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

Phase 1 Report:
Technology Status Assessment

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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Current State of Technology

Industry and Academic Background

To date, most deep-water hydrate studies have been done by academic groups. These efforts have applied excellent science to the evaluation of hydrate systems but have been constrained by small budgets and thus limited to modest data collection because of the cost of research cruises and deep-water operations. Most academic studies have concentrated on Blake Ridge, offshore South Carolina (for example, Hornbach et al., 2003), and on the Cascadia Margin, offshore British Columbia (for example, Spence et al., 2000). Few studies have been done in the Gulf of Mexico (GOM) or in any petroliferous marine basin where gas-production facilities are already in place.

One exception to the lack of academic hydrate studies within the GOM is the Deep-Water Hydrate Observatory being developed by a consortium of 15 academic groups headed by The University of Mississippi. This academic effort is striking because it maybe one of the largest academic efforts ever in deep-water hydrate research and it coincides with an area of extensive conventional oil and natural gas industry activity. This observatory will be constructed across Mississippi Canyon Block MC118 in water depths of approximately 850 meters. The deployment of seafloor instrumentation has just started. The project is jointly funded by DOE/NETL, Minerals Management Service (MMS), and the National Oceanographic and Atmospheric Administration (NOAA).

Some oil and gas companies have recently become engaged in deep-water hydrate investigations. Two projects are noteworthy because they are two unique, large industry efforts, in deep water. One is the effort by several Japanese companies and government agencies in the Nankai Trough (Matsushima, 2004). The other is the Joint Industry Project (JIP) effort in the GOM that is partially funded by DOE/NETL. The JIP group has applied modern oil/gas seismic technology, deep-water coring/logging operations, and laboratory testing of core samples (Francisca et al., 2005) at sites in two GOM lease blocks: Atwater Valley Block 14 (AV14) and Keathley Canyon Block 195 (KC195).

Tools, Approaches, and Data Being Used

Seismic Tools and Data

Most seismic investigations of deep-water hydrate systems have been limited to the use of towed-cable seismic technology. These data involve only P-P seismic modes, which typically have a wavelength spectrum of 16 to 200 meters across near-seafloor strata (assuming the frequency spectrum extends from 10 to 100 Hz and the P-wave velocity ranges from 1,600 to 2,000 m/s for near-seafloor sediments). Autonomous Underwater Vehicle (AUV) technology has recently been used to improve P-P resolution of near-seafloor geology. These unmanned, GPS-guided systems travel 50 meters or so above the seafloor, illuminate subseafloor strata with a chirp-sonar pulse having a frequency bandwidth of 2 to 10 kHz, and also acquire side-scan sonar and multibeam bathymetry data.

Two European projects are exceptions to the use of only P-P seismic data in marine gas hydrate investigations. One study by Bunz et al. (2005) utilized multicomponent seismic data across the Storegga Slide in the Norwegian North Sea. A second project, *HYDRATECH* , is supported by the European Commission under EC contract EVK3-CT-2000-00043 (http://www.hydratech.bham.ac.uk). This latter effort uses multicomponent ocean-bottom seismometers to determine seismic attributes that can then be used to estimate hydrate concentration in near-seafloor sediments.

Nonseismic Tools and Data

Nonseismic tools involve seafloor inspection, collection of fluid, gas, and sediment samples, and deployment of seafloor experiments that measure physical, chemical, and biological processes across deep-water hydrate systems. Using manned submersibles, investigators have deployed temperature gauges, bubble-rate flow meters, gas-sample collectors, and other instruments at numerous GOM sites (for example, Roberts, 2001). Fluid/sediment samples extending to subseafloor depths of approximately 20 meters have been collected at several deep-water sites using drop-core devices. Samples extending to subseafloor depths of more than 1,000 meters have been acquired in GOM Blocks AV14 and KC195 in the DOE/NETL-sponsored Joint Industry Program.

Benefits of Current State-of-the-Art

Deep-water gas hydrates are now better understood through the use of current technologies. Seafloor temperature monitoring has shown that warm eddies that spin off of the eastern-GOM Loop Current and then progress across the central and western GOM play a major role in dissociating hydrates near the seafloor (Roberts, 2001). Geochemical analyses have been particularly important, with sulfate reduction and chlorine concentration analyses of subseafloor samples defining vertical boundaries of hydrate occurrence, and carbon isotope studies confirming whether methane found in hydrate clathrates has a biogenic or thermogenic origin (for example, Sassen et al., 1999). P-P seismic data have been instrumental in identifying two phenomena that define the presence of subseafloor hydrate accumulations: bottom-simulating reflectors, and more recently, Robert's (2001) seafloor bright spots.

Inadequacies of Current State-of-the-Art

Current technology usage and research practice are inadequate for optimal evaluation of deep-water hydrate systems. First, deep-water studies have been confined to small areas, and broad-scale pictures of deep-water hydrate distribution and hydrate-system architecture have not been evaluated. Second, dependence on only P-P seismic modes for subseafloor illumination has been too restrictive. Towed-cable P-P data do not image near-seafloor geology with adequate resolution because of the long wavelengths associated with these data. Also, the P-P mode reacts weakly to variations in S-velocity V_S and shear modulus, which are important descriptors of some deep-water hydrate systems. Chirp-sonar data acquired with deep-running AUV systems overcome the P-P subseafloor resolution problem, but AUV chirp-sonar pulses penetrate only 40 to 60 meters below the seafloor and provide no information about deeper portions of marine hydrate systems, which can extend to subseafloor depths of perhaps 1,000 meters in some environments. Third, rock physics models have not been optimized for deep-water, near-seafloor sediments where effective pressure is low and sediment porosity is high.

Surprisingly, the two European studies mentioned previously, although involving multicomponent seismic data, have not emphasized the advantages of the converted-S (P-SV) seismic mode. Published papers (Bunz et al., 2005) and project Web sites (http://www.hydratech.bham.ac.uk/) discuss applications of P-P seismic attributes but do not properly emphasize the value of the P-SV mode for gas hydrate studies. The potential value of P-SV seismic data is discussed below, but its use in deep-water gas hydrate evaluations needs to be demonstrated.

Development Strategies

Why a New Approach Is Required

A new approach to deep-water gas hydrate research is needed, with this approach tailored to overcome the inadequacies of current state-of-the-art technology practice. New seismic technology must be implemented that provides (1) near-seafloor spatial resolution equivalent to AUV chirp-sonar data (meter scale) together with (2) deep penetration and deep-image resolution equivalent to towed-cable P-P data. Both of these objectives can be partially achieved with the P-SV seismic mode provided by four-component ocean-bottom-cable (4C OBC) and ocean-bottom-seismometer (OBS) data. Rock physics concepts must also be implemented that relate key P and S seismic attributes to percentage mixtures of sediment and hydrate in the high-porosity, low-effective-pressure environment of deep-water hydrate systems. These new technologies must then be integrated into a structured framework that allows large deep-water areas to be studied so deep-water hydrate systems can be evaluated in their entirety and not in small, isolated sectors.

Problems to Be Addressed by This Research

Problem-solving actions implemented in this research will

1. Develop seismic data-processing procedures for the P-P mode extracted from 4C OBC data that optimize the resolution of P-P images across deep-water, near-seafloor strata.
2. Devise seismic data-processing procedures for the P-SV mode of 4C OBC data that demonstrate the value of S-wave data for studying deep-water geology.
3. Formulate rock physics concepts and models that allow combinations of P-wave and S-wave seismic attributes to be correlated with hydrate concentration in deep-water environments.

4. Demonstrate how these new technologies can be applied over wide deep-water areas to characterize large-scale hydrate systems and to estimate regional hydrate resources.

Future Technology

Barriers Research Will Overcome

This research will overcome several technology barriers that to date have limited the evaluation of deep-water gas hydrates. A major barrier that will be removed is the restriction of using only the P-P seismic mode to study gas hydrate geology. We will show how deep-water gas hydrate systems can be evaluated with both P-P and P-SV seismic modes. A second barrier that will be eliminated is the inability to estimate elastic moduli of strata associated with deep-water gas hydrates. With the availability of seismic-based values of V_P and V_S velocities, both bulk and shear moduli can be estimated across targeted subseafloor intervals. A third barrier that will be overcome is the failure of investigators to integrate multicomponent seismic technology with rock physics modeling to determine concentrations of hydrate in deep-water units. Developing and applying rock physics concepts that allow estimates of hydrate concentration to be made in media that have low effective pressures and excessively high porosity will be key elements of this research.

Potential Impact on Hydrate Exploration and Production

This research can have significant impact on hydrate exploration and production. With regard to exploration, one research objective will be to demonstrate how to use 4C OBC seismic data and rock physics principles to construct maps showing spatial variations of hydrate concentration across selected study sites. Such estimations will be essential for deciding where deep-water gas hydrate exploration should be focused and where production efforts should be attempted. With regard to production, two points should be stressed. First, robust estimates of interval values of V_P and V_S developed with the technology provided by this research will lead to more reliable geomechanical evaluations of seafloor strata. These new geomechanical insights should lead to safer seafloor operations during hydrate production. Second, there seems to be a genetic link between deep-water gas hydrates and the shallow water-flow phenomena that plague deep-water drilling and production. Techniques developed in this research will predict hydrate distribution and concentration in seafloor strata and will provide information that engineers can use to minimize the risks of shallow water flow while drilling hydrate-bearing sediments.

Deliverables

Deliverables produced in this research will be new methodologies that will be critical for future exploration and exploitation of deep-water gas hydrates. These methodologies include

1. New seismic data-processing methods for optimizing P-P and P-SV images of deep-water, near-seafloor geology. Current production-style processing of 4C OBC seismic data is sufficient for imaging geology at

considerable depths below the seafloor, but a new methodology is needed to optimize near-seafloor images.

2. New rock physics concepts and application techniques that allow P-P and P-SV seismic attributes to be related to hydrate concentration in near-seafloor sediments.
3. A new methodology for depth registering P-P and P-SV data so V_P, V_S, V_P/V_S, and other seismic attributes are determined across depth-equivalent data windows. This modeling will be based on raytracing P-P and P-SV reflection arrival times using a layered-seafloor model, comparing these calculated times with reflection times observed in real P-P and P-SV data, and then iterating model layer thicknesses and layer velocities until there is an acceptable convergence of calculated and observed reflection times.
4. Demonstration of how all of these methodologies can be integrated to study deep-water gas hydrates over large seafloor areas for regional resource evaluation and exploration planning.

These methodologies will be made available to industry through DOE/NETL reports and Web sites, publications in peer-reviewed journals, and public presentations before professional societies.

References

Bunz, S., Mienert, J., Vanneste, M. and Andreassen, K., 2005, Gas hydrates at the Storegga Slide: constraints from an analysis of multicomponent, wide-angle seismic data: Geophysics, 70, B19–B34.

Francisca, F., Yun, T.S., Ruppel, C., and Santamarina, J.C., 2005, Geophysical and geotechnical properties of near-seafloor sediments in the northern Gulf of Mexico gas hydrate province: Earth and Planetary Sci. Letters, 237, p. 924–939.

Hornbach, M.J., Holbrook, W.S., Gorman, A.R., Hackwith, K.L., Lizarralde, D., and Pecher, I., 2003, Direct seismic detection of methane hydrate on the Blake Ridge: Geophysics, 68, p. 92–100.

Matsushima, J., 2004, Attenuation measurements from full waveform logs in gas hydrate sediments: SEG Expand. Abstracts, BG P1.5, p. 346–349.

Roberts, H.H., 2001, Fluid and gas expulsion on the northern Gulf of Mexico continental slope: mud-prone to mineral-prone responses: Geophys. Monograph, 124, p. 145-161.

Sassen, R., Joye, S., Sweet, S.T., DeFreitas, D.A., Milkov, A.V., and McDonald, I.R., 1999, Thermogenic gas hydrates and hydrocarbon gases in complex chemosynthetic communities: Gulf of Mexico continental slope: Organ. Geochem., 30, p. 485–497.

Spence, G.D., Hyndman, R.D., Chapman, N.R., Riedel, N., Edwards, N., and Yuan, J., 2000, Cascadian margin, northeast Pacific Ocean: hydrate distribution from geophysical investigations, *in* Max, M.D., ed., Natural gas hydrate in oceanic and permafrost environments: Kluwer Acad. Pub., Netherlands, p. 183–198.