Project Title
Seismic Gas Hydrate Quantification by Cumulative Attributes (CATTs)

Technology Status Assessment

DE-FC26-06NT42961

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Date: February 1, 2007

1. CURRENT STATE OF TECHNOLOGY

1.1. Summary of Background

To characterize a gas hydrate reservoir, we must relate the elastic properties of the sediment to the volume of gas hydrate and the host-rock properties and conditions, such as mineralogy, porosity, pressure, and temperature. One way of achieving this goal is through rock physics effective-medium modeling and utilizing this modeling to account for the effects of scale and geometry, reservoir properties and conditions, and the properties and conditions of the background for quantitative seismic interpretation.

1.2. Technologies/Tools/Approaches/Data Being Used

Seismic-driven characterization of methane hydrate reservoirs has a short but saturated history. It has been driven by the availability of public funds provided by the governments of the USA, Japan, Canada, Norway, EU, India, South Korea, and China. Private company investments into methane hydrate characterization has been driven by a need to justify the use of new acquisition technology, project a positive public image of concern about the environment, and a real need to locate and map shallow-subsurface and sea-bottom hydrate accumulations in offshore platform and pipeline placement.

Arguably the first attempt of employing seismic data to quantitatively characterize methane hydrate is by Ecker et al. (2000) who used the seismic velocity at the BSR at the Outer Blake Ridge to relate the positive velocity anomaly to the amount of hydrate in the pore space. This work shows that (1) it is easier to quantify the in-situ amount of hydrate than that of conventional hydrocarbon (e.g., free gas) because unlike in the free gas case, the velocity is a strong function of hydrate saturation; and (2) while trying to remotely estimate the volume of hydrate, one inevitably encounters the inherent “bottleneck” which stems from the fact that a single measurable parameter (be it the velocity or impedance) depends on a number of rock attributes (e.g., hydrate saturation, porosity, and the elastic properties of the background). Ecker et al. (2000) have partly resolved this non-uniqueness by comparing the velocity profile at an apparent hydrate location to that where hydrate was apparently absent and then assuming that the observed seismic signature difference is purely due to the presence of hydrate in the pore space of the sediment. Therefore, additional assumptions always have to be made to resolve the inherent non-uniqueness of the remote sensing of rock properties.

1.3. Benefits and Inadequacies of Current State-of-the-Art

Essentially all investigations published after 2000 follow the same scheme: an elaborate analysis of the seismic data followed by the derivation of either seismic velocity or seismic impedance volumes and a consecutive application of a rock physics transform to map this seismic attribute volume into gas hydrate saturation. A recent example of this approach is in Dai et al. (2004). The emphasis in all such papers is on seismic acquisition and analysis rather than on the subtlety of transforming the seismically-derived elastic volumes into reservoir properties and conditions.

Correct processing of seismic data and/or impedance inversion is an obvious necessary condition for quantifying a methane hydrate reservoir. However, this condition is far from being sufficient. We have already given an example of a rock physics "bottleneck" that requires certain assumptions to be made to translate seismically derived velocity or impedance into gas hydrate saturation. Yet, there is one more factor that contributes to the ambiguity of quantitative seismic interpretation. It is the spatial scale.

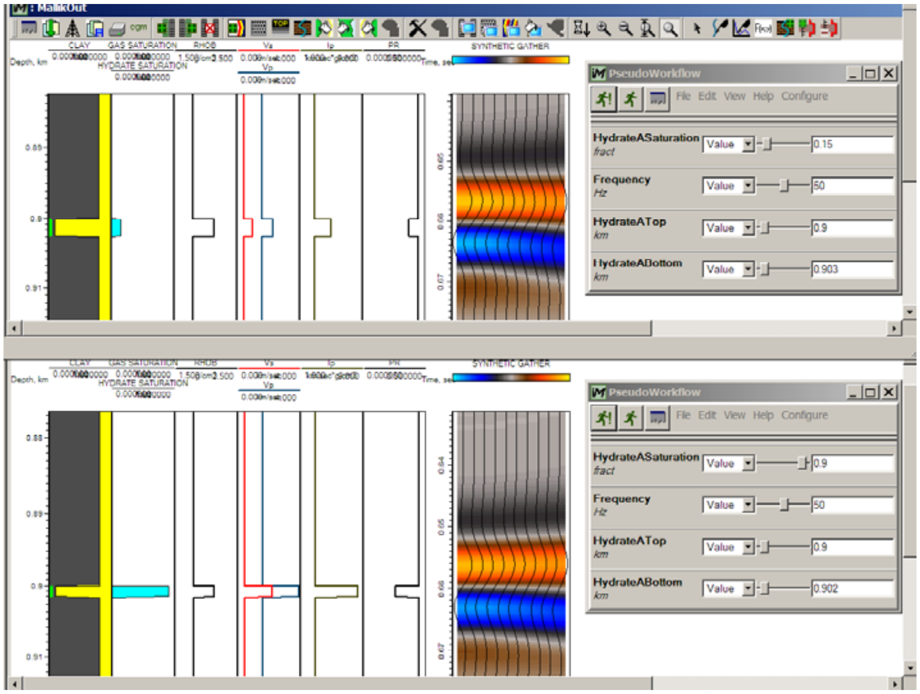
Synthetic seismic modeling in Figure 1 illustrates that the seismic gather recorded from a methane hydrate reservoir whose thickness is 3 m and hydrate saturation is 0.15 will be essentially identical to that recorded from a thinner reservoir whose thickness is only 2 m but with much higher hydrate saturation of 0.9. This example shows that giving an estimate of hydrate saturation at a point in space from seismic data is somewhat a futile task. Then the question is: what is the property (if any) that can be definitely and unambiguously derived from a seismic attribute? In the past, researchers have implicitly acknowledged this problem referring to it sometimes as the "thin layer problem." Nobody, however, has clearly and rigorously formulated the problem and attempted to solve it. Below we will pose a problem and outline a solution.

2. DEVELOPMENT STRATEGIES

2.1. Why New Approach is Required: Caveat of Seismic Resolution

Rock physics model are usually utilized on a point-by-point basis at the well log and/or core scale. The scale of seismic data may exceed that of well log data by two or three orders of magnitude. A seismic wave averages the elastic features observed at a smaller scale. Sharp impedance contrasts that manifest the presence of gas hydrate and free gas become smaller and may even disappear in impedance inversion volumes.

Consider a gas hydrate pseudo-well where the upper part of the sand body is filled with methane hydrate and the lower part contains free gas (Figure 2). The hydrate sand is manifested by large impedance while the sand with free gas is manifested by small Poisson's ratio. The smoothing effect of the seismic wave on the elastic attributes (upscaling) simulated via Backus (1962) averaging of the elastic moduli by a running 5 m window is also displayed in Figure 2. The sharp impedance and PR contrasts apparent at the log scale become smaller. Even the vertical positions of the extreme of the elastic properties change.



PseudoWorkflow (top)

HydrateASaturation *fract*: Value 0.15
Frequency *Hz*: Value 50
HydrateATop *km*: Value 0.9
HydrateABottom *km*: Value 0.903

PseudoWorkflow (bottom)

HydrateASaturation *fract*: Value 0.9
Frequency *Hz*: Value 50
HydrateATop *km*: Value 0.9
HydrateABottom *km*: Value 0.902

Figure 1. Synthetic gathers at two pseudo-wells that sample a blocky methane hydrate reservoir. Top – the thickness of the reservoir is 3 m while hydrate saturation is 0.15. Bottom – the thickness of the reservoir is 2 m while hydrate saturation is 0.9. All other parameters of the two pseudo-wells are identical.

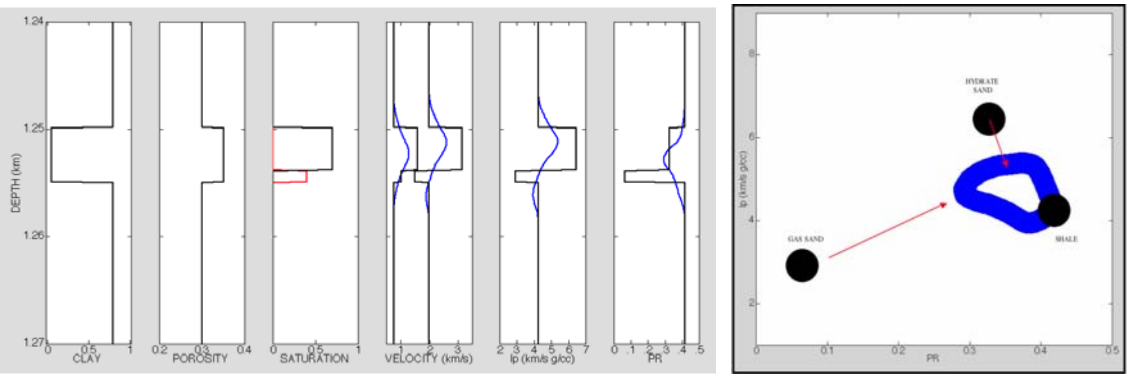


Figure 2. Pseudo well with methane hydrate. From left to right: clay content; total porosity; hydrate (black) and gas (red) saturation; P- and S-wave velocity; P-wave impedance; and Poisson's ratio. In the last three frames the black curves are for the original log data while the blue curves represent Backus-average upscaling. The frame on the left displays the impedance versus Poisson's ratio from these 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.

2.2. Problems to Address in this Research Project

Rock physics transforms are based on data generated in the laboratory at the scale of inches or in the well at the scale of feet. We aspire to use them at the seismic scale in tens or hundreds of feet. The vast disparity between these scales may lead to erroneous results during direct application of rock physics to seismic data. Small hydrate saturation in a relatively thick reservoir may produce exactly the same seismic reflection in the near and far offset as large hydrate saturation in a thinner sand layer. *Downscaling* of seismic-scale measurements is impossible without additional assumptions about the structure of the subsurface. Such assumptions could be quite groundless without direct well control. Therefore, we pose the problem differently by seeking a *scale-independent volumetric reservoir property* and a *scale-independent seismic attribute* to quantify this property.

One such reservoir property is the cumulative volume of hydrate which is the integral of hydrate saturation with respect to depth. By introducing this property, we depart from the traditional goal of inferring hydrate concentration at a point in space. Instead we aim at determining the total hydrate reserve in a reservoir.

An elastic property commonly used in seismic reservoir characterization is the acoustic impedance I_p. It is related to the compressional modulus M as $I_p^2 = \rho_b M$, where ρ_b is the bulk density. The density of methane hydrate is close to that of water and the total porosity of shale and sand are close to each other in the shallow subsurface where hydrates occur. As a result, ρ_b is almost constant and I_p^{-2} is *approximately* scale-independent because averaging I_p^{-2} is analogous to harmonically averaging the compressional modulus. Therefore, the integral of the anomaly of the inverse squared acoustic impedance can be considered as a scale-independent seismic attribute to be related to the cumulative volume of hydrate.

This cumulative attribute (or CATT) belongs to a new class of seismic attributes: while the seismic impedance (acoustic and elastic alike) can be, simply speaking, estimated by integrating the trace, a CATT is estimated by integrating the trace *repeatedly*. It has to be designed based on rock physics transforms relevant to the problem under examination. *Designing an appropriate CATT, supporting this design by rock physics, and applying this methodology to real data is the emphasis of this project.*

3. FUTURE

3.1. Barriers to Overcome and Potential Impact on the Exploration of Hydrates

The rock physics transforms between a CATT and hydrate volume are site- and case-specific. They have to be adjusted and calibrated at a location. Relevant and correct rock physics treatment is a key in designing a CATT optimally suitable for hydrate characterization. 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 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 based approach has to be upscaled to become applicable to seismic reservoir characterization where seismically derived acoustic and elastic impedances are used. One way of upscaling – using cumulative seismic attributes to map accumulated reservoir properties is introduced and discussed in the previous section. The challenge and road ahead is to rigorously apply it to a carefully selected data set that contains both well and seismic data for the purpose of method calibration and blind testing at selected wells.

3.2. Deliverables – Tools, Methods, Instrumentation, Products

The deliverable is a methodology of selecting a CATT for hydrate characterization based on rock physics principles and site-specific data and its application to seismic data, as well as examples of this application to real seismic data.

4. RELEVANT AND QUOTED REFERENCES

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