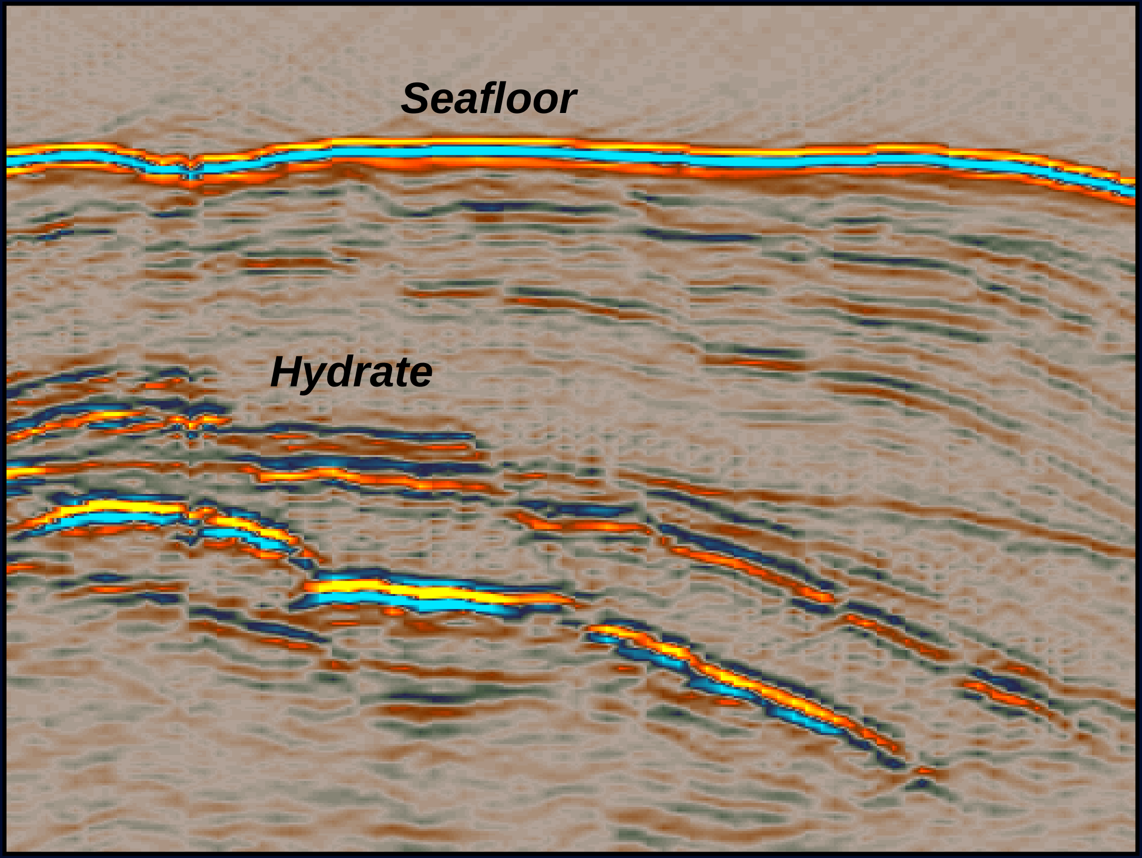


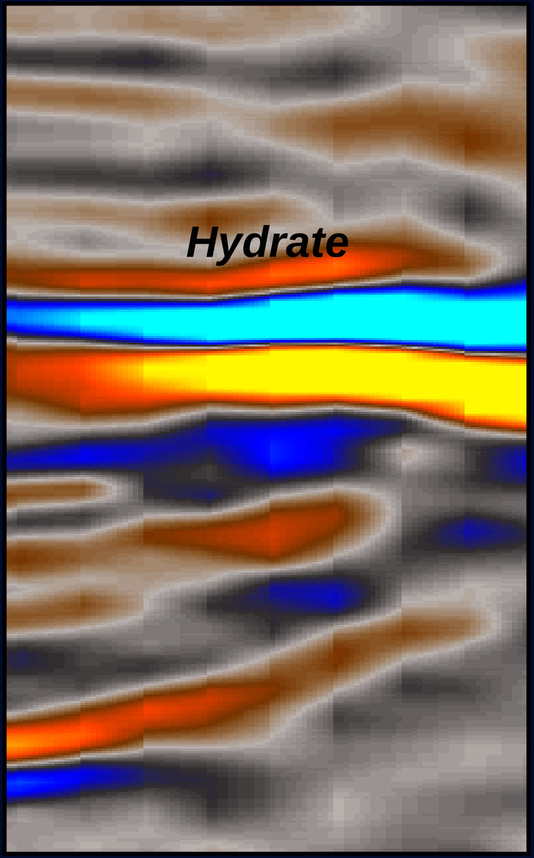






SEISMIC REFLECTIONS OF GH -- REAL

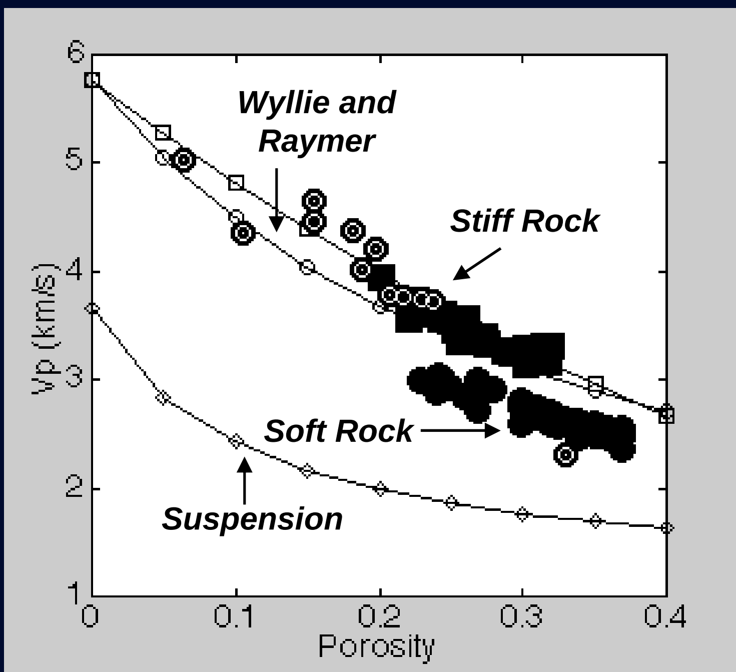




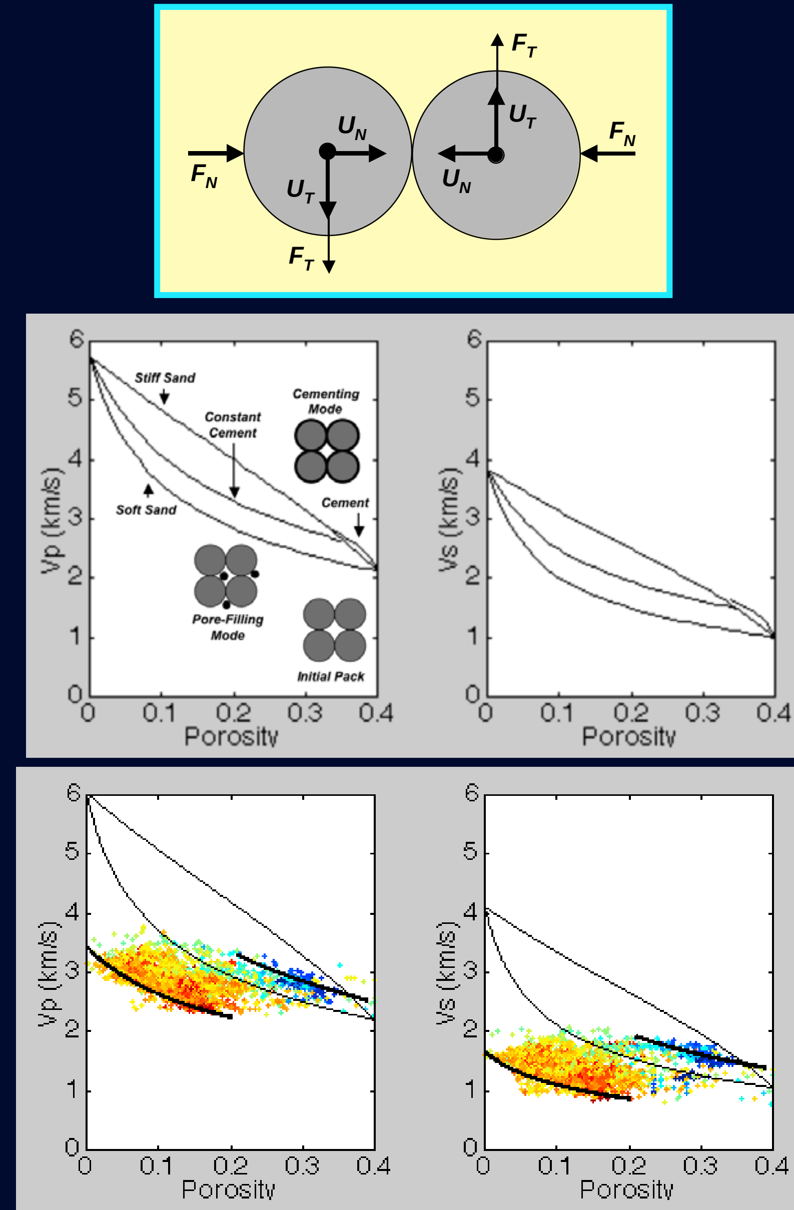
Question: What could stand behind real reflections?

ROCK PHYSICS -- CORE-SCALE

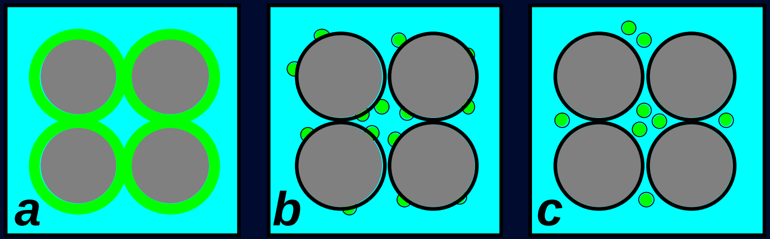
Traditional transforms do not work in soft sediment.



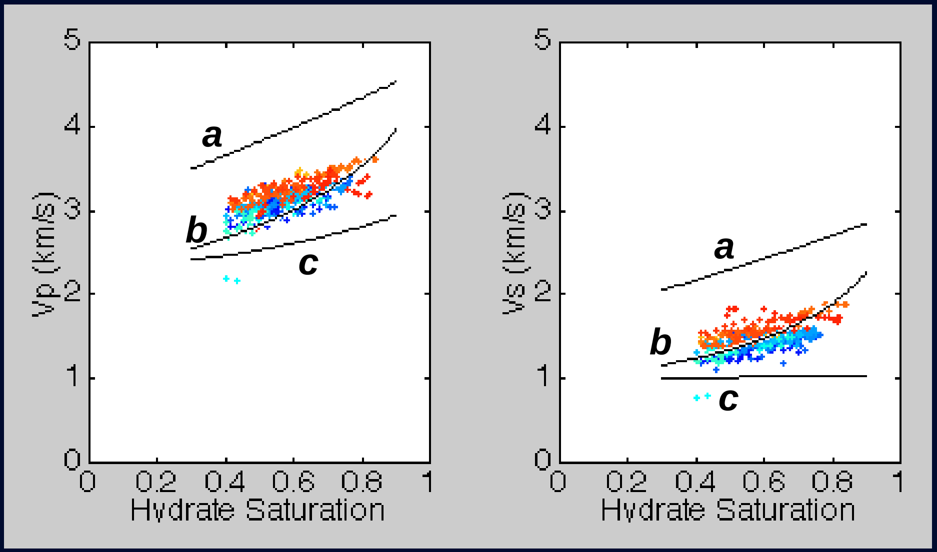
Soft-Sand Models.



HYDRATE IN SOFT SAND

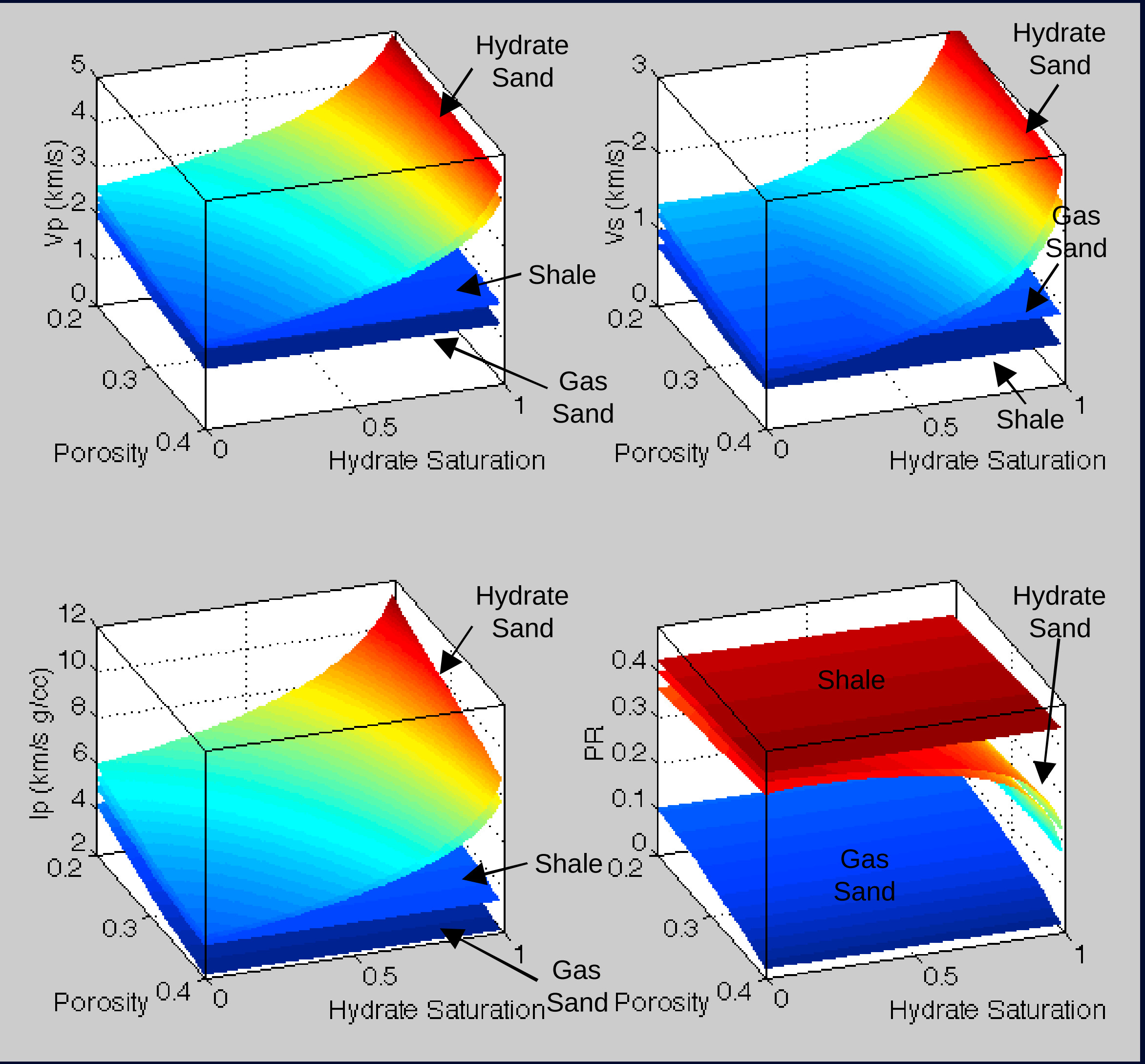


Three types of methane hydrate arrangement in the pore space. From left to right – (a) hydrate as contact cement; (b) non-cementing hydrate as part of the mineral frame; and (c) hydrate as part of the pore fluid. The mineral grains are gray; brine is cyan; and hydrate is green.



P- and S-wave velocity versus methane hydrate saturation in a quartz-sand-brine-hydrate system. The upper curves are from the stiff-sand model. The lower curves are from the hydrate-in-fluid model. The middle curves are from the soft-sand model. The symbols are log data from a methane hydrate exploratory wells at the Mallik site (2L-38). The data are color-coded by depth.

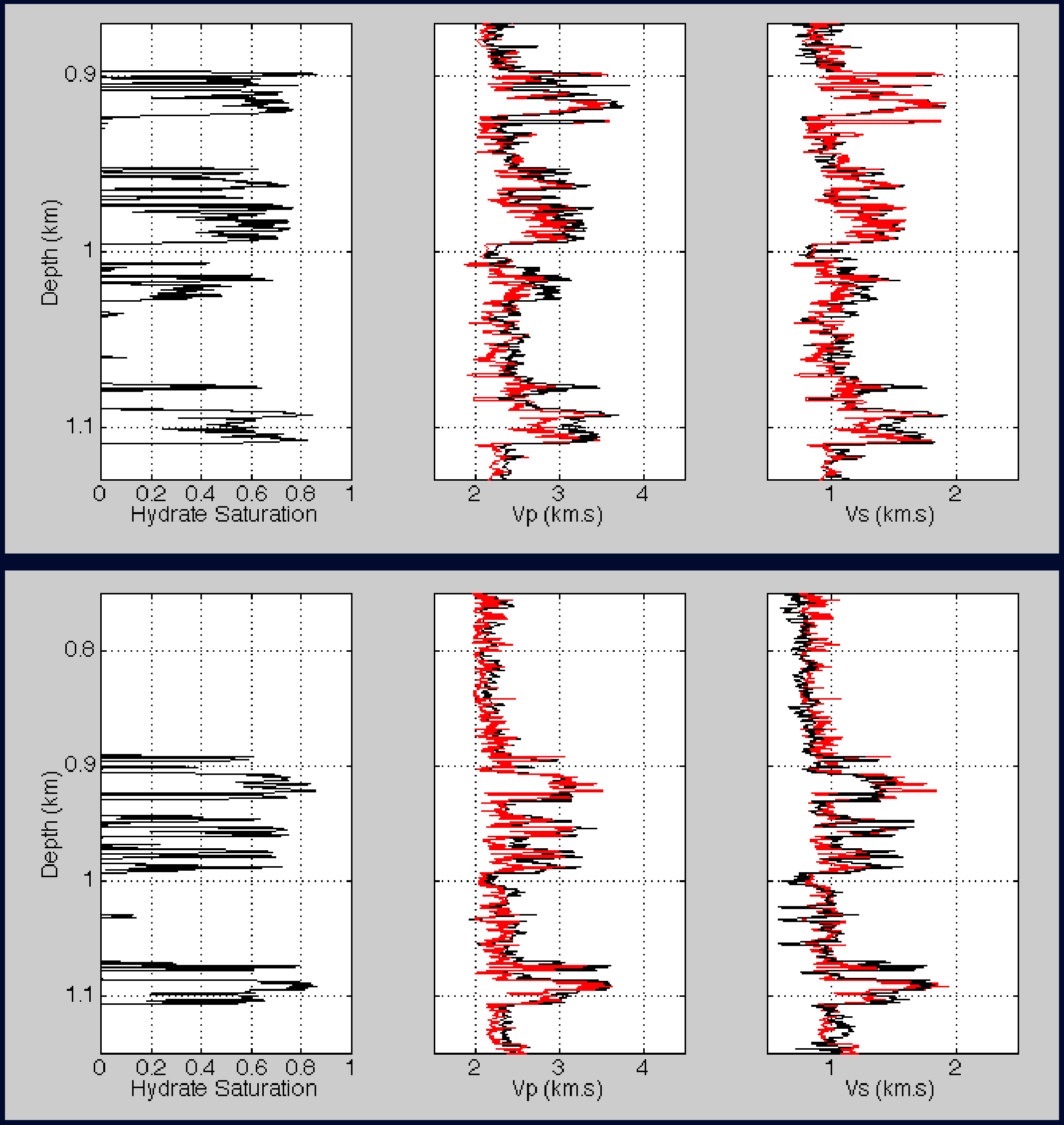
HYDRATE IN SOFT SAND -- MODEL



P- and S-wave velocity (top row) and acoustic impedance and Poisson's ratio (bottom) of sand with zero and 0.4 clay content versus the porosity of the host sand and methane hydrate saturation of the pore space. Also displayed are these elastic properties of shale with clay content 0.8 and gas sand (30% gas saturation) with zero clay content. Color-coding is by the vertical axis value.

HYDRATE IN SOFT SAND -- DATA

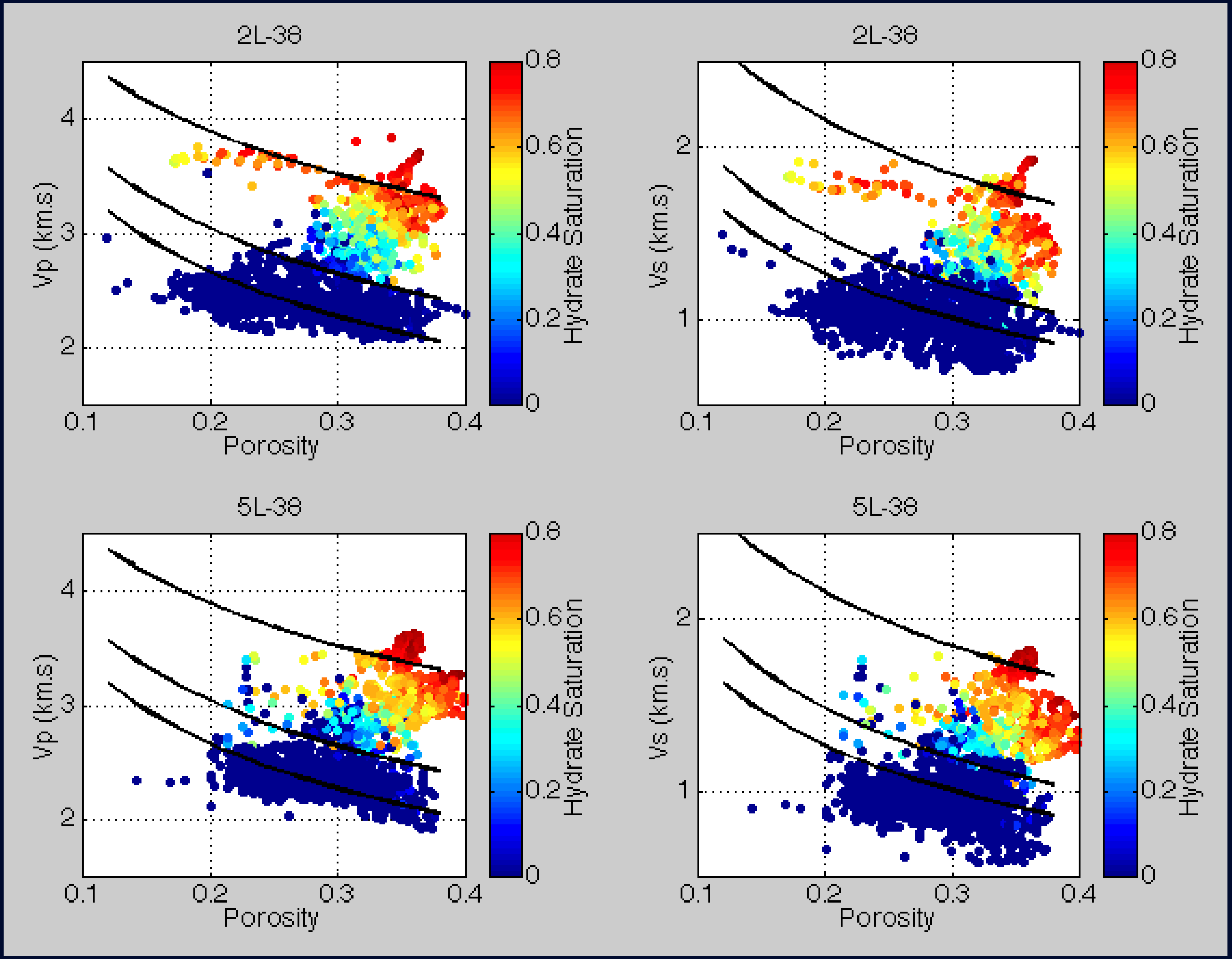
MALLIK



Mallik well 2L-38 (top) and 5L-38 (bottom) depth curves. From left to right – hydrate saturation as calculated from resistivity (Cordon et al., 2006); the P-wave velocity measured (black) and calculated (red) using model (b); and the S-wave velocity measured (black) and calculated (red) using model (b).

HYDRATE IN SOFT SAND -- DATA

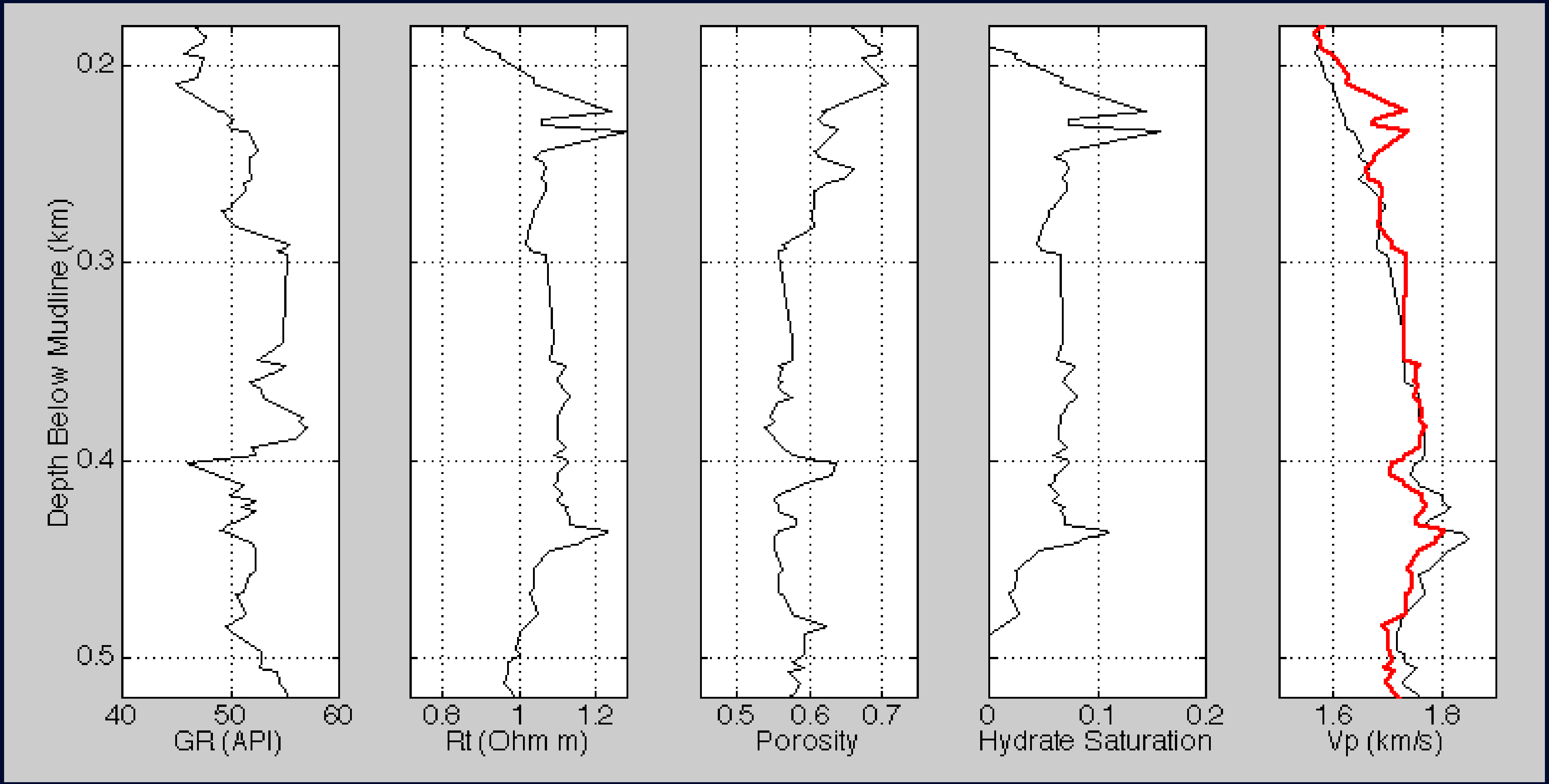
MALLIK



Mallik wells 2L-38 (top) and 5L-38 (bottom). P- (left) and S-wave velocity (right) versus the porosity of the mineral frame (without hydrate) color-coded by hydrate saturation. The model curves are (from top to bottom) for 0.8, 0.4, and zero hydrate saturation in the clean host sand. The data points falling below the zero hydrate saturation curves are from intervals with clay.

HYDRATE IN SOFT SAND -- DATA

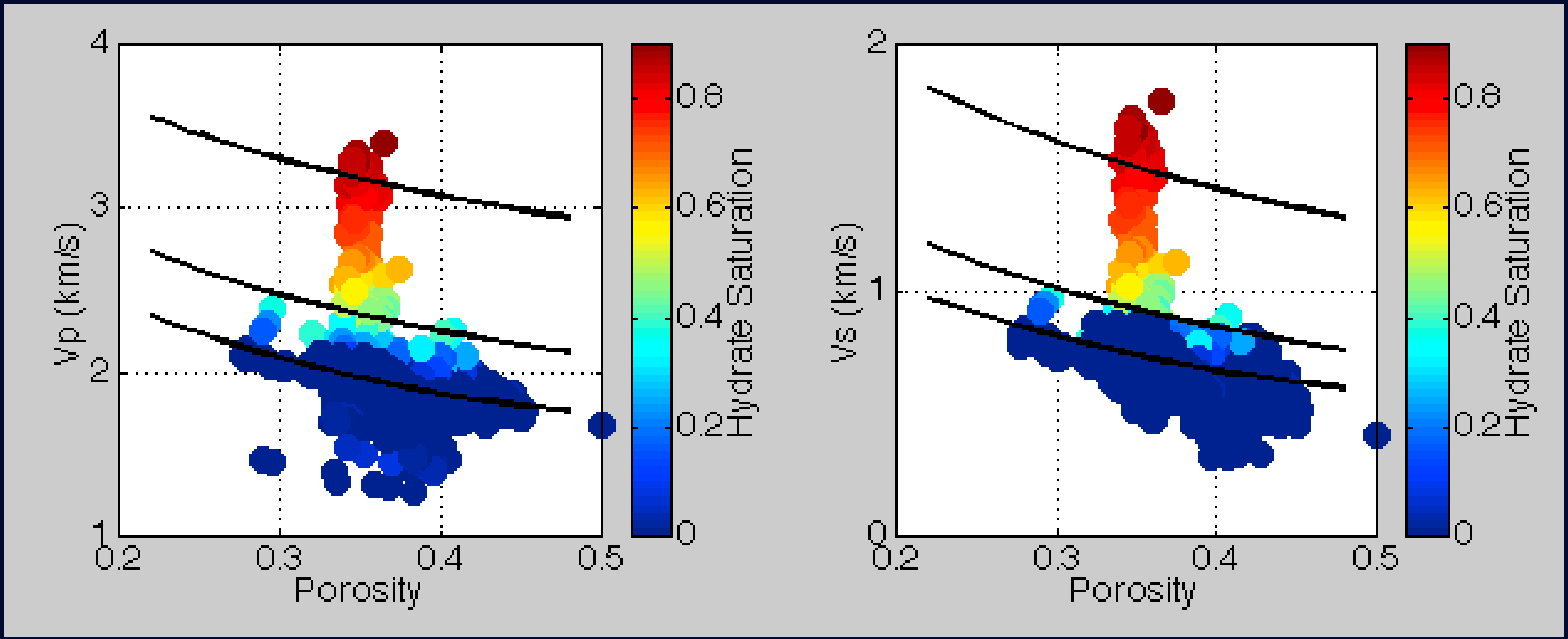
BLAKE RIDGE



Well 995 at the Outer Blake Ridge depth curves. From left to right – GR; resistivity; porosity of the mineral frame without gas hydrate; hydrate saturation; and P-wave velocity measured (black) and reproduced by the soft-sand model (red).

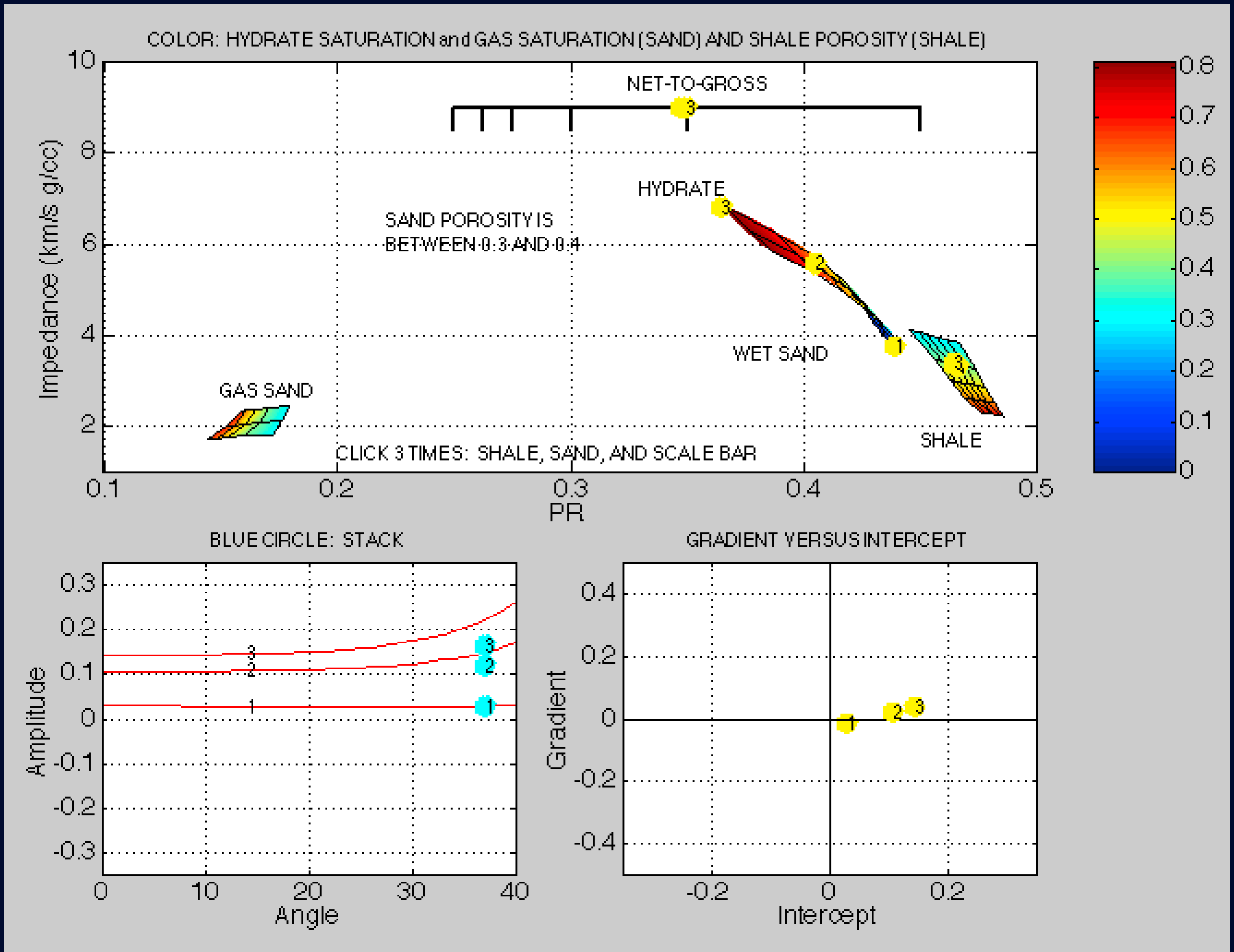
HYDRATE IN SOFT SAND -- DATA

NANKAI



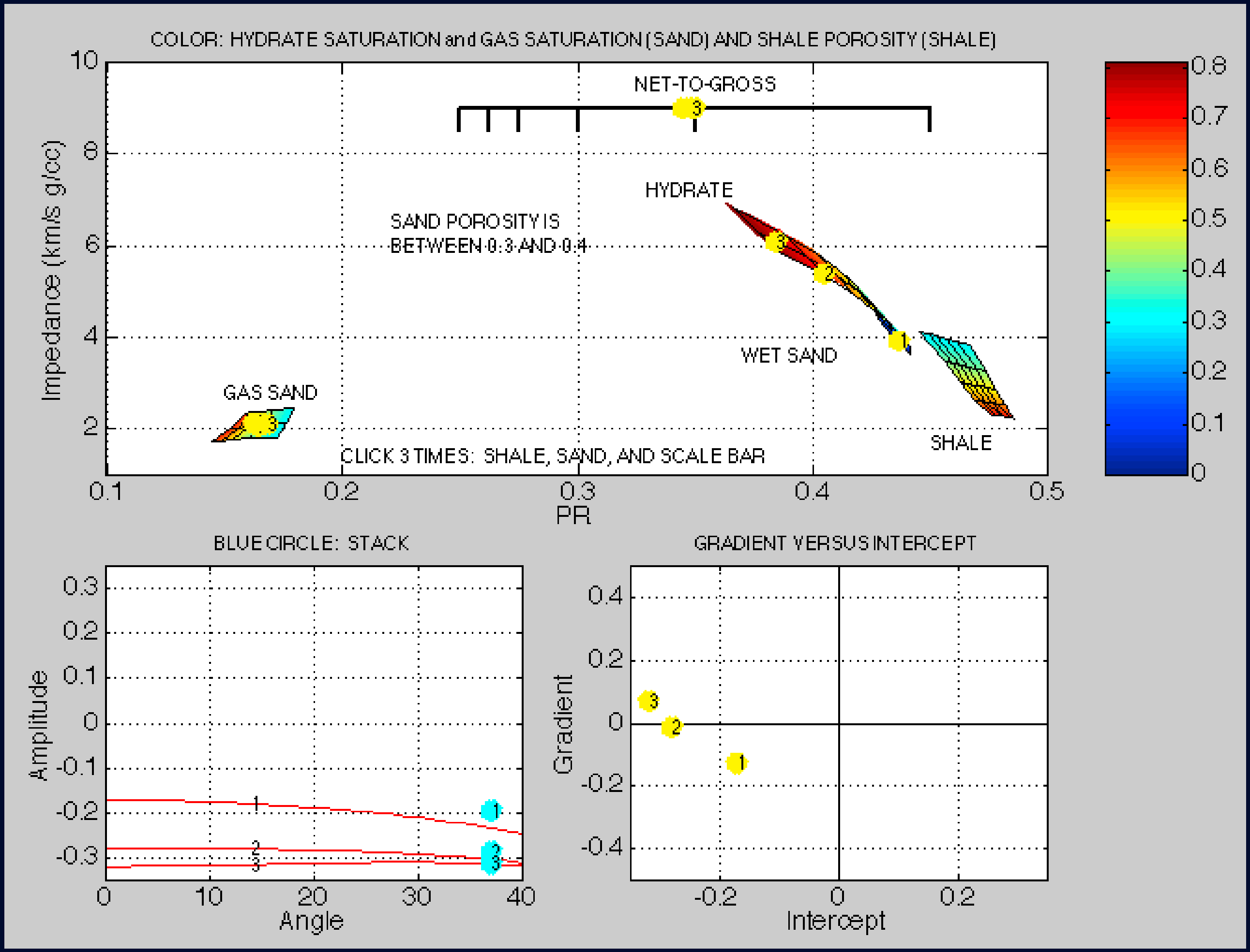
Velocity data from two Nankai Trough wells. P- (left) and S-wave velocity (right) versus porosity of the mineral frame (without hydrate) color-coded by hydrate saturation. The soft-sand model curves are (from top to bottom) for 0.8, 0.4, and zero hydrate saturation in clean sand with 10% clay. The data points falling below the zero hydrate saturation curves are from intervals with clay.

USING MODEL IN PREDICTIVE MODE



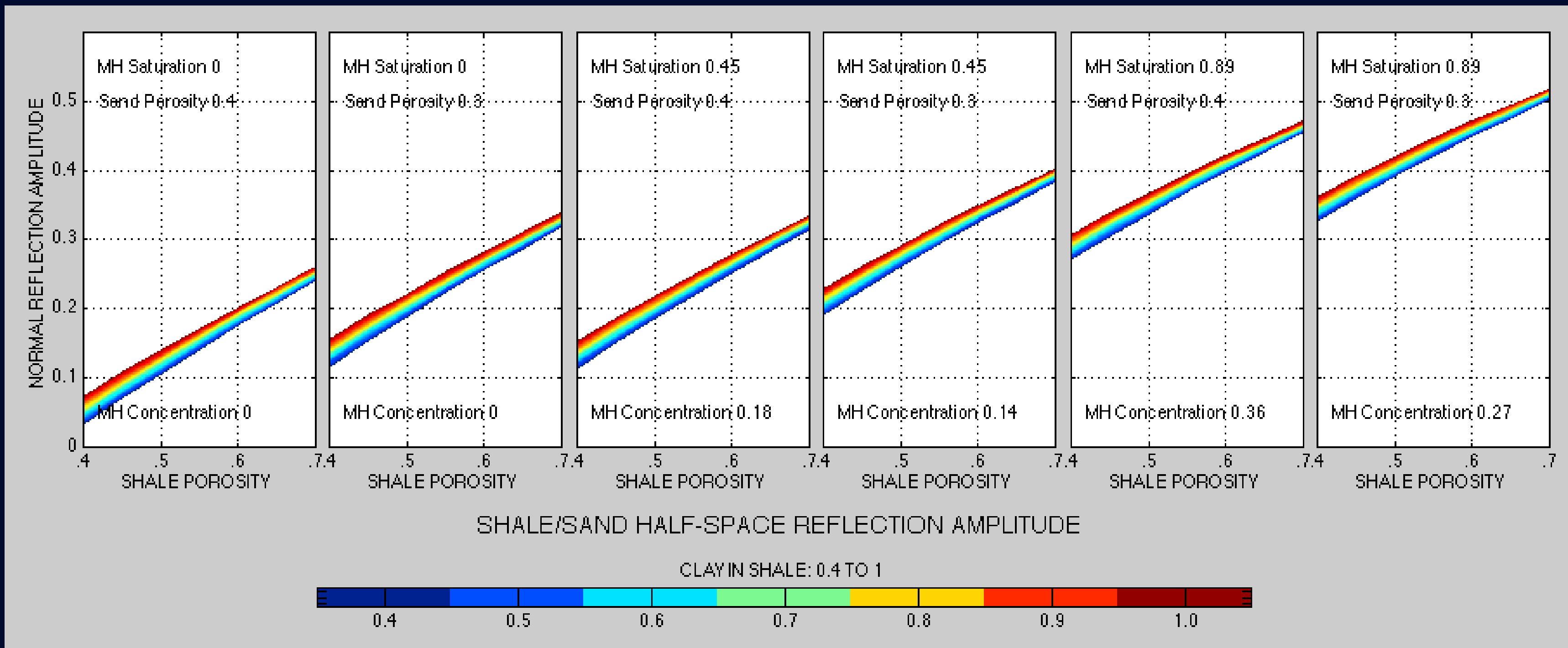
Reflectivity modeling at an interface with a methane hydrate reservoir. From overburden shale to wet sand (1); sand with small hydrate saturation (2); and sand with large hydrate saturation (3). The net-to-gross value is 0.5. Color coding is explained in the panel title.

USING MODEL IN PREDICTIVE MODE



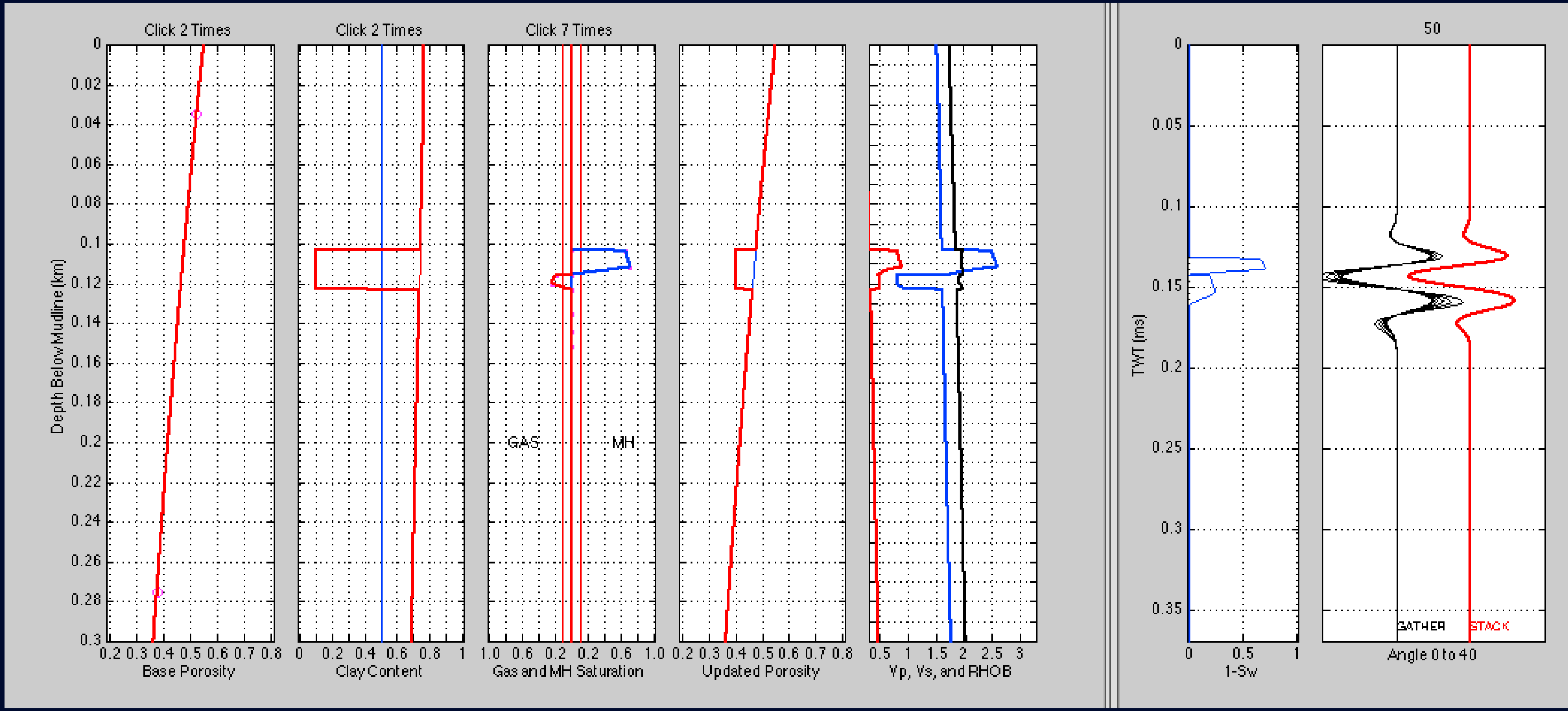
Reflectivity modeling at an interface with a methane hydrate reservoir. Modeling reflections between sand with hydrate (overburden) and gas sand. From wet sand to gas sand (1); from sand with small hydrate saturation to gas sand (2); and from sand with large hydrate saturation to gas sand (3).

USING MODEL IN PREDICTIVE MODE



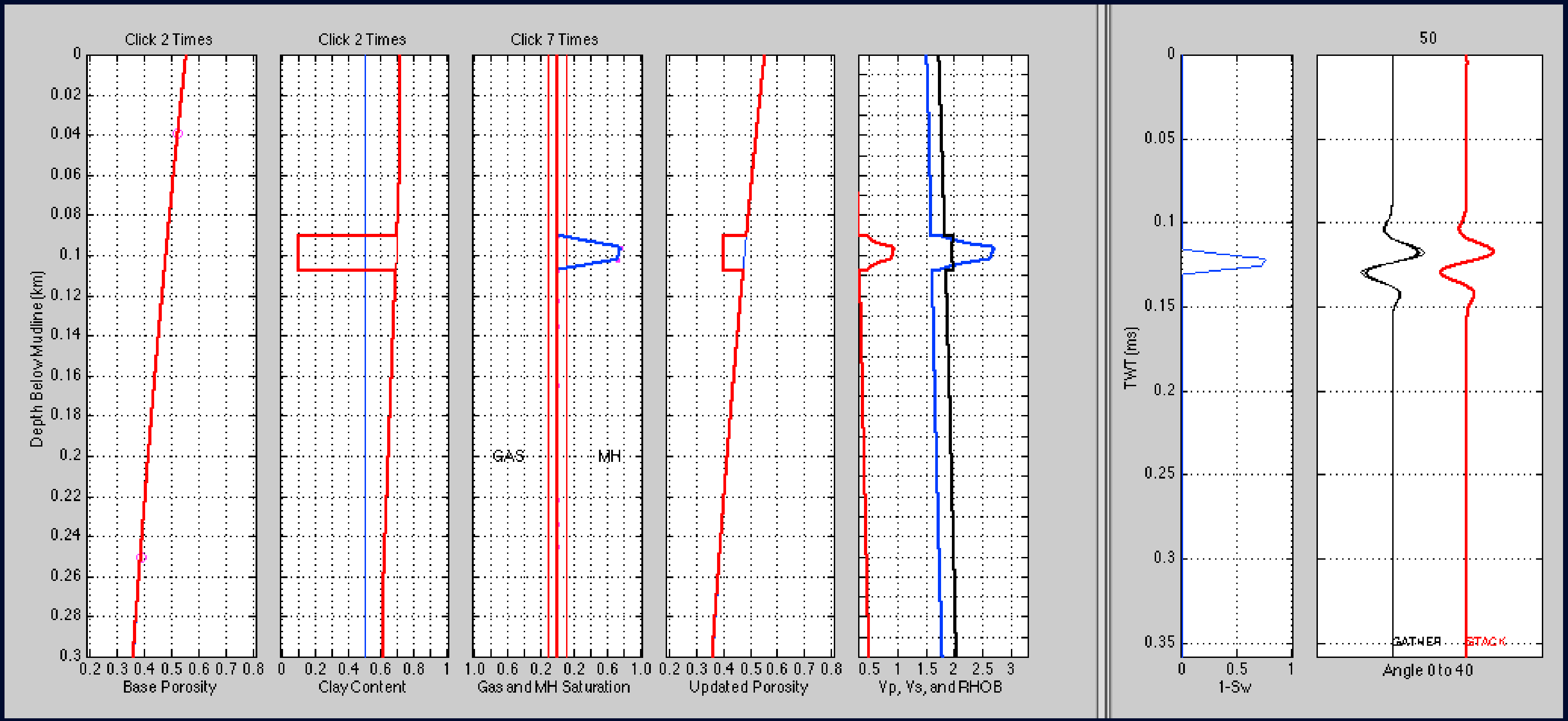
Normal reflection amplitude at the interface between shale and sand (both are treated as infinite half-spaces). The soft-sand model is used for both shale and sand. The horizontal axis in all frames is the total porosity of the shale. The color-code is the clay content in the shale which varies between 0.4 and 1.0. In the first and second frames, the hydrate saturation in the sand is zero while the porosity of the sand is 0.4 (left) and 0.3 (right). In the next two frames, the hydrate saturation is 0.45 with all other parameters being the same as in the first two frames. In the final two frames, the hydrate saturation is 0.9. The hydrate concentration which is the product of the sand porosity and hydrate saturation is also displayed in the frames.

USING MODEL IN PREDICTIVE MODE



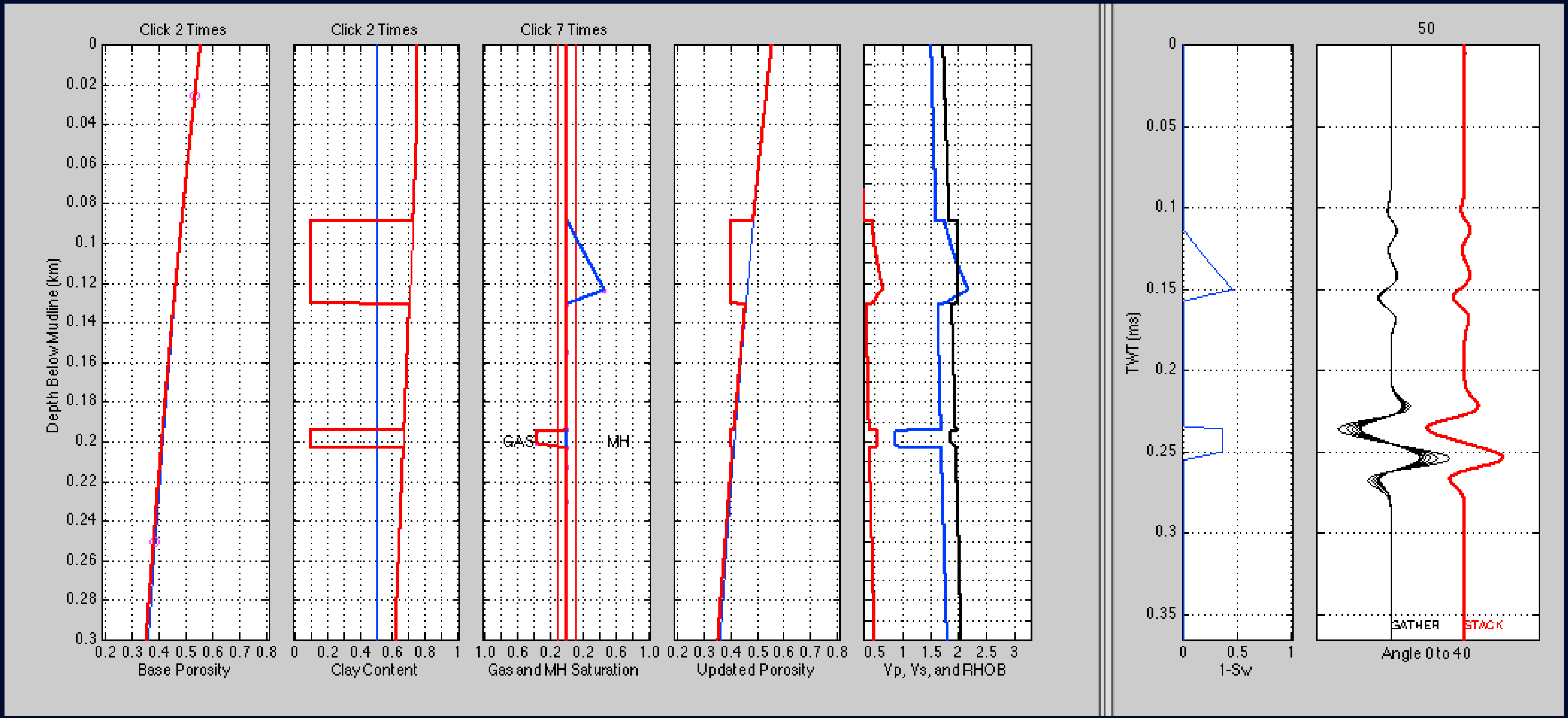
Synthetic traces, gather and full stack (right), generated on the earth model constructed in the left-hand frames. The porosity of the sand is fixed at 0.4 while its clay content is 0.1. In the fifth from left frame, the bulk density is shown in black. A raytracer with a Ricker 50 Hz wavelet is used to generate synthetic seismic traces. In this example, the hydrate sand with high hydrate saturation is immediately followed by sand with very small gas saturation.

USING MODEL IN PREDICTIVE MODE



Hydrate without free gas.

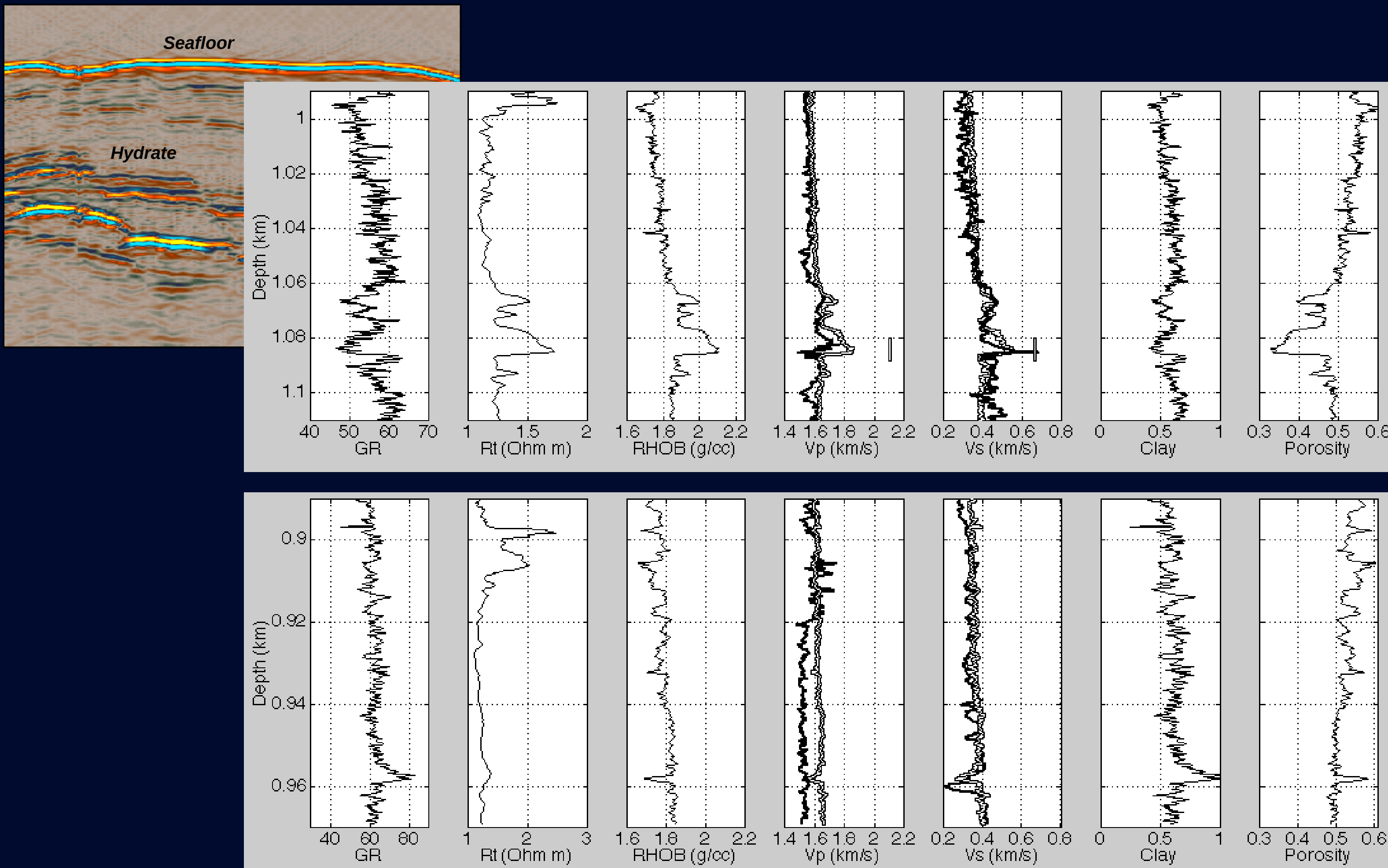
USING MODEL IN PREDICTIVE MODE



Wedge-shape hydrate profile. Free gas is separated from hydrate.

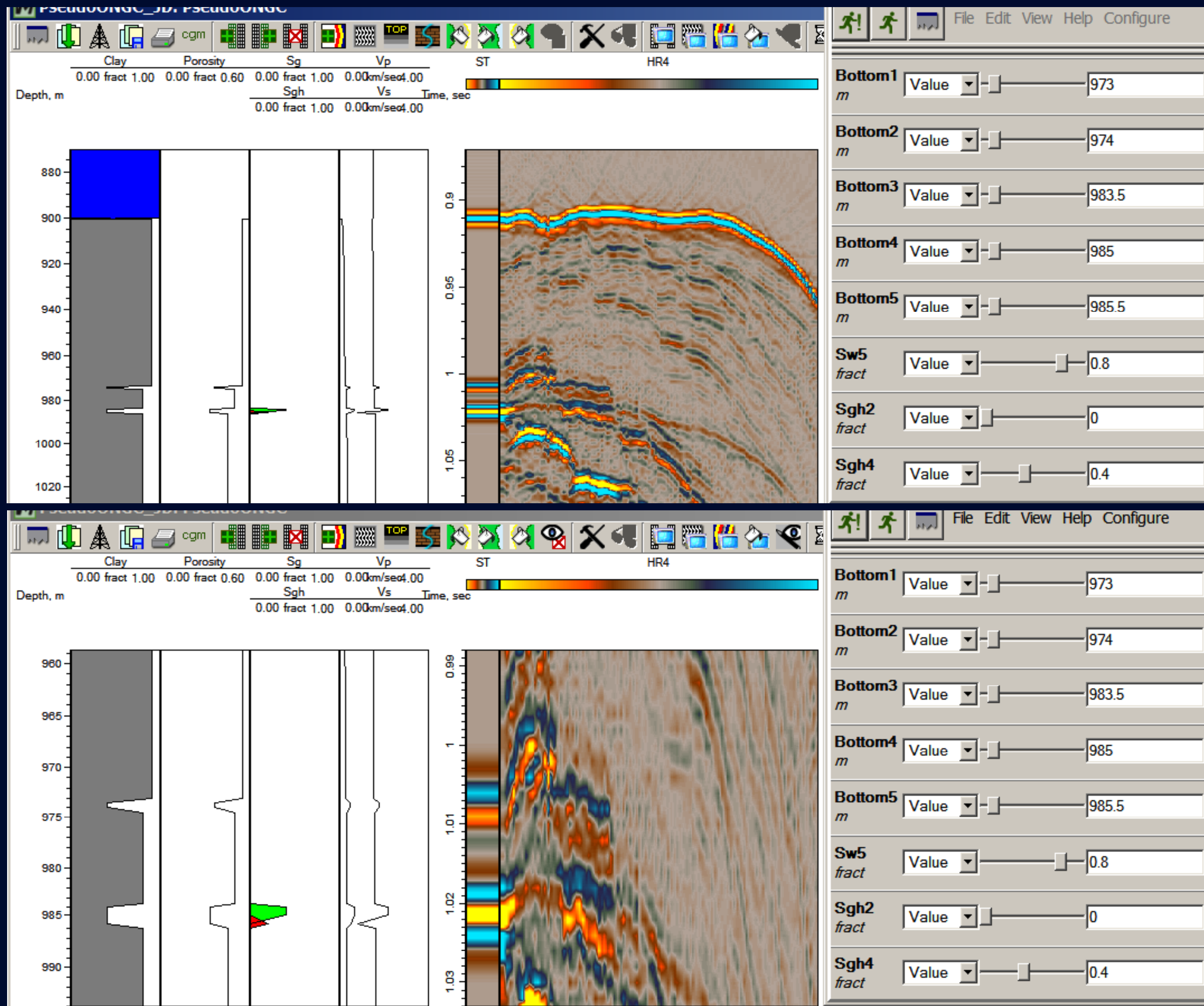
EXPLAINING REAL TRACES

Hydrate Ridge



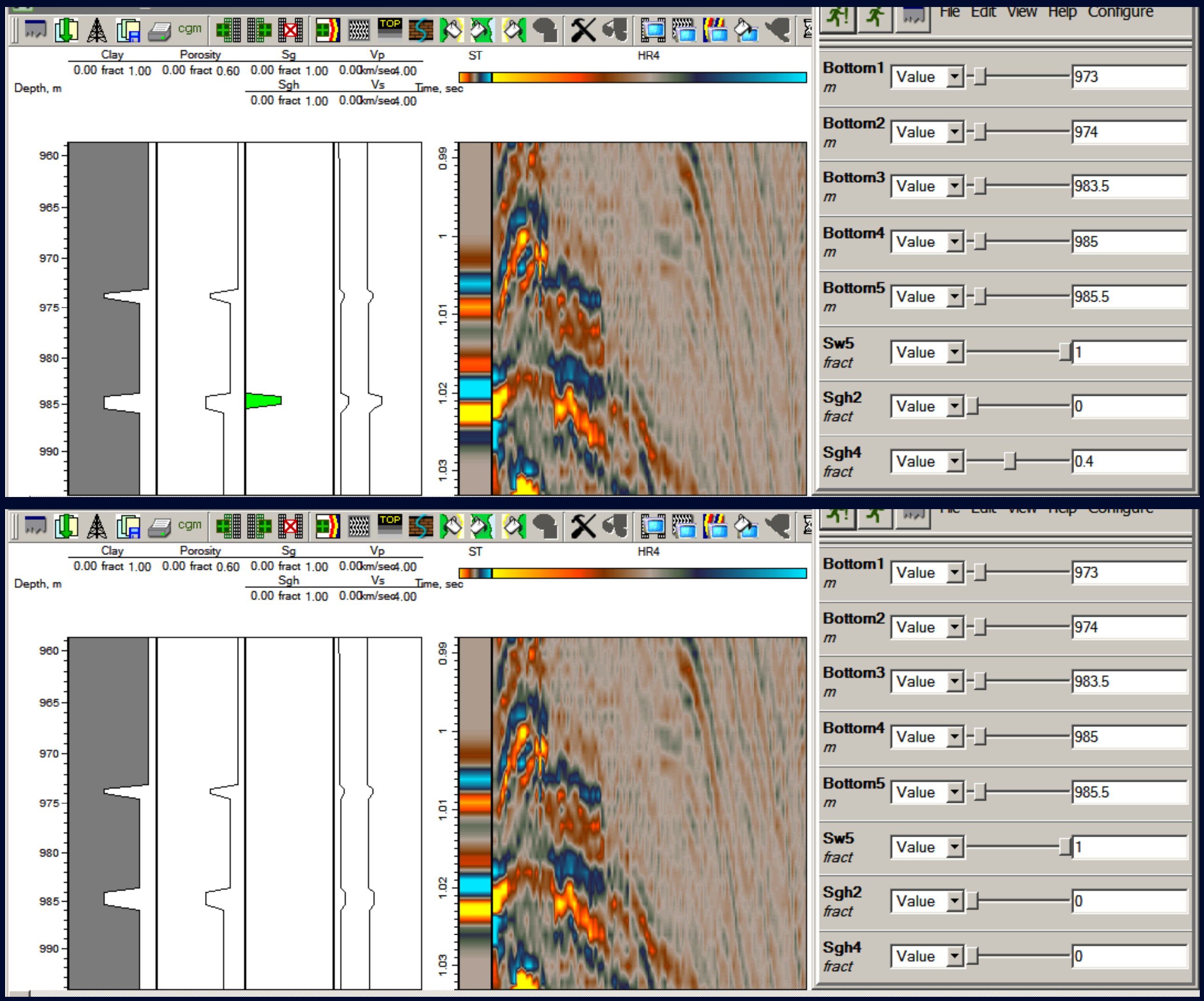
Two wells from the Hydrate Ridge (data courtesy Nathan Bangs of UT Austin). The clay curves are calculated by linearly scaling GR. The porosity is calculated form density by assuming that the mineral density is 2.65 g/cc and that of water is 1.00 g/cc. The bold black curves in the velocity frames are from MWD data while the hollow black curves are from the soft-sand model assuming zero hydrate saturation. The vertical hollow black bars are from the same model but assuming 0.3 hydrate saturation.

EXPLAINING REAL TRACES



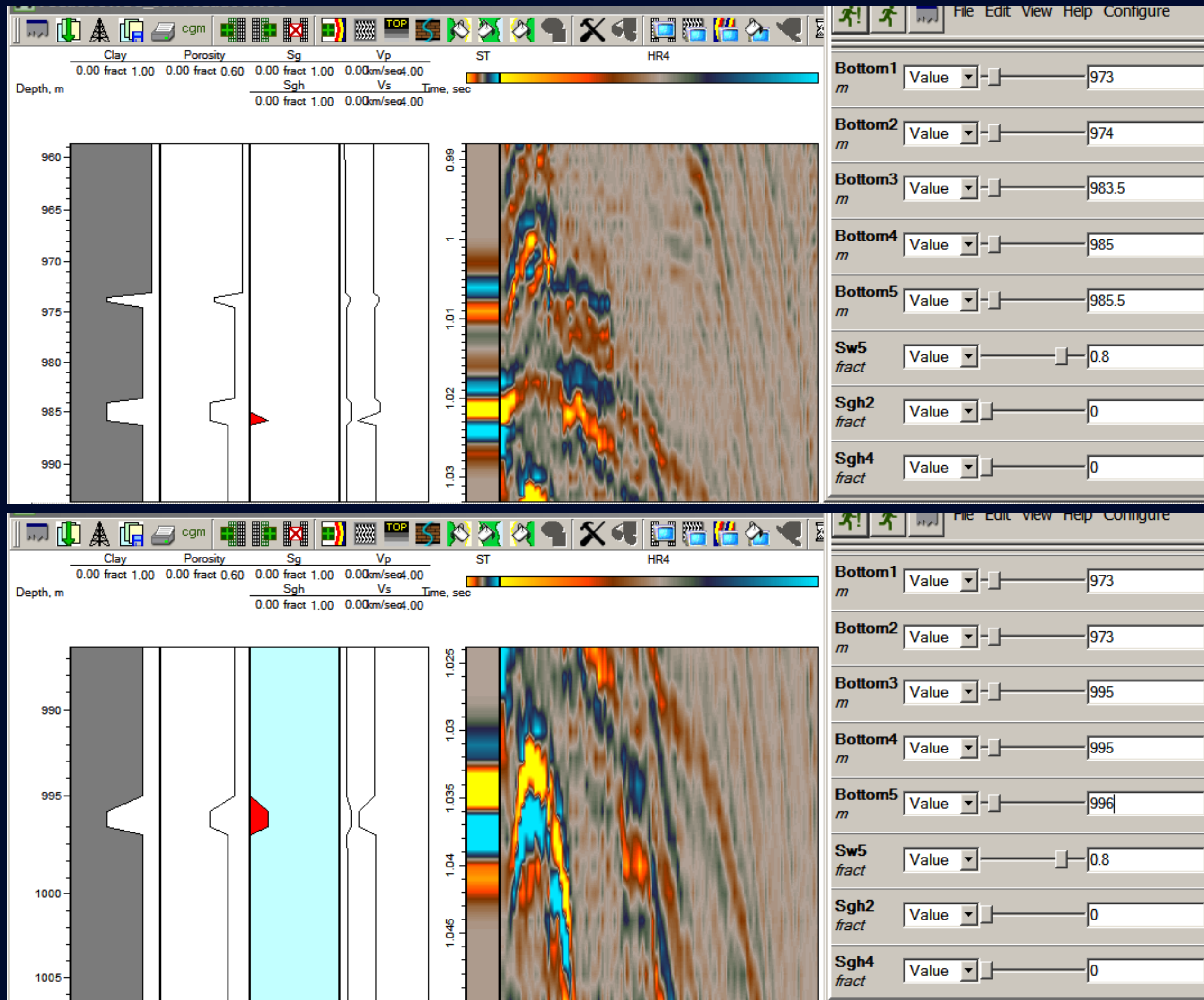
The Hydrate Ridge full-stack section with a synthetic stack to the left. Top – sections with the sea-bottom reflection. Bottom – zoom on the BSR. Blue is peak while red is trough. The clay content, porosity, and hydrate and free gas saturation curves are displayed on the left. The resulting velocity profile is next, followed by the synthetic and real stacks. The interactive panel with the depths of the layer bottoms and water and hydrate saturations in the layers is shown on the right. The top sand layer does not contain hydrate while the bottom layer has hydrate with free gas underneath. Green indicates hydrate while red is for free gas.

EXPLAINING REAL TRACES



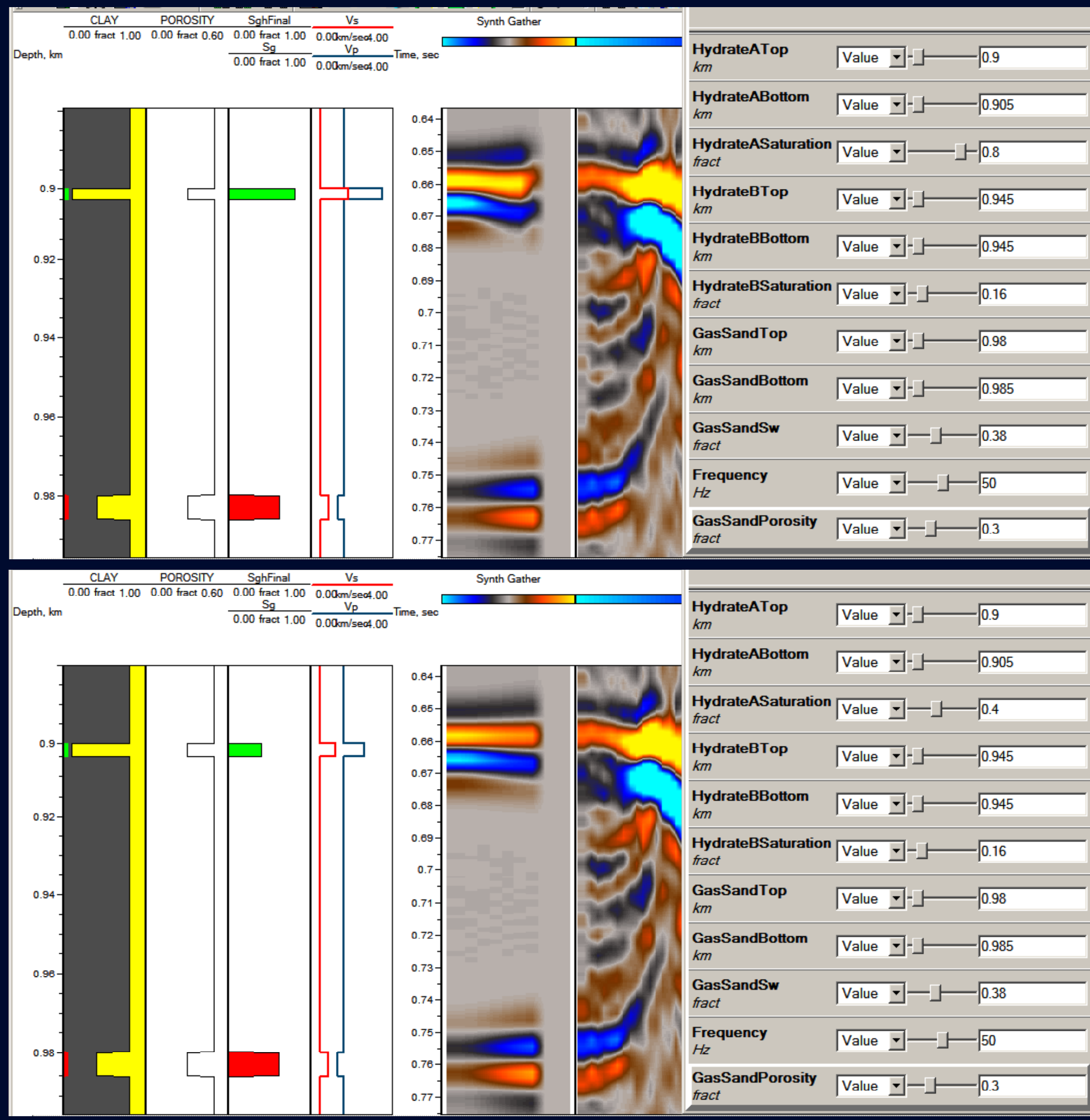
The Hydrate Ridge. Perturbations on the pseudo-well to eliminate scenarios.

EXPLAINING REAL TRACES



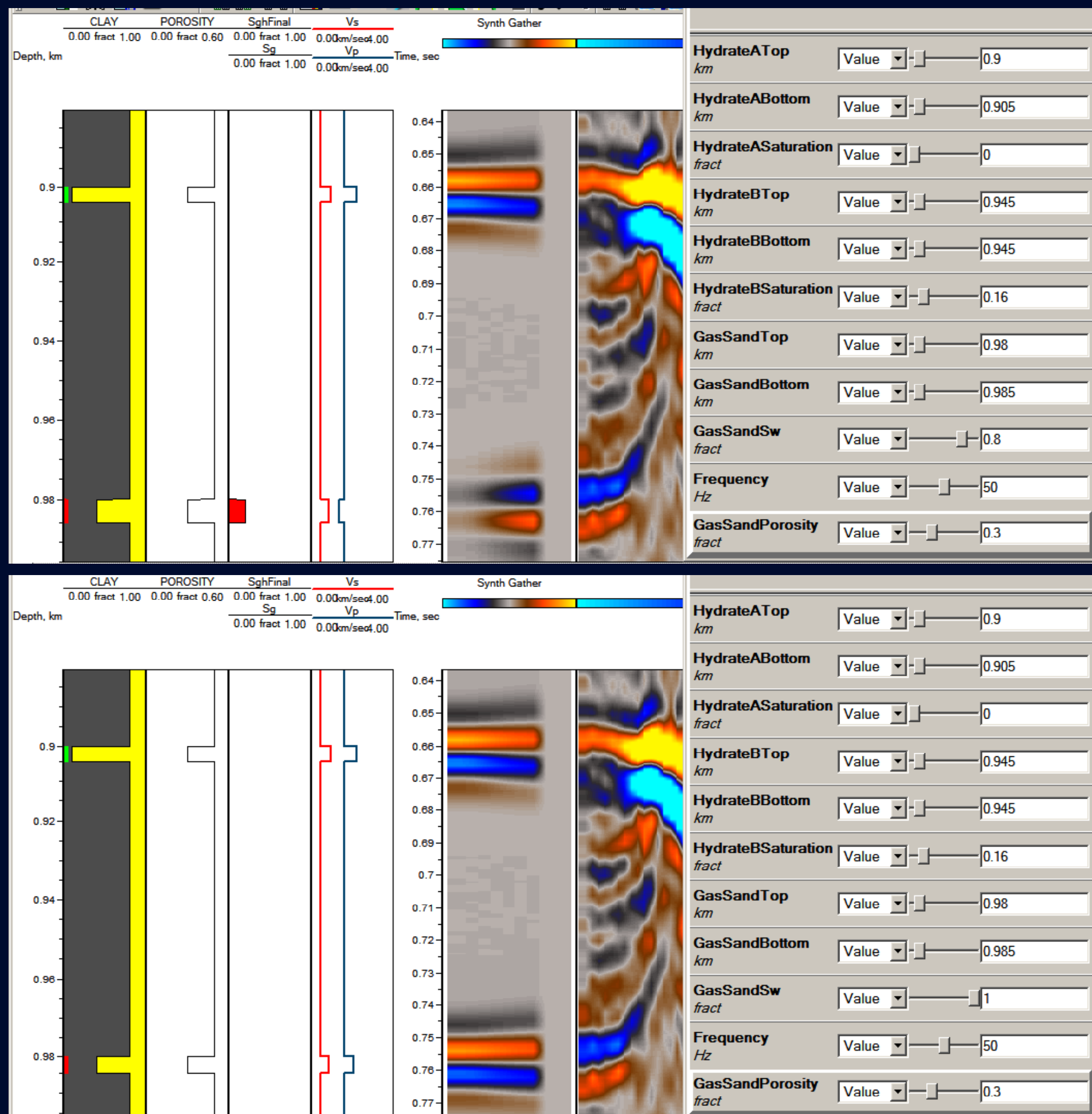
The Hydrate Ridge. Perturbations on the pseudo-well to eliminate scenarios. Is there hydrate in the Hydrate Ridge?

EXPLAINING REAL TRACES



Undisclosed offshore location. Calibrating at the free gas layer and varying hydrate saturation.

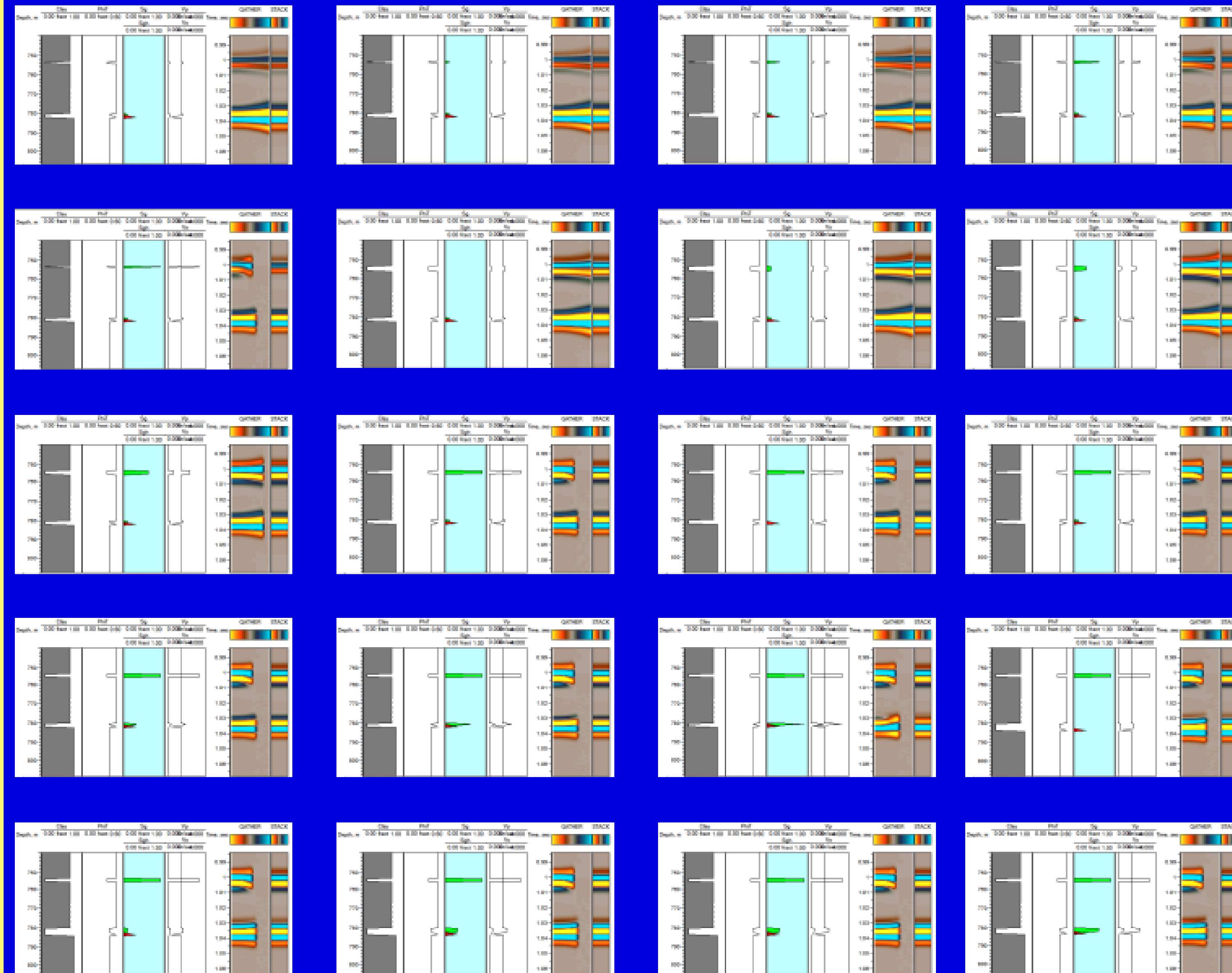
EXPLAINING REAL TRACES



Undisclosed offshore location. Varying hydrate and gas saturation.

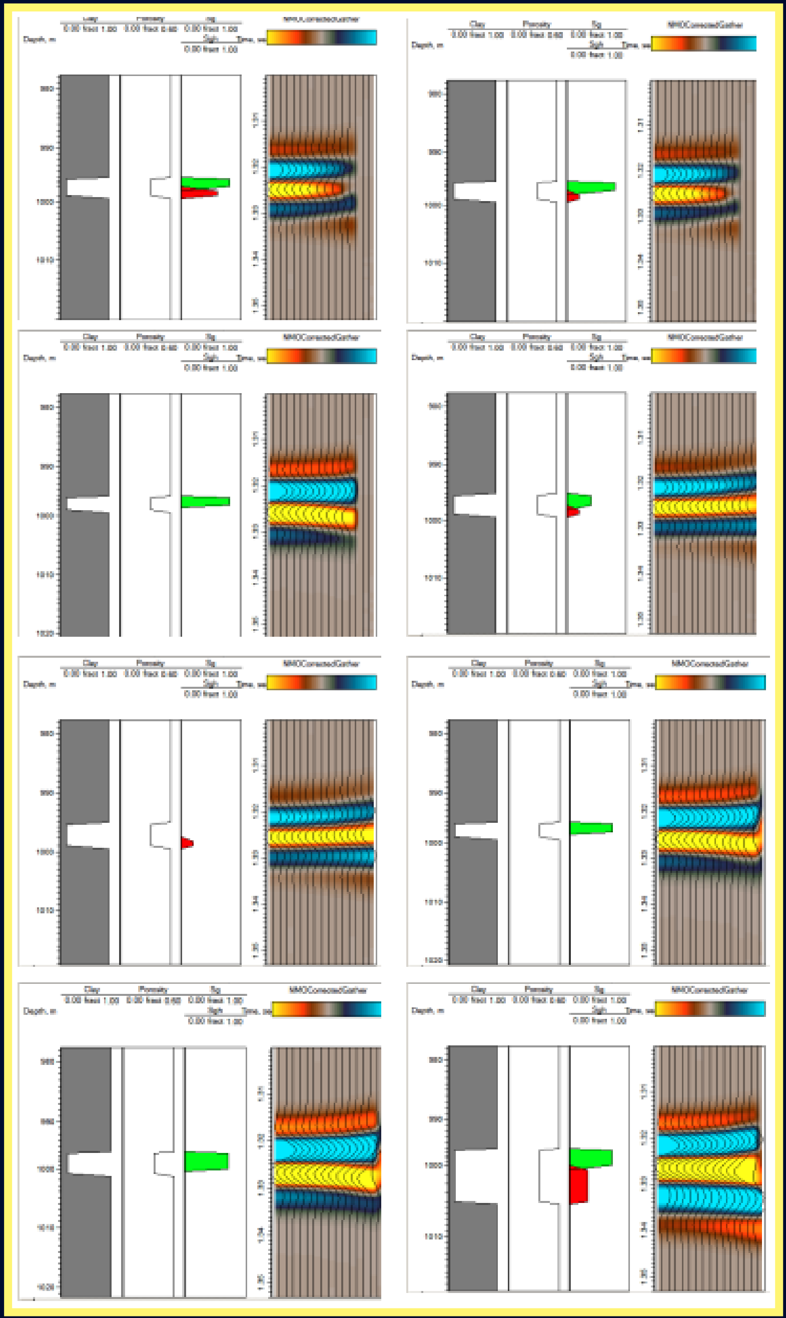
MODEL-BASED CATALOGUE

PSEUDO WELL MODELING: VARYING HYDRATE AND GAS SATURATION AND THICKNESS



MODEL-BASED CATALOGUE

Rock-physics-based catalogue of the gathers of adjoining gas hydrate and free gas layers with varying saturations and thickness.



CONCLUSION

Rock physics that links the properties and conditions of a natural methane hydrate reservoir to its elastic properties can help create synthetic variants of the reservoir's seismic response.

This technique, combined with complementary geologic and geochemical considerations, can help quantify hydrate resource from remote seismic measurements.

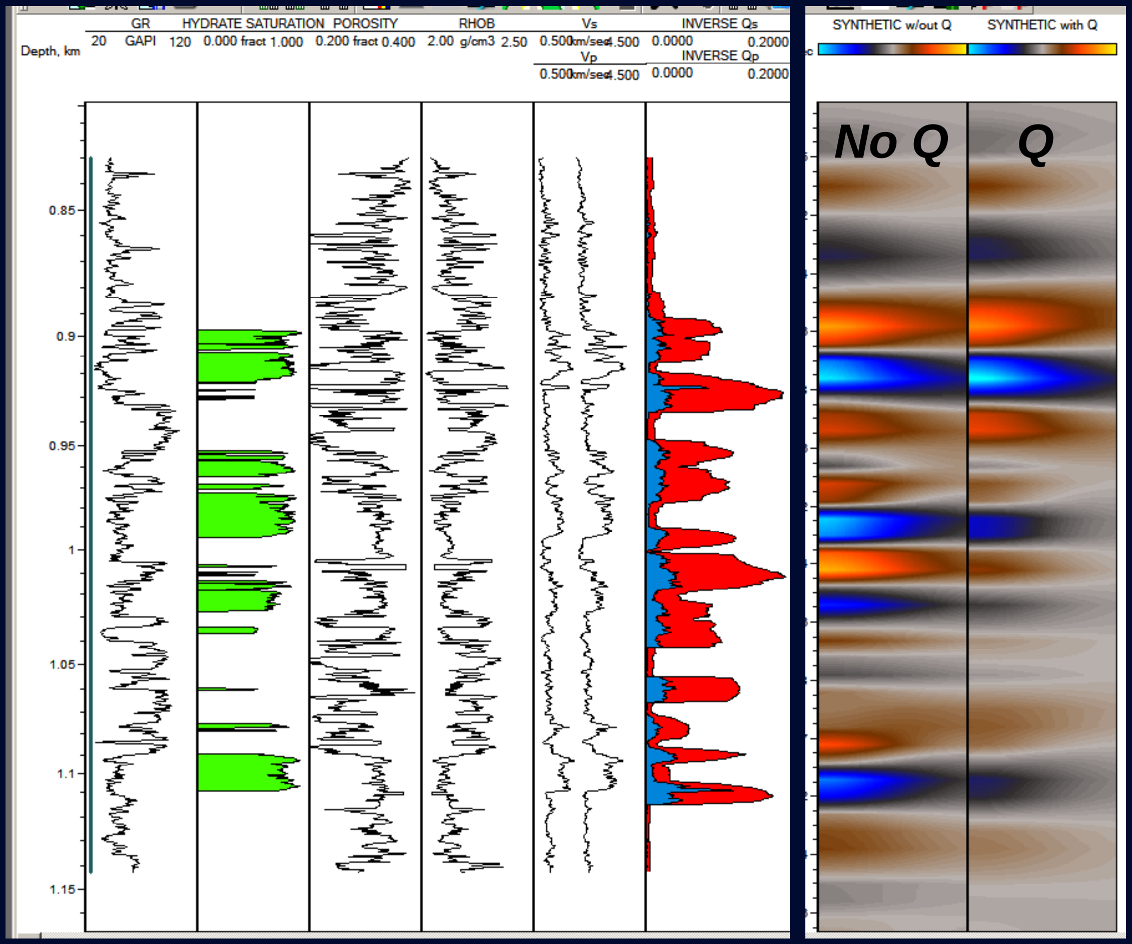
Catalogues of synthetic traces may serve as a field guide to hydrate quantification. The method also allows the interpreter to interactively assess the ambiguity of such quantification.

The use of a first-principle-based rock physics model is crucial for gas hydrate reservoir characterization because only within a physics-based framework can one systematically perturb reservoir properties to estimate the elastic response with the ultimate goal of characterizing the reservoir from field elastic data.

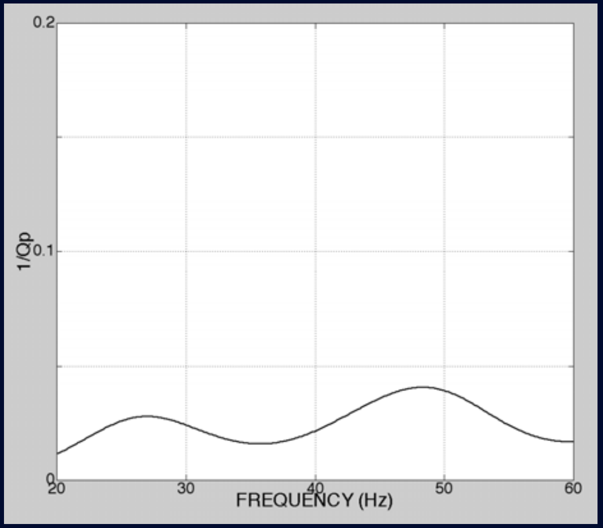
Intrinsic and scattering attenuation (Appendix I) due to the presence of gas hydrate may noticeably affect the seismic amplitude and, therefore, has to be taken into account during modeling and interpretation of seismic data. It can also serve as an indicator of a gas hydrate reservoir.

Reservoir geometry and thickness affect the seismic amplitude. Therefore, rock physics relations have to be upscaled to become applicable to seismic reservoir characterization where seismically derived acoustic and elastic impedances are used (Appendix II).

APPENDIX I: ATTENUATION



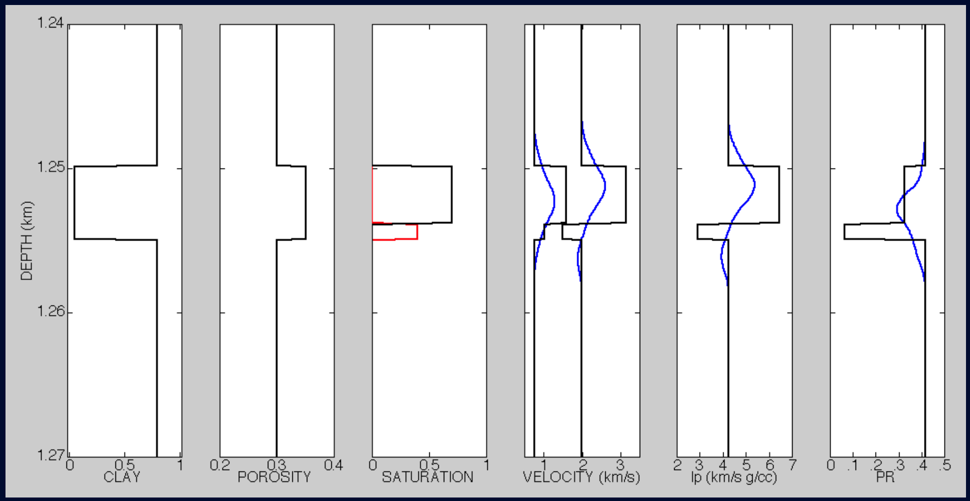
Well log curves in Mallik 2L-38 with calculated inverse quality factor shown in the middle (red for P-wave attenuation and blue for S-wave attenuation). The migrated synthetic gathers with and without attenuation are shown on the right.



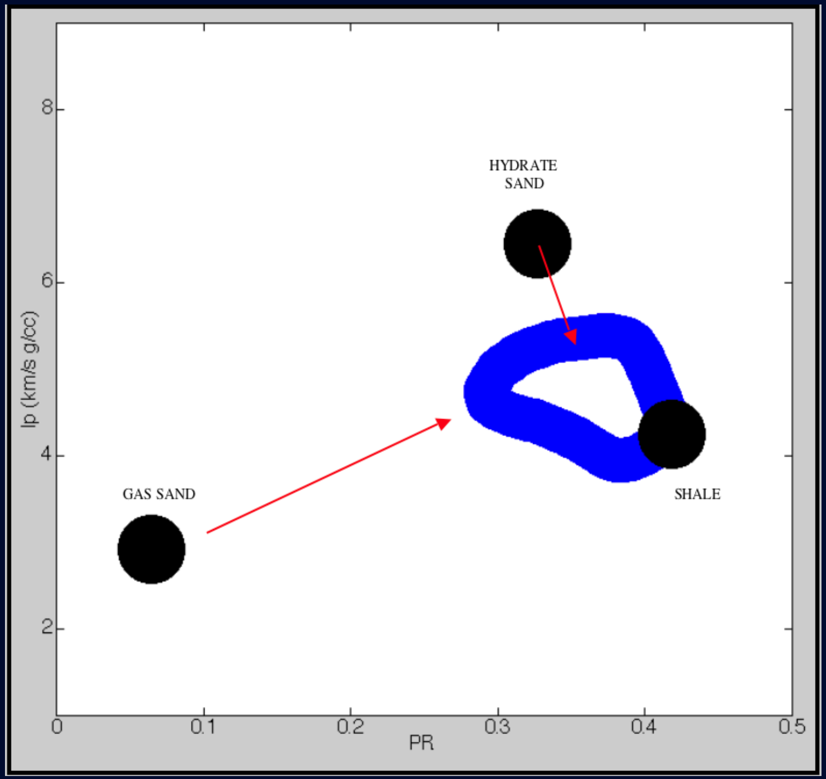
The inverse quality factor due to scattering in Mallik 2L-38.

It is about 1/3 of intrinsic attenuation.

APPENDIX II: CAVEAT OF RESOLUTION

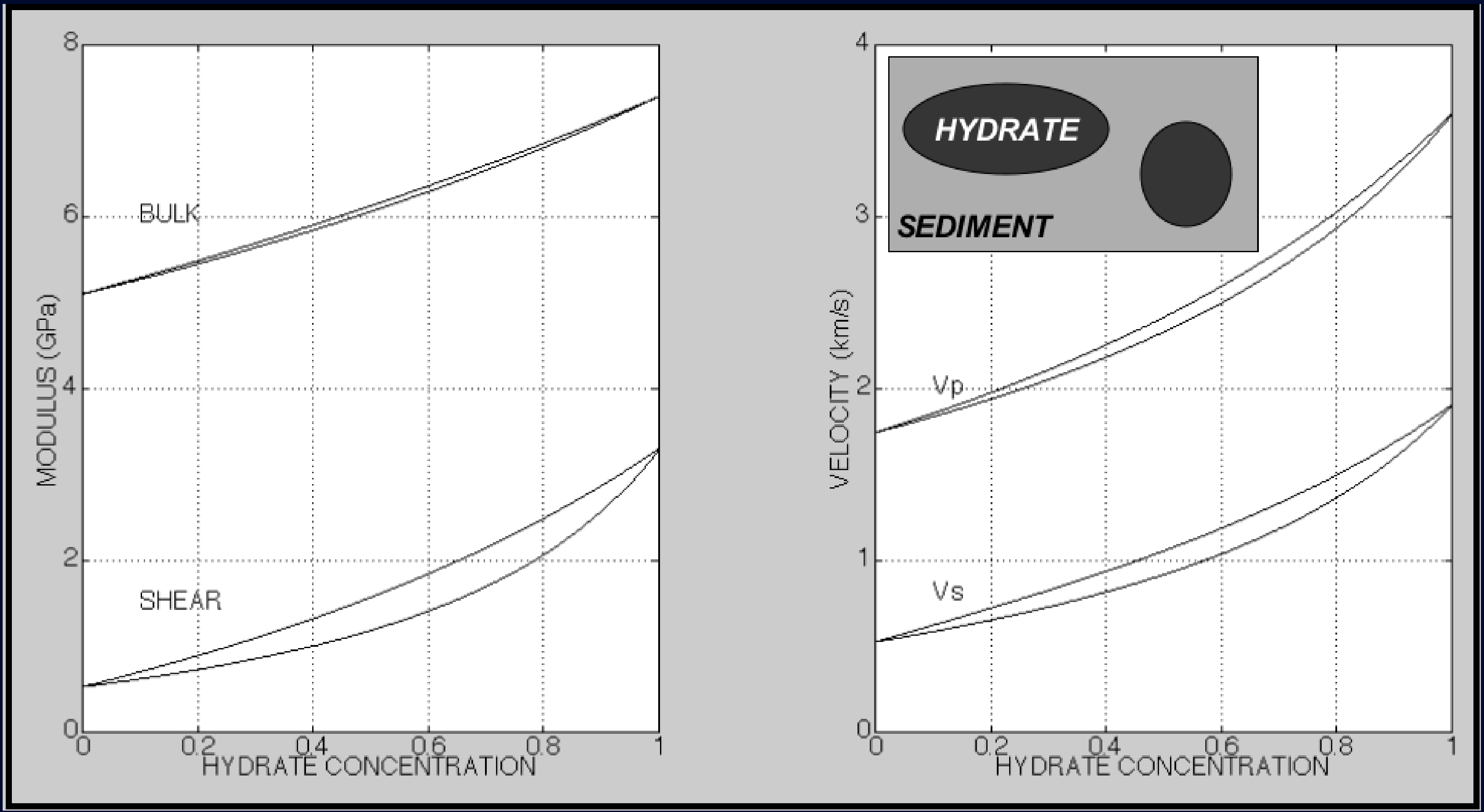


Pseudo well with methane hydrate. From left to right: clay content; total porosity; hydrate (black) and gas (red) saturation; P- and S-wave velocity; P-wave impedance; and Poisson's ratio. In the last three frames the black curves are for the original log data while the blue curves represent Backus-average upscaling.



Impedance versus Poisson's ratio from pseudo-log data. Black symbols indicate the positions of the three lithofacies, shale, hydrate sand, and gas sand at the log scale. Blue symbols are the cross-plot of the upscaled elastic properties. Red arrows show how the position of hydrate sand and gas sand move due to this upscaling.

APPENDIX III: HYDRATE LENSES



Upper and lower Hashin-Shtrikman bounds for the moduli (left) and velocity (right) of a mixture of soft sediment and methane hydrate.