Combining Multicomponent Seismic Attributes, New Rock Physics Models, and In Situ Data to Estimate Gas-Hydrate Concentrations in Deep-Water, Near-Seafloor Strata of the Gulf of Mexico

TECHNICAL PROGRESS REPORT

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Principal Investigators: Bob A. Hardage
Paul E. Murray
Diana C. Sava

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Submitting Organization: Bureau of Economic Geology
The University of Texas at Austin
University Station, Box X
Austin, TX 78713-8924

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Abstract

In order for PP and PS images of near-seafloor geology to be created with 4C OBC seismic data, it is necessary to first create the downgoing wavefield by adding the responses of the hydrophone and geophone sensors that are encased in a seafloor receiver module and then to create the upgoing wavefields by subtracting the geophone response from the hydrophone response. If the data recorded by the hydrophone and geophones do not have equivalent amplitude, frequency, and phase properties, these addition and subtraction steps will not produce wavefields appropriate for good-quality imaging. During this report period, the research team investigated several options by which these sensors can be calibrated to each other so that we can create optimal images of near-seafloor strata and lithofacies.

Executive Summary

Two critical steps in processing 4C OBC seismic data are to: (1) add the responses of the hydrophone and vertical geophone in the 4C sensor package to create the downgoing compressional wavefield that illuminates near-seafloor geology, and then (2) subtract the hydrophone and geophone responses to create the upgoing compressional and converted-shear reflected wavefields. These simple addition and subtraction steps produce poor-quality wavefields unless the hydrophone and geophone sensors are calibrated so that each sensor creates data that have the same amplitude, frequency, and phase character. Our research team focused on developing software procedures that allow any sensor in a 4C sensor package to be calibrated to any other sensor at the same receiver station. The results of this sensor-calibration effort have been improved images of the near-seafloor geology associated with deep-water hydrate systems.

Approach

Research activity during this report period consisted of software development and seismic data processing.

Results and Discussion

Basic responses of the sensors embedded in a 4C seafloor receiver package are described in Figure 1. The physics of the sensor responses is explained in the detailed caption attached to the figure. Using the notation in Figure 1, if we assume that all sensors are calibrated to have the same amplitude-frequency-phase response, then the seafloor hydrophone response (**P**) and the vertical-geophone response (**Z**) can be combined to create the downgoing (**D**) and upgoing (**U**) PP wavefields using the following equations:

(1) $D = P + Z/\cos(\Phi)$, and

(2) $U = P - Z/\cos(\Phi)$.

The P and Z sensors must record data with identical waveshape properties in order for these simple equations to create high-quality downgoing and upgoing wavefields.

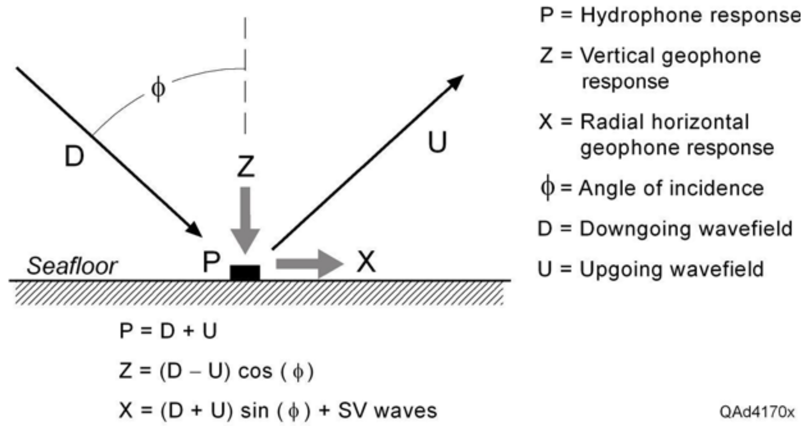

Figure 1. Basic responses of 4C OBC sensors. The three response equations are the keys to optimal imaging. This model assumes that the response of the **Y** (crossline) horizontal geophone can be ignored in 2D OBC profiling. A second assumption is that the V_P/V_S velocity ratio is high, thus causing the P-to-SV conversion point to be almost directly beneath the seafloor receiver station. As a result, the upgoing SV response is recorded by the inline horizontal geophone **X**.

The technique that we implemented to equalize responses of the 4C hydrophone and geophones used early-arrival events that occur before the downgoing direct arrival at large source offsets from each seafloor receiver station. These early-arrival events originate at rather deep interfaces and are appealing as an option for sensor calibration because the events are all upgoing and are not contaminated by any downgoing events.

The top panel of Figure 2 shows impulse responses of the hydrophone and vertical-geophone operators determined from early-arrival data observed at one receiver station. The bottom panel illustrates the frequency responses of the filters. The curve labeled "**Coher**" is the product of the two filter functions. A value of ~1.0 for this "Coher" curve indicates the frequency range over which a reliable sensor-to-sensor calibration should be achieved. The calibration is limited to ~70 Hz because the early-arrival events used in the sensor-calibration procedure are deep, lower-frequency events that have minimal signal response above 70 Hz. The research team is now developing techniques that will isolate shallow high-frequency reflection events from the 4C data, which will expand the frequency range over which our sensor calibration operators can be applied.

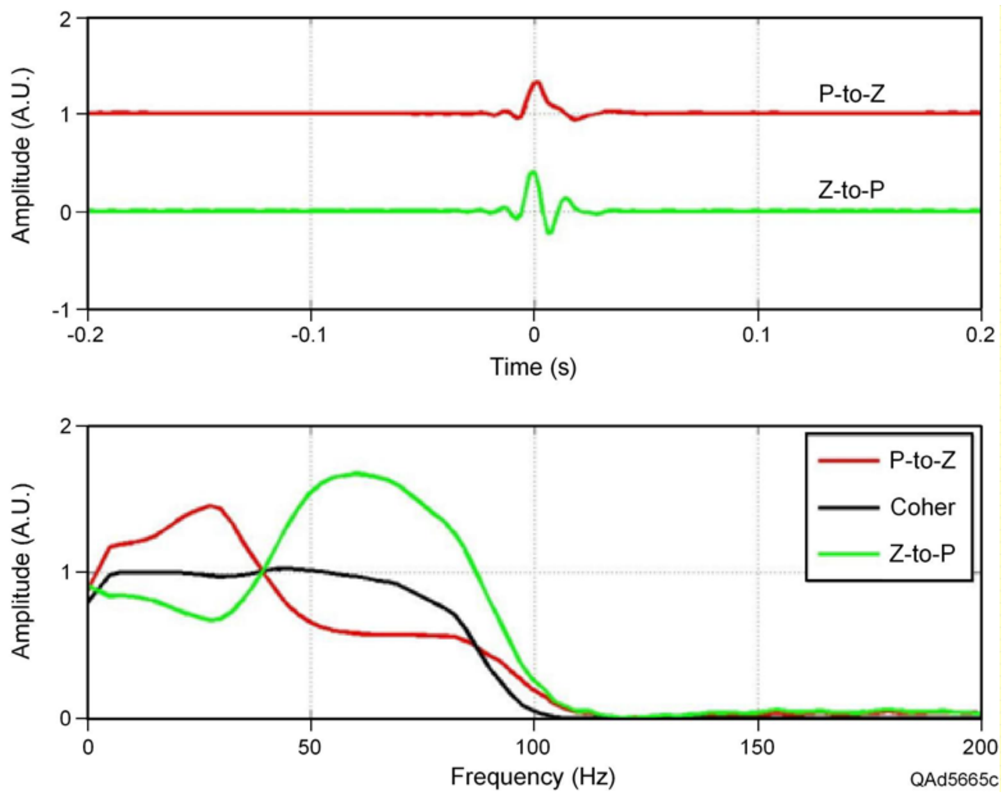

Figure 2. Cross-equalization filters (or sensor-to-sensor calibration operators) determined from far-offset, early-arrival events. The curve **Coher** is a type of coherence measurement that defines the frequency range over which the filters are valid.

Calibrated vs. Uncalibrated Data

How important is it that hydrophone (P), vertical-geophone (Z), and horizontal-geophone (X) sensors be calibrated before P, Z, and X wavefields are combined to create downgoing and upgoing PP and PS wavefields? Many commercial data-processing shops ignore sensor calibration and simply add and subtract P, Z, and X wavefields using time-invariant scaling factors. The 4C OBC data acquired across our study area allow PP and PS images to be made with either calibrated-sensor or uncalibrated-sensor data and provide the opportunity to determine the value of each imaging strategy. Portions of PP images along one OBC profile that has been analyzed to determine the value of a calibrated-sensor approach to data processing are illustrated in Figure 3. The top displays illustrate geology that extends to only 200 ms below the seafloor. The bottom displays focus on the geology that exists between 200 and 500 ms below the seafloor.

These images show that sensor calibration improves imaging only for the shallowest geology that extends to 50 ms below the seafloor. Below 50 ms, calibrated-sensor data and uncalibrated-sensor data produce equivalent images. However, we have found that the improvement in PP imaging across this shallow window immediately below the seafloor is important for accurate depth registration of PP and PS images used in studies of near-seafloor hydrate

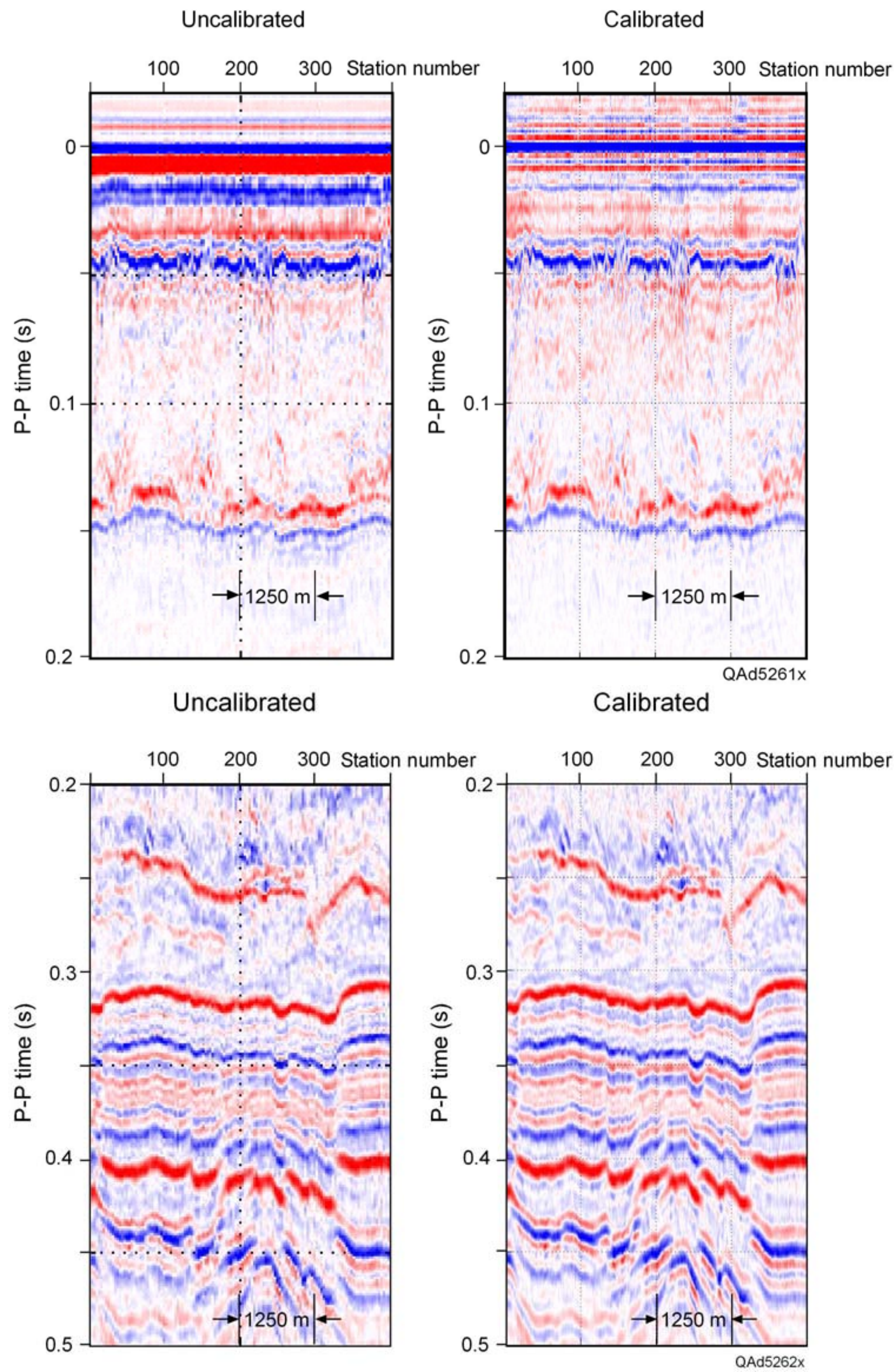

Figure 3. Comparisons of PP images made with (right) and without (left) calibrated P and Z sensors. Calibrated data produce a superior image of the shallowest geology (top 50 ms, upper right). There are no significant differences between the calibrated-sensor and uncalibrated-sensor images at deeper depths (bottom displays). The improved PP image in the first 50 ms of image space is important for PP to PS image registration when studying geology immediately below the seafloor.

systems. In previous studies, we had to use high-frequency (2 to 8 kHz) chirp-sonar data acquired using deep-running Autonomous Underwater Vehicle (AUV) technology to achieve accurate PP imaging of geology within 50 ms of the seafloor. With sensor-calibrated P and Z data, we now have the ability to image within this 50-ms interval with PP images constructed from air gun source OBC data.

Conclusion

Our research is now focused on processing 4C OBC seismic profiles that traverse the two hydrate study sites that have been selected in the Green Canyon area of the Gulf of Mexico. Specialized software code not available from commercial vendors is required to create high-quality PP and PS images of near-seafloor geology from the deep-water 4C OBC data acquired along these profiles. The Bureau research team is constructing this proprietary software. A critical part of our software development—algorithms that calibrate responses of the hydrophone and geophone sensing elements of each 4C seafloor receiver station—was developed and tested during this report period. We have demonstrated that applying our sensor-calibration operators to 4C OBC data results in significant improvements in the imaging of near-seafloor geology, which is a critical advance in our study of near-seafloor hydrate systems.

Cost Status

DOE has not funded our study at the level specified in Contract DE-FC26-06NT42667. We are now 13 months into the project and should have received $412,164 for our research activities. We have received only $319,945, which is a shortfall of $92,219. We have done the best investigation that we can do with this restricted funding. As of the date of this report (March 26, 2007), $7,289 remains in our research account. Our research activities will have to be reduced until DOE can catch up with their obligated funding.

Schedule Status

The project is on schedule. We delivered Special Reports in Year 1 that satisfied Milestones 1 and 2 and Decision Points 1 and 2. We are now in the data-processing phase, as planned. The next Milestone and Decision Point will be August 2007, the end of Quarter 6 of the project.

Accomplishments

Our accomplishments to date have been significant. Our Year 1 Special Reports show that (1) we have an excellent database for deep-water hydrate studies and (2) resistivity logs across the study areas indicate that the 4C OBC profiles we are analyzing will traverse several hydrate-bearing intervals. Our latest accomplishment, described in this report, is development of a seismic-sensor-calibration procedure that results in improved imaging of near-seafloor strata that host deep-water hydrate.

Problems and Delays

None, other than we have received less DOE funding than is needed for the planned research activity.

Technology Transfer

The unique imaging software that we are developing has caught the attention of two major oil companies, Chevron and Statoil, who are considering the possibility of using our software to analyze some of their proprietary deep-water 4C OBC data.

Our research team authored or co-authored six papers in the May 2006 issue of ***The Leading Edge***, a publication of the Society of Exploration Geophysicists. This issue was a special publication devoted to gas hydrate. Links to pdf versions of these papers have been forwarded to DOE. The papers can also be downloaded from the Publications (Gas Hydrate) section of the following Web site: http://www.beg.utexas.edu/indassoc/egl.

Acronyms and Abbreviations

4C: four-component
OBC: ocean-bottom-cable
PP: downgoing and upgoing compressional (P) wavefields
PS: downgoing P and upgoing SV wave modes

References

None.