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SEISMIC DETECTION AND QUANTIFICATION OF GAS HYDRATES IN ALAMINOS CANYON, GULF OF MEXICO

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ABSTRACT

In this paper, we present the results of our recent study of quantitative estimation of gas hydrates in Alaminos Canyon block 818, Gulf of Mexico. The study was conducted as a part of the JIP Gulf of Mexico gas hydrates project. Sizable high concentration gas hydrates zones were detected as a result of the study, with hydrates saturation as high as 80% of the pore space.

Comparison of the seismic prediction with estimation from one available shallow well shows high level of consistency, adding further to the reliability of the seismic prediction. Based on our findings, multiple wells are planned for drilling through the high concentration anomaly zones by JIP in the summer of 2008. The confirmation of our prediction through drilling will lead to the discovery of the first major gas hydrate accumulation in the Gulf of Mexico.

Keywords: gas hydrates, Gulf of Mexico

1 INTRODUCTION

In the past decade, naturally occurring gas hydrates have drawn significant attention from the scientific community and industry 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 agent of long-term, global climate change. Gas hydrates have been known to exist extensively in shallow sediments from the Arctic permafrost regions to the deepwater oceans of the Equator. The vast amount of naturally occurring hydrates is a large potential for an energy resource. While the world demand for fossil fuel is ever-increasing and the supply is dwindling, it is essential to have a methodology for reliable assessment of gas hydrates accumulation in worldwide deepwater basins. As a principle and matured technology for hydrocarbon exploration, the 3D reflection seismic method becomes a natural choice for detecting and characterizing gas hydrates.

Previously, we (Dai, et al., 2004) have developed an integrated five-step workflow for seismic characterization of gas hydrates. Rock properties at shallow depth, within the gas hydrates stability zone, vary largely due to heterogeneity and strong influence of compaction. Because of the lack of good-quality well data in this zone, our seismic predictions use analogue models based on geologic interpretation, seismic inversion, and the basic principles of rock physics. We also calibrate our models with real data whenever available. This workflow integrates geological interpretation, seismic processing and inversion, and rock physics modeling to ascertain the existence and quantify the naturally occurring hydrates. The process has

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been validated and improved through applications in GoM and elsewhere (Dai, et al., 2007 a and b).

Recently, we have carried out a detailed gas hydrates characterization study in Alaminos Canyon OCS 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. The final estimation of gas hydrates saturation was done using both a direct deterministic regression-based transform method and also from a Bayesian statistical inversion. Based on these inversion results, and integrating with the concept of gas-hydrate-system (source, charging, reserving, sealing, and preserving), a series of prospects are generated within the study area. We present these results in the paper.

2 GEOLOGICAL SETTING

AC818 is located in the southwest part of the Northern Gulf of Mexico (Fig. 1). Water depth varies from about 2500 to over 2800 meter from northwest to southeast (Fig. 2, left panel) of the study area. In this area, ridges, channel, and a crater-like feature are evident at the seafloor (Fig. 2, right panel). The shallow sediments from the seafloor to about 1.0 second below the seafloor were the focus of the study and they are mostly young sediments from Pliocene to Pleistocene in geological time. These young sediments are predominantly sourced by the Mississippi River and the Red River from northeast (Galloway et al., 2000) throughout these periods.

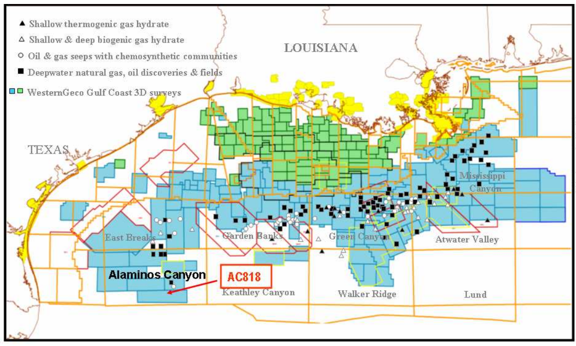

Figure 1. The location of the study area is indicated by the red box.

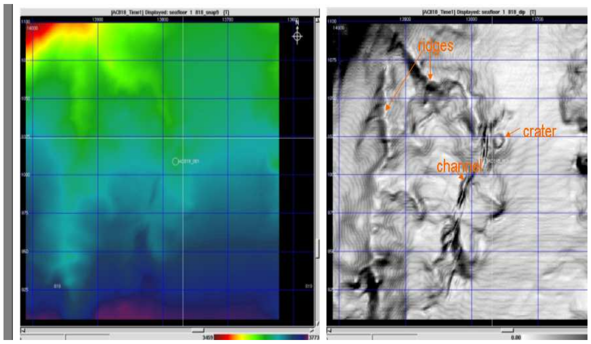

Figure 2. Water depth (left) and seafloor dip (right)

Local stratigraphic framework is shown in figure 3, where the shallow sediments are characterized by the stacking of deepwater fan systems that truncate each other. The red line at the bottom is the anticipated “BSR”. And the light-green unconformity just above the BSR is thought to be the top of Oligocene. Structure and faulting are more prevalent below the Oligocene unconformity, providing pass and driving-force for deeper thermogenic gases.

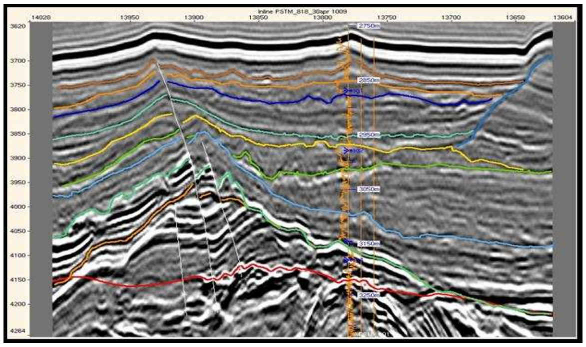

Figure 3. An interpreted inline section of AC818 which ties to the key well AC818#1. The red horizon represents the Base of the Hydrate Stability Zone.

3 SEISMIC DATA REPROCESSING

The existing seismic data covering the study area was processed with the main objective of imaging the deep, sub-salt, Perdido Fold Belt structures at depths of 5000-8000 meters. For this reason, the previous flow was not optimized for the shallow sediments. It was necessary to reprocess the seismic data for reliable inversion and gas hydrate delineation.

To enhance shallow resolution and amplitude fidelity, a shallow gas-hydrate optimized, high-resolution seismic data processing, including iterative high-definition velocity model building, curved-ray Kirchhoff migration, and followed by an advanced gather flattening technique was applied to the data set. The reprocessing flow includes: reformat, trace edits, despike, binning, sea level datum static, spreading correction, diversity weighting, channel scalars, linear tau-p filter, designature filter, demultiple, shot scalars, residual de-bubble / de-ghost, 2D SRME, Radon filter, de-absorption.

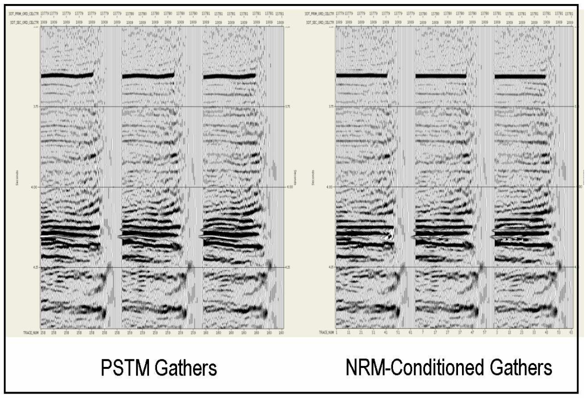

Figure 4. Left 3 panels are from raw PSTM gathers. Right 3 panels show the result after NRM.

Despite high definition velocity analysis, the initial PSTM gather output is not very flat. Sinusoidal distortions are clearly observed in the sea floor reflection and the significant events below (Fig. 4, left 4 panels). Non-rigid matching (NRM^{TM}), a newly developed proprietary method was applied for flattening these events in the final image gathers. The effects of NRM processing are shown by the rightmost 3 panels of Figure 4, in which all the major events align perfectly flat. The NRM procedure helps not only the image but also the AVO inversion.

As a result, a high resolution, clear, sharp image is derived from the seismic data re-processing. A comparison between the previous PSDM section with the hydrate-optimized flow result is given in Figure 4. Higher resolution and more lateral continuity are manifest in the newly-processed result (right panel of Fig. 5).

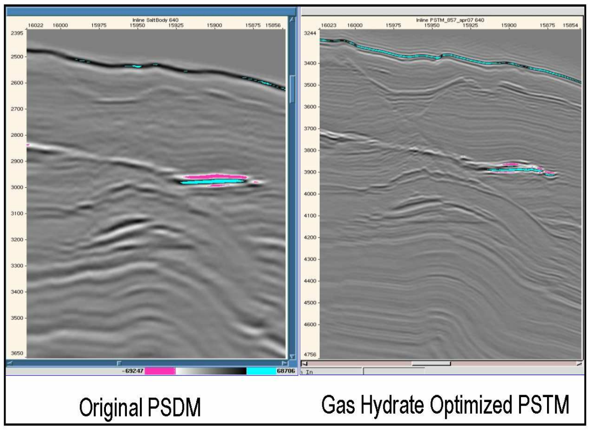

Figure 5. Comparison between PSDM stack (left) and the newly-processed PSTM stack (right). The spatial continuity and high resolutions are clearly seen in the newly-processed data.

4 SEISMIC INVERSIONS

The inversion work was done by first performing Prestack Full Waveform Inversion (PSWI) at selected locations to help build the background model (0-8 Hz) and estimate wavelets for different angle stacks, then by implementing ISIS^{TM}, a 3D simultaneous inversion (Rasmussen et al., 2004) to generate P-wave impedance (PI), S-wave impedance (SI), and density volumes.

PSWI was developed by Mallick (1995, 1999). It is a statistical optimization technique that operates much like biological evolution and derives P- and S-wave velocities and density profiles from a given CMP seismic gather.

An example of PSWI run at a key well location was shown in Fig. 6. The left three curves on the left are inverted Vp, Poisson's ratio (PR), and density respectively. The curves in green are the values of elastic properties and the yellow bands show the range of possible errors corresponding to the individual properties. The middle and right panels display the observed seismic angle gather and the synthetic angle gather after convergence during the iteration process. Note that the correlation coefficient between the two gathers is over 0.90, signifying a good match.

The local highs and lows in the derived Vp reflect possible lithology or fluid variations although there are uncertainties associated with noise accumulated during the inversion process due to the lack of full bandwidth frequencies in the input gather and the noise in the gather that corrupts the inversion results. The extreme high Vp event indicated by the red arrow reveals a very likely, high-concentration gas hydrate anomaly. This high Vp anomaly was later confirmed by the acoustic logging result at the actual well location.

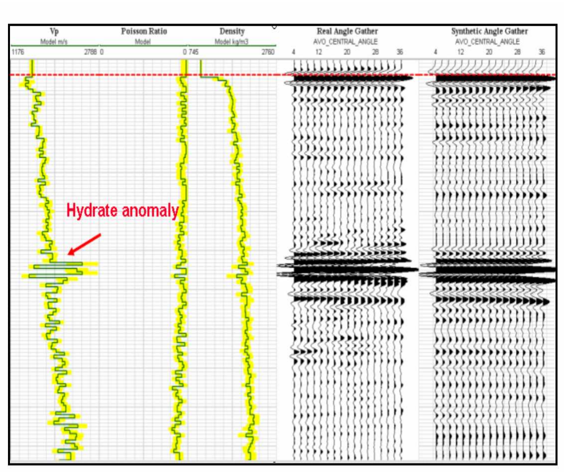

Figure 6. PSWI result at the key well location. Left 3 curves are Vp, PR, and density respectively. The middle sections are the real and synthetic data.

Multiple PSWI runs were performed in AC818. The low frequency model was constructed based on the pseudo-logs of PSWI inversion and constrained with seismic horizons. PSWI inversion results were also used to generate the wavelets for different angle stacks. We applied ISIS to invert for the elastic impedances and density volumes.

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 PI, SI (or PR), and density are the initial low frequency models of the elastic parameters that form a basis for the objective and the cost functions of the inversion. A simulated annealing method is used to generate and update model parameters. The forward modeling is done by convolving reflection coefficient series (linearized Zoeppritz equation-based) with wavelets. The wavelets may vary spatially and temporally for each angle stack in order to generate optimal results.

Figure 7 shows the PI and SI inversion results along the inline that passes the key well (pseudo-well) location. The vertical lines indicate the well position. Both PI and SI show a general increasing trend with time. They also reveal detailed variations both vertically and laterally, indicating possible subtle changes in litho-facies.

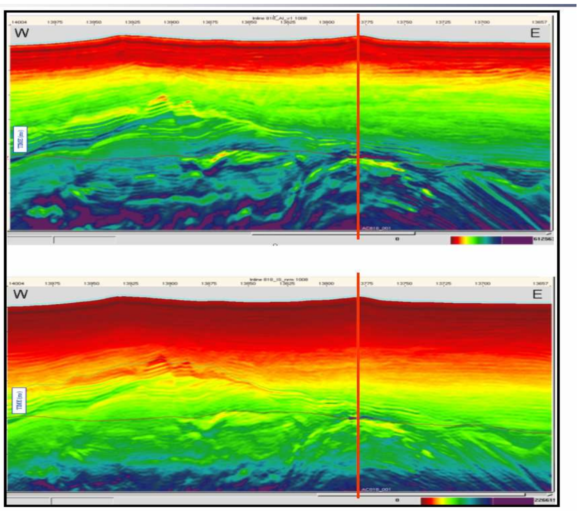

Figure 7. Simultaneous inversion: PI (upper panel), SI (lower panel)

Anomalous high impedances were obtained at both sections at the level as indicated from PSWI result in Fig. 6, and in the vicinity of the key well (pseudo-well) location. Consistency between PSWI and ISIS inversions and with the actual acoustic measurement at the well location underscores the reliability and accuracy of the inversion result, which provides a solid basis for hydrate estimation in the following section.

5 GAS HYDRATE ESTIMATION

Having generated 3D elastic property volumes, hydrate estimation/quantification was done by mapping the elastic property to hydrate saturation through gas hydrate rock physics modeling and inversion. Readers are referred to Dai et al. (2004), Xu et al. (2004), and Dai et al. (2007a) for a detailed discussion of the technique. Hydrate saturations are mapped both deterministically and statistically, using P-wave and S-wave independently and jointly. Figure 8 shows the saturations estimated from PI and SI of the same inline as shown in Figure 7.

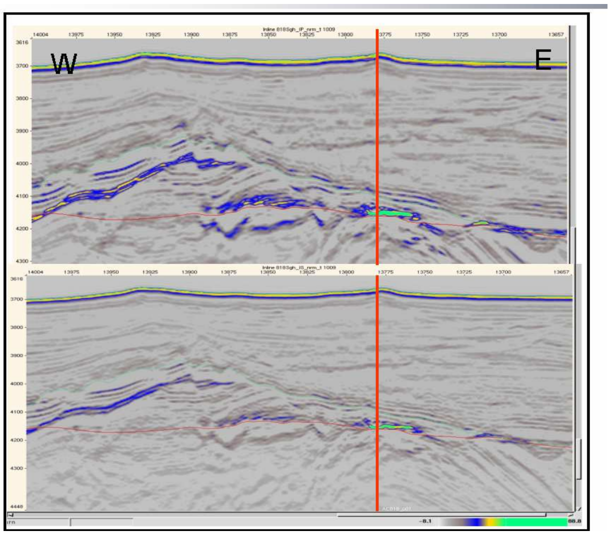

Figure 8. Gas hydrate saturations from PI (upper panel), and from SI (lower panel). The red line shows the location of the well.

Both sections show high-saturation anomalies (as high as 80% of the pore space) in the vicinity of the existing well location. Also a few anomalies of moderate-saturation are present at similar and/or shallower levels. We note that the saturation from SI is systematically lower than that from PI. The difference is thought to be caused by the errors in either seismic inversion or rock-physics modeling, or in both.

6 SYNTHSIS OF INVERSION RESULT

The method of seismic-based gas hydrate saturation estimation described above involves multiple-steps, from initial data processing, inversion, rock-physics modeling, to quantification. Uncertainty that involves with each of these steps will propagate to cause the ensemble error/uncertainty in the final saturation prediction. One way to effectively utilize the results and reduce the uncertainty is to check for consistency among information from different sources, and apply the concept of gas hydrate systems to further validate, like an oil explorationist utilizing the concept of petroleum systems in search for hydrocarbons.

Our criterion is to look for zones that reveal distinct and consistent physical evidence, indicating potential large-scale and high-concentration gas hydrate anomalies. Also, these anomalies are at optimum locations for forming gas hydrates, taking advantage of the gas hydrate system with the key elements, such as, availability of gas source, charging or migration pathway, existence of reservoirs, and trapping mechanism.

We also studied various attributes 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.

Figure 9 shows an areal view of the anomalous gas hydrates (Sgh) saturation throughout the inversion volume. Saturation values for gas hydrates in the pore space 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 sands. Anomaly “n” may also contain some Frio sands. The other anomalies occur in sediments younger than the Frio, most likely Pleistocene (or Pliocene) in age. As mentioned in the previous section, the seismic-based estimate of Sgh is quite consistent with log-based estimate at the key well location near f. However, we find even higher saturation northeast of the key well location.

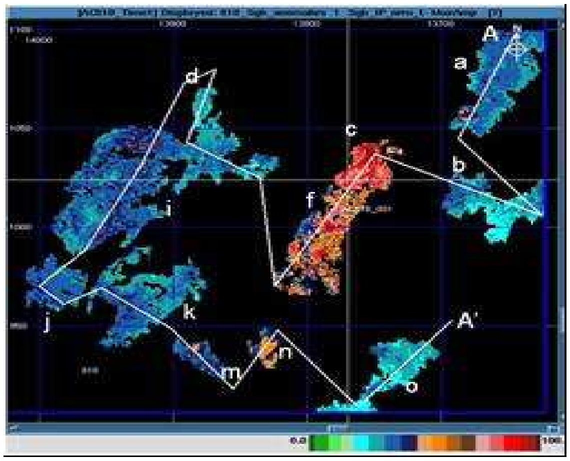

Figure 9. Map of maximum saturation gas hydrates anomalies in AC818. Saturation for gas hydrates in the pore space values are between 0% and 100%.

7 CONCLUSIONS

Comprehensive seismic characterization of gas hydrates was done in AC818 using our five-step workflow, which includes high resolution seismic re-processing, PSWI at selected locations and 3D simultaneous inversion, rock physics modeling and hydrate quantification. The study identified a large area, about 1 km^2 in the middle east of the AC818, containing high concentration gas hydrates bearing sediments. The average Sgh concentration in this area is about 60%, with some as high as over 80%. Based on this study, the JIP has selected multiple drill locations for Leg II drilling in the summer of 2008. The drilling will provide key information to calibrate our models and prediction. Should the drilling confirm the predicted anomalies; it may become the first sizable natural gas hydrate discovery in the GoM.

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REFERENCES

[1] 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.

[2] Dai, J., Banik, N., Gillespie, D., and Dutta, N., 2007a. Exploration for Gas Hydrates in the Deepwater, Northern Gulf of Mexico: Part II. Model validation by drilling. Marine Petroleum Geology, in press.

[3] Dai, J., Banik, N., Gillespie, D., and Dutta, N., 2007b. Exploration for Gas Hydrates in the Deepwater, Northern Gulf of Mexico: Part II. Model validation by drilling. Marine Petroleum Geology, in press.

[4] Galloway, W.E., Ganey-Curry, P.E., Li X., and Buffler, R.T., 2000. Cenozoic depositional history of the Gulf of Mexico basin. AAPG Bulletin, V. 84, No. 11, p1743-1774.

[5] Rasmussen, K.B., Bruun, A., and Pedersen, J.M., 2004. Simultaneous Seismic Inversion, 66th Mtg.: Eur. Assn. Geosci. Eng., P165.

[6] Mallick, S., 1995. Model-based inversion of amplitude-variations-with-offset data using a genetic algorithm: Geophysics, 60, p.939-954.

[7] Mallick, S., 1999. Some practical aspects of prestack waveform inversion using a genetic algorithm: An example from East Texas Woodbine gas sand: Geophysics, 64, p.326-336

[8]Xu, H., et al., Seismic detection and quantification of gas hydrates using rock physics and inversion. Advances in the Study of Gas Hydrates, ed. C.E. Taylor and J.T. Kwan. 2004, New York: Kluwer 117-139.