7th International Conference & Exposition
on Petroleum Geophysics

"HYDERABAD 2008"

P - 274

Seismic Data Processing and Quantification of Gas Hydrates in a Deepwater GOM Basin

Jianchun Dai, Niranjan Banik*, Dianna Shelander, John McCleery, George Bunge, and Nader Dutta,
Schlumberger, 10001 Richmond Avenue, Houston, TX 77082, nbanik@slb.com

Summary

The Perdido Fold Belt in Western Gulf of Mexico (GOM) is a relatively new frontier for exploration of hydrocarbons, witnessing substantial exploration activities and discoveries. The exploration targets in the area are reservoir lithology of clastic and carbonates in the Miocene/Oligocene at target depths of 4000m-8000m and deeper sections. This area has been found to contain high saturation gas hydrates in the hydrates stability zone (GHSZ) which is within about 600ms two-way time from the water bottom. Several wells have been drilled in the area and at least one of them has penetrated naturally occurring gas hydrates in high concentration (> 70 %). We have recently completed a detailed study of seismically characterizing gas hydrates in the Perdido Fold Belt area. In this presentation we emphasize seismic data processing, rock physics modeling, 3D prestack inversion, and integrated interpretation for gas hydrates saturation studies in the area.

The high-resolution seismic data processing, including a curved ray Kirchhoff prestack migration followed by an advanced gather flattening method, greatly improved the resolution of the stack data and the elastic parameter inversion results. This along with the use of a 3D, simultaneous, prestack inversion method tremendously helped the gas hydrates quantification process. The availability of a well that contained a 50ft net pay of gas hydrates was also beneficial in prestack inversion and in building the rock physics parameters. The geological study enabled understanding of the hydrocarbon migration pathways and gas flow conduits. A previous study by the USA Minerals Management Service (MMS) has shown that in the GOM sand-prone areas are more suitable for gas hydrates generation and accumulation than the shale-prone areas. Through a lithofacies classification scheme we identified sand-prone areas. Saturation of gas hydrates was computed from the inverted acoustic impedance using a direct regression method Through this integrated approach, we have identified a large area in Alaminos Canyon (ACA) block 818 containing gas hydrates of saturation exceeding 70%. The JIP site selection committee has selected several locations for Leg-2 drilling as a result of this work.

Introduction

Naturally occurring gas hydrates have drawn significant attention from the scientific community worldwide due to their potential as an alternative energy resource, as possible sources of shallow hazards for drilling and production of oil and gas, and as agents of long-term, global climate change. Because of considerable hydrocarbon exploration and production activities in the deepwater GOM, a Joint Industry Participation (JIP) group was formed and a project partially funded by the U.S. Department of Energy (DOE) began in October 2001. The primary objective of this project is to develop technology and data to assist in the characterization of naturally occurring gas hydrates in the deep water GOM. We have been actively participating in this program, providing results of seismic characterization of gas hydrates. In the Phase I part of the project, we processed and analyzed seismic data in Keathley Canyon and Atwater Valley areas and provided predrill predictions based on a five-step workflow (Dai et al., 2004) which included enhanced processing, rock physics modeling, prestack inversion, and integrated interpretation. This work, the subsequent JIP Leg-1 drilling, and the post-drill analysis suggested that the seismic method based on the five-step workflow is a powerful hydrates characterization method, although the area studied in Phase I seemed to contain only low saturation (<20%) gas hydrates. Previously we have shown that if the predicted gas hydrates saturation is 20% or less, the seismic prediction results may be unreliable (Dai et al., 2007).

Following the Phase I work and the recommendations by the US Minerals Management Service (MMS) that sand-rich environment has a greater chance to find gas hydrates in the GOM, JIP decided to concentrate on the Perdido Fold Belt area in Western GOM. The blocks 818 and 857 in the Alaminos Canyon (ACA, Figure 1) were selected for the Phase II seismic characterization study. This area has been recently quite active for hydrocarbon exploration in deep Perdido Fold Belt structures, focusing especially on the thick Wilcox sand. Shallow gas and high GOR oil have also been reported. One of many wells drilled, at least one well, ACA 818-1, has reportedly penetrated substantial gas hydrates (~70% saturation, ~50ft net pay) as determined from the analysis of well-log data.

We have carried out a detailed study of the gas hydrates characterization in ACA blocks 818 and 857, using our five-step work flow. A special data processing scheme was applied for the purpose. The workflow has been modified to incorporate a fast, yet robust simultaneous prestack inversion scheme for inversion of elastic impedances and density. We have also identified sand-prone areas through a lithofacies classification method. The final estimation of gas hydrates saturation was done using a direct regression based transform method and also from a Bayesian statistical inversion of elastic impedances. An integrated interpretation method identified hydrocarbon pathways and fluid-flow conduits. We present these results in the paper.

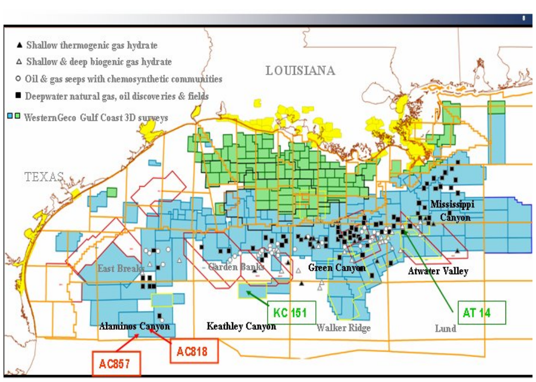

Figure 1: Location map of GOM Alaminos Canyon blocks 818 and 857 in red rectangles.

Workflow

Our five-step workflow, discussed in details elsewhere, (Dai et al., 2004), consists of (a) High-resolution seismic data reprocessing with special attention to the first 1s of data below the mudline, (b) Stratigraphic interpretation, highlighting various faults, hydrocarbon pathways, and fluid-flow conduits, (c) Attributes analysis, identifying anomalous zones for possible hydrates zones, (d) Rock physics modeling and elastic parameter inversion, and (e) Quantitative analysis to estimate hydrates saturation. A schematic of this workflow is shown in figure 2. In the present study we followed this general workflow, but substantially modified the details of data processing, prestack inversion procedure, rock model building, and in the estimation algorithms. These are discussed in some detail below.

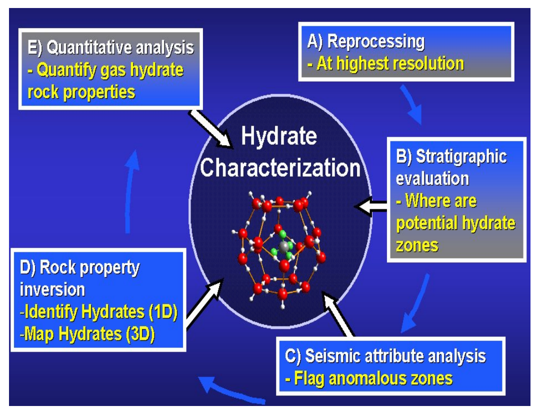

Figure 2: Schematic Five-step workflow for seismic characterization of gas hydrates

<u>Seismic data processing</u>

Since gas-hydrate bearing layers are generally thin, and the workflow includes identification of all relevant stratigraphic details as clearly as possible, amplitude preserving 3D high-resolution processing is a prerequisite for gas hydrates evaluation. The recommendation is to use a 2ms or finer sampling in all processing steps, which most often means going back to the field tapes. But in this case, because of resource limitation, we decided to use 4ms processing. The inputs were 9 blocks of 32 fold, 25m x 40m, 4ms data for each of the two blocks of output. The image gathers had a nominal fold of 64. The inputs and outputs of the block 818 were modified so as to make the 828-1 well as close to the center of the block as possible. The following pre-processing steps were applied: Reformat, Trace edits, Despiking, Binning, Sea level datum static, Spherical spreading correction, Diversity weighting, Channel scalars, Linear tau-p filter, Designature filter, Demultiple, Shot scalars, Residual de-bubble/de-ghost, 2D SRME, Radon filter, and Q-filter. The primary objective was to provide a prestack migration for prestack seismic inversion and characterization of gas hydrates.

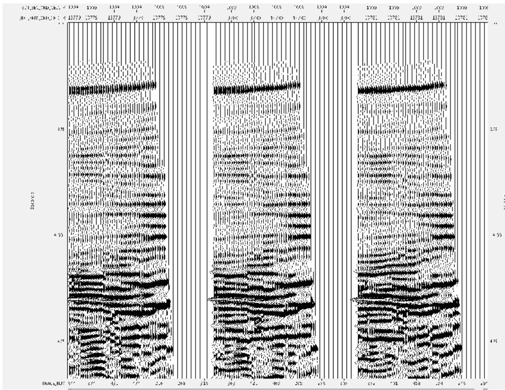

Figure 3 (a): CMP Gathers before regularization

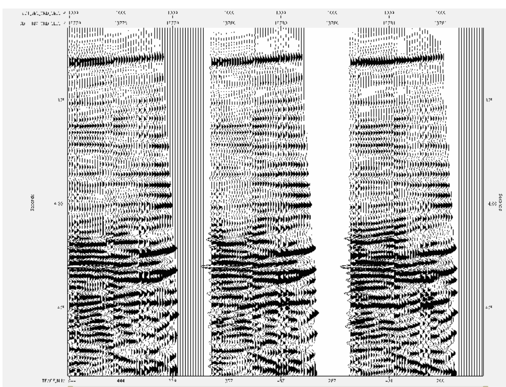

Figure 3 (b): CMP Gathers after regularization

A proprietary curved ray Kirchhoff migration was applied for prestack time migration. The aperture radius was a time-variant function of the specified (75^0) dip-limits. For each input trace and output sample, travel times were computed to determine the proper input sample to sum. Travel times were computed using an algorithm which took into account true 1-D ray bending at interfaces. Input sample values were scaled and filtered before summing. Anti-alias filters as a function of dip and midpoint distance were applied to the data during migration. A V^2T amplitude correction is effectively applied during the migration process, so any geometrical spreading correction previously applied was removed prior to migration.

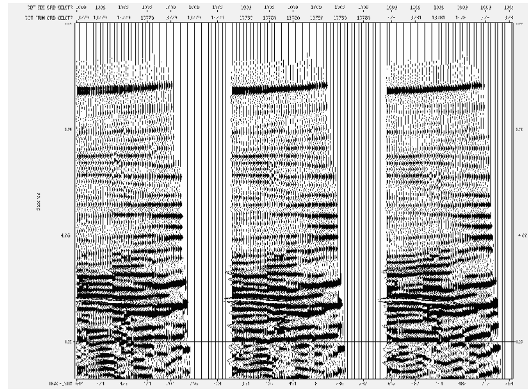

Figure 4(a): CMP gathers before footprint removal

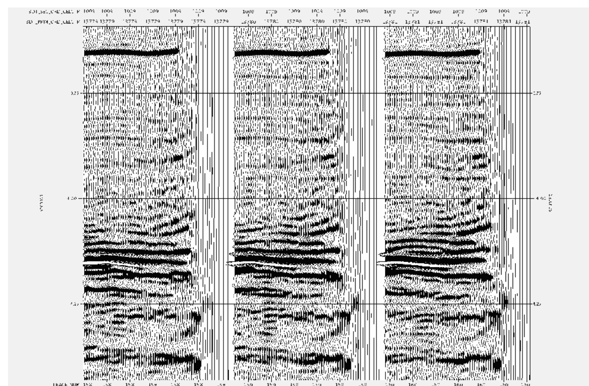

Figure 4(b): CMP gathers after footprint removal

The migration was run on common offset volumes, and as migrated velocities were required, it was run in an iterative fashion, giving improved velocity control with each pass. Several key processing steps made a major difference in the quality of the final PSTM product. Crossline interpolation provided an improved method of regularizing 3D fold of coverage relative to the typical flex binning approach. The footprint removal process in which we adjusted the short period amplitude envelope to its local median value removed the acquisition foot-prints substantially. Non-rigid matching (NRM^{TM}), a newly developed proprietary method to time-align two cubes of data was applied for flattening events in the final image gathers. Examples of the effects of these processing steps are shown in figures 3-6.

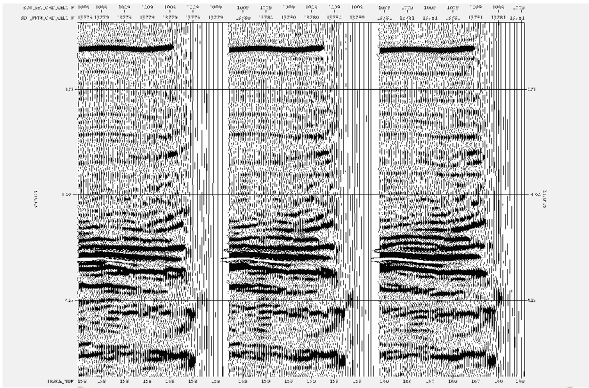

Figure 5(a): PSTM image gathers

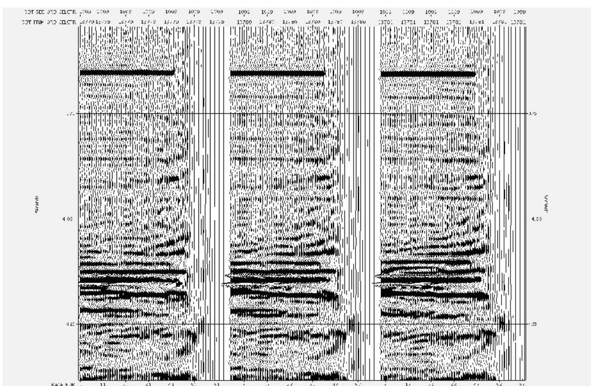

Figure 5(b): PSTM image gathers after NRM^{TM} application

Hydrates Modeling and saturation calculation

The first step in rock physics modeling is to determine the gas hydrate stability zone (GHSZ). Using the water depth (~2500m) and available shallow temperature, salinity, and pore-pressure data, we

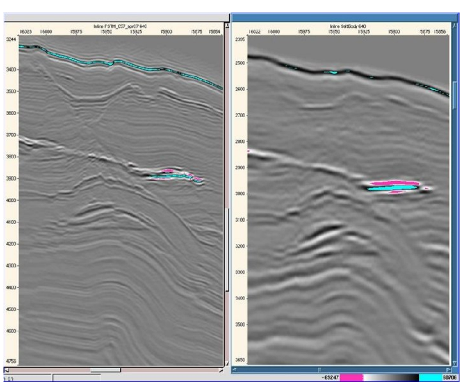

Figure 6: Comparison between PSDM stack (right) and the newly processed PSTM stack.(left). The spatial continuity and high resolutions are clearly seen in the newly processed data.

estimated that the GHSZ in the area lies within about 500m below the sea floor. This is about 600ms two-way time from the water bottom horizon. The BSR could be identified in parts of the area, but it was not continuous throughout. The BSR surface was interpretated based on this information and the discontinuous indications in the migrated seismic stack volume.

The next step was to build the shallow trend models for porosity and impedances using available well data, migration velocity, and the GOM data base. Out of many wells in the area, only the ACA 818-1 well had some acoustic, shear, and density data above the BSR. For shallow background models, we took advantage of pseudo-well data generated from our prestack full waveform inversion method. The third step is to choose a hydrate forming model. It is well known that the introduction of gas hydrates causes an increase in rock velocity. There are several rock physics models in the literature that attempted to quantify this effect. We used the model in which the hydrates grow in the interior of the porous frame and support the overburden together with the grains. This model has been found to describe the rock properties of hydrates in the Mallik 2L-38 well. We had previously used the same model in the GOM Keathley Canyon area with good results. Based on this model, we then estimated nomograms of acoustic and shear impedances as a function of depth or time for various saturations of gas hydrates and then estimated the hydrate saturation from the nomograms. These steps were repeated with various combinations of rock model parameters until satisfactory results were obtained. The final rock model was used to transform inverted seismic impedances into probable hydrate saturation volumes.

Prestack inversion

ISIS^{TM} based inversion (Rasmussen et al., 2004) is an industry-leading seismic inversion method for simultaneous inversion of elastic parameters from prestack seismic data. Preconditioned seismic data are input as multiple angle stacks. Prior models for Vp, Vs (or Poisson Ratio), and density are the initial low frequency background models for elastic parameters and form a basis for the objective and the cost functions for inversion. The prior models are derived from seismic velocity, interpreted seismic horizons, and available well information. A simulated annealing method is used to generate and update model parameters. The forward modeling is done using the linearized Zoeppritz equation based reflection coefficient series and convolution of wavelets. The wavelets may vary spatially and temporally for each angle stack.

We have applied ISIS, inverting for the elastic impedances and density. Background models were generated using the available well data, the PSWI pseudo-logs, and the migration velocity field.

<u>Lithofacies classification</u>

Based on the MMS study in the GOM, hydrates are more likely to occur in the sand-prone layers than in shaly layers. We, therefore, classified layers in terms of shale fractions, Vsh. Vsh was estimated based on the inverted acoustic and shear impedance values and the compaction models for sand and shale in the area. We assumed that sequences are brine-filled, the pressure is hydrostatic, and the impedances are linearly dependent on shaliness.

<u>Stratigraphic interpretation</u>

Seismic stratigraphic analysis was done and was incorporated with well-log data where possible. Relative high stand facies, which are more shale rich, will generally be characterized by more continuous and parallel seismic reflectors. In contrast, relative low stand facies, which have more sand content, will be characterized by more hummocky, discontinuous seismic character and will often lie on erosional surfaces. Understanding the stratigraphy throughout the section is important since, similar to oil and gas traps, sand will often provide beneficial reservoir conditions and shale will provide more impervious sealing qualities. The interpretation also focused on migration pathways, such as faults and gas chimneys, and the presence of gas charge. These are important so that reservoirs within the GHSZ can be charged. Figure 7 shows an interpreted inline section with ties at well AC818 #1.

Synthesis of results

After creating the elastic impedances, hydrates saturation, and the shale fraction volumes, we have studied various attributes and horizon maps to identify and characterize gas hydrates in the area. We find that the maximum hydrates saturation map within the gas hydrates stability zone, created from the hydrates saturation volume, provides a consistent and reliable method for delineating zones of gas hydrates. The acoustic impedance and the shear impedance based maps provide similar results.

Figure 8 shows the anomalous gas hydrates (Sgh) saturation in block 818. Saturation for gas hydrates in the pore space values are between 0% and 100% in the volume. The map shows anomalous areas of continuous, high saturations. Anomalies "c" and "f" have continuous high values of Sgh and occur in the porous Oligocene Frio sand. Anomaly "n" may also contain some Frio sand. The other anomalies occur in sediments younger than the Frio, most likely Pleistocene in age. The Sgh volume, was calibrated to the Well 818_001.

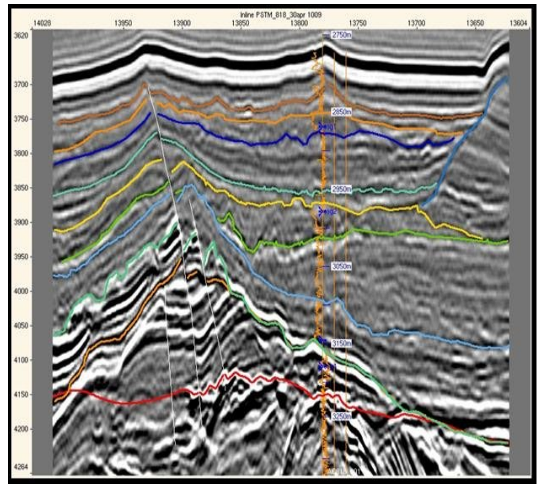

Figure 7: An interpreted inline section of AC818 which ties well AC818 #1.The red horizon represents the Base of the Hydrate Stability Zone.

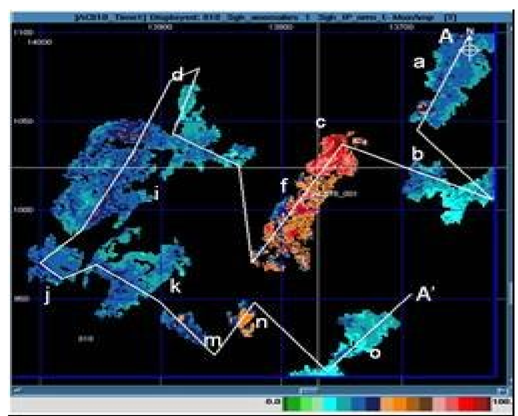

Figure 8: Map of maximum saturation gas hydrates anomalies in block 818. Saturation for gas hydrates in the pore space values are between 0% and 100% in the volume .

Values are most reliable near the well and become more relative in nature away from the well. The random line illustrated in white ties the various anomalies and is shown in figure 9. Anomalies "c" and "f", in green, are separated from each other by a fault. The approximate BHSZ is a red line at about 4200ms. A prominent unconformity (light green line) was mapped to the other survey AC857. Seismic character of some sediments beneath this unconformity (seen between anomalies "I" and "m") is often characterized by high amplitude banded seismic events and are most likely a result of strong acoustic differences between lithologic layers rather than the occurrence of gas hydrates.

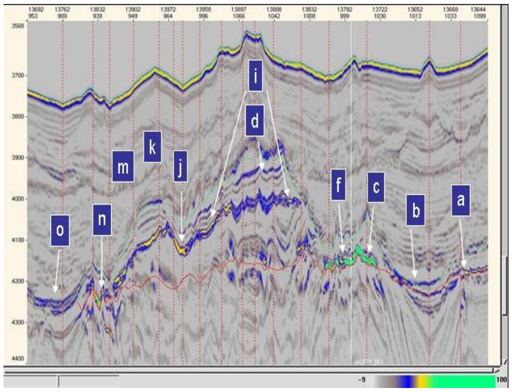

Figure 9: Survey AC818, random line of Sgh through anomalies shown in the previous figure.
The section shows high saturations in green and yellow.

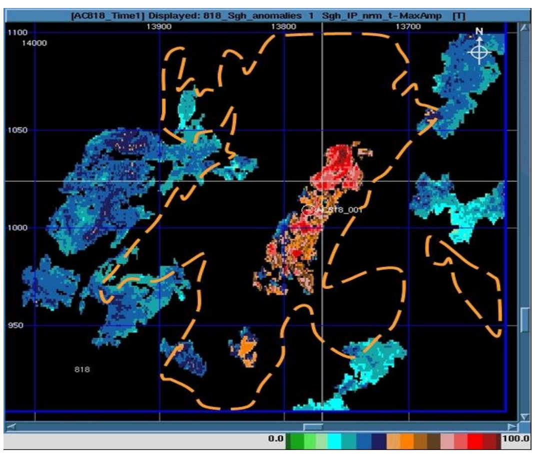

Figure 10: Map of maximum Saturation gas hydrates (Sgh) anomalies with orange dashed line indicating areas below the GHSZ that has indicators of free gas.

The orange broken line in figure 10 was defined by observation of high seismic amplitudes typical of free gas in class 3 AVO sands, which occurred near and below the BHSZ. The availability of source increases the probability of gas hydrate accumulations, high grading the anomalies that occur within these areas. Seismic amplitudes are sensitive to low concentrations of free gas, such as those drilled by the AC818#1 well.

Conclusion

We have done a comprehensive study of seismic characterization of gas hydrates in two Alaminos Canyon blocks, 818 and 857, situated in the deepwater Western GOM. Based on our five-step workflow, which includes high resolution processing, 3D inversion, and integrated inversion, the study identified a large area, about 1 km^2 in block 818, containing deposits of high concentration gas hydrates. The average concentration in this area is about 60%. JIP has selected multiple drill locations in block AC 818 for Leg II drilling in the Spring of 2008, based on this work.

Acknowledgements

This paper was prepared with the support of the U.S. Department of Energy, under Award No. DE-FC26-01NT41330. However, any opinions, findings conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the DOE

References

Dai, J., Xu, H., Snyder, F., and Dutta, N., 2004. Detection and estimation of gas hydrates using rock physics and seismic inversion: Examples from the northern deepwater Gulf of Mexico, The Leading Edge, 23, p.60-66.

Dai, J., Banik, N., Gillespie, D., and Dutta, N., 2007. Exploration for Gas Hydrates in the Deepwater, Northern Gulf of Mexico: Part II. Model validation by drilling (Submitted for Journal of Marine Petroleum Geology).