Seismic Analysis and Characterization of Gas Hydrates in the Northern Deepwater Gulf of Mexico*

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Abstract

The deepwater Gulf of Mexico contains many known hydrate environments. Complex lithostratigraphy and active salt movement create complicated thermal regimes and fluid chemistry. These in turn affect hydrate formation and distribution. In an effort to study and eventually test different hydrate settings, two separate areas were selected for review by a multi-disciplinary team. Reprocessed 3D and high-resolution 2D multichannel seismic data were analyzed over Keathley Canyon block 195 and Atwater Valley block 14, both of which are in water depths of approximately 1300 meters. Keathley Canyon exhibits a deep (250 to 500 meters sub-seafloor), pronounced regional bottom simulating reflector (BSR), a notable geologic and geophysical barrier between free gas and solid hydrate. The BSR is bounded to the east by a salt-produced fault ridge, which is also a probable fluid migration pathway. The BSR has reverse polarity relative to the water bottom interface and obliquely cuts stratigraphic reflections. In some areas the BSR is also defined by periodic, high amplitude terminations of free gas in the coarser-grained, interbedded sands below. The Atwater Valley study area is located in the middle of the Mississippi Canyon and contains numerous hydrate mound features. Most mounds show strong seismic evidence of hydrates including gas chimneys, amplitude blanking, and near-seafloor BSRs. Beginning in 2004, drilling through the gas hydrate zone within these two areas, for research purposes, will test these ideas of hydrate occurrences. The complexity and diversity of all these hydrate occurrences clearly drives the need for a cross-disciplinary approach.

General Statement

The northern deepwater Gulf of Mexico (GOM) contains many naturally occurring gas hydrate environments (Figure 1). Here and in other areas, hydrate concentrations, once viewed as a drilling safety hazard, are fast gaining attention as potential energy sources. The reason is simple: natural gas hydrates, 99% of which exist in deep offshore marine basins (Makogan, 1997) are estimated to account for more than half of the total carbon content of the world's known hydrocarbon resources (Kvenvolden, 1993), with 1 m^3 of natural gas hydrate yielding approximately 164 m^3 of CH_4 methane (Collett, 1993).

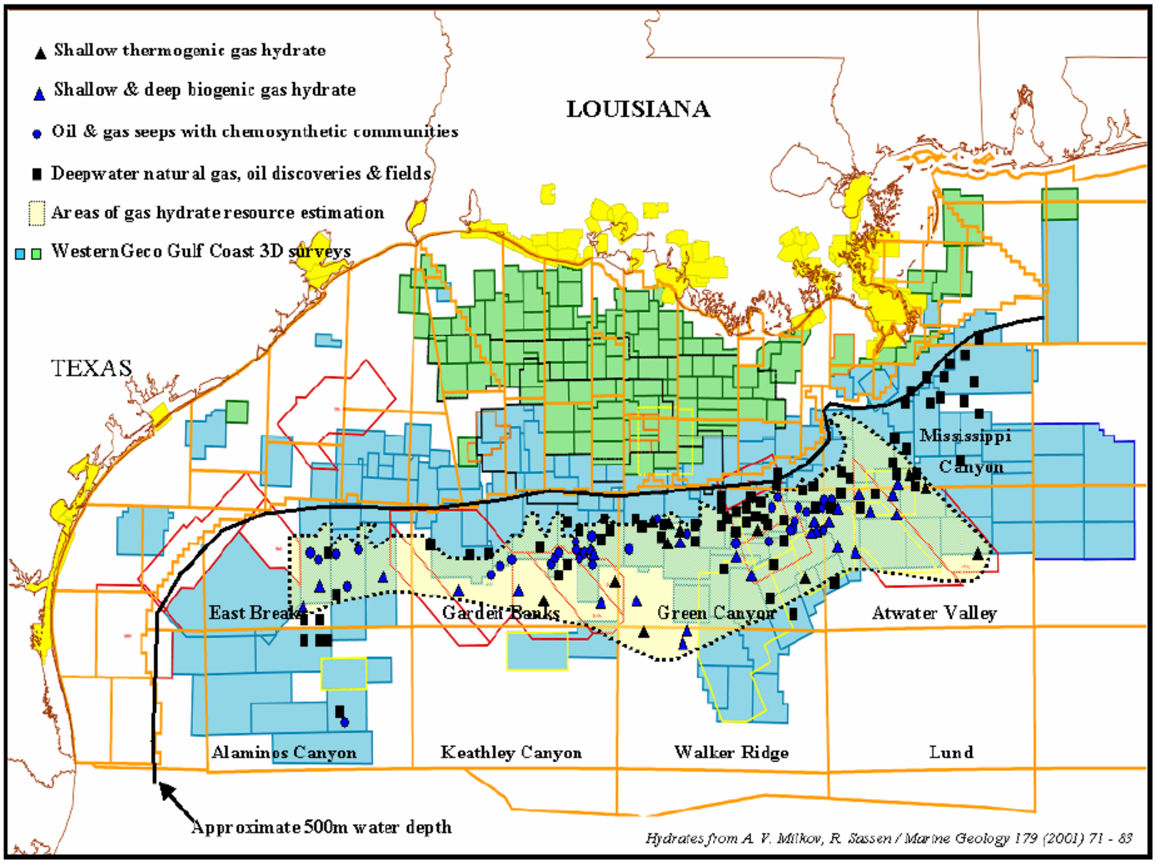

Figure 1. Known and estimated deepwater gas hydrate occurrences in the Gulf of Mexico.

Finding and assessing areas of gas hydrate occurrence is therefore important, although not always straightforward. Traditionally, a bottom-simulating reflection (BSR), a strong thermobaric barrier and seismic impedance contrast between free gas and solid hydrate in sediment, has been used to delineate zones where gas hydrates are likely present. In areas of the world where BSRs are evident on the seismic data, the spatial extent of gas hydrates can be inferred with a high degree of confidence. The GOM, however, provides only a handful of documented regional BSR examples. This may be because the complex GOM lithostratigraphy and active salt movement create complicated thermal regimes and fluid chemistry. Also, low-permeability sediments in the shallow section inhibit free gas migration. These conditions will greatly affect hydrate formation, distribution, and seismic amplitude of the BSR. While the presence of a BSR is a prime indicator of hydrate occurrences, high-quality seismic data can provide a wide range of other indicators as well.

In an effort to study and eventually drill different hydrate settings, two separate GOM deepwater areas were selected for review by a multidisciplinary team. Reprocessed 3D prestack time migrated data (PSTM) and high-resolution 2D multichannel seismic data

(MCS) were analyzed over one Keathley Canyon (KC) block (195) and one Atwater Valley (AV) block (14), both of which are in water depths of approximately 1300 m.

Keathley Canyon

A dominant feature in the KC area is a pronounced regional BSR about 250-500 m below the seafloor mudline (Figure 2). The BSR is bisected to the east by a salt-produced faulted ridge, which is also a probable fluid and gas migration pathway. The BSR has reverse polarity relative to the water bottom reflector and obliquely crosscuts stratigraphic events. In some areas, the BSR is also interpreted along high-amplitude terminations of free gas in the coarser-grained sediments immediately below the BSR (Figure 3). There may also be several seafloor hydrate mounds in close proximity to the fault ridge (e.g., right side of Figure 2).

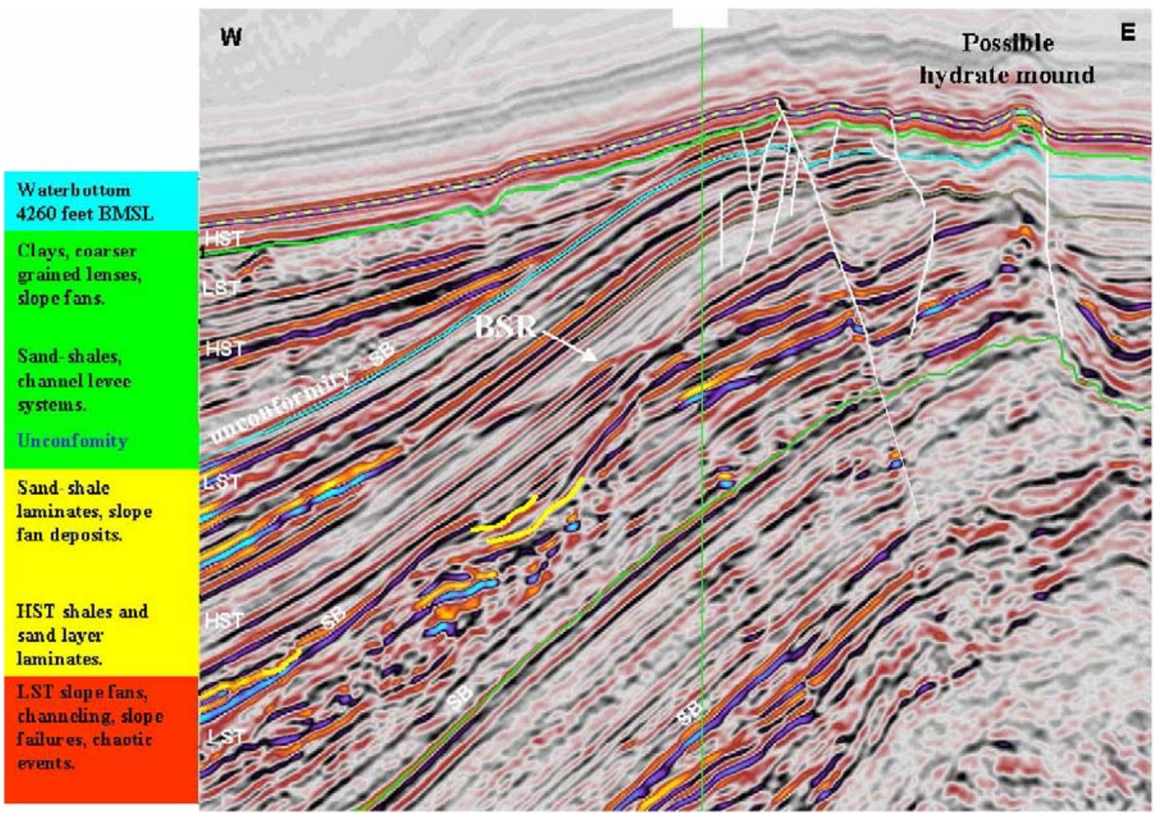

Figure 2. A seismic section from the 3D PSTM volume with stratigraphic interpretation at Keathley Canyon showing the BSR and hydrate mound. (LST: low stand system track, HST: high stand system track, SB: sequence boundary, color code denotes relative hazard risk).

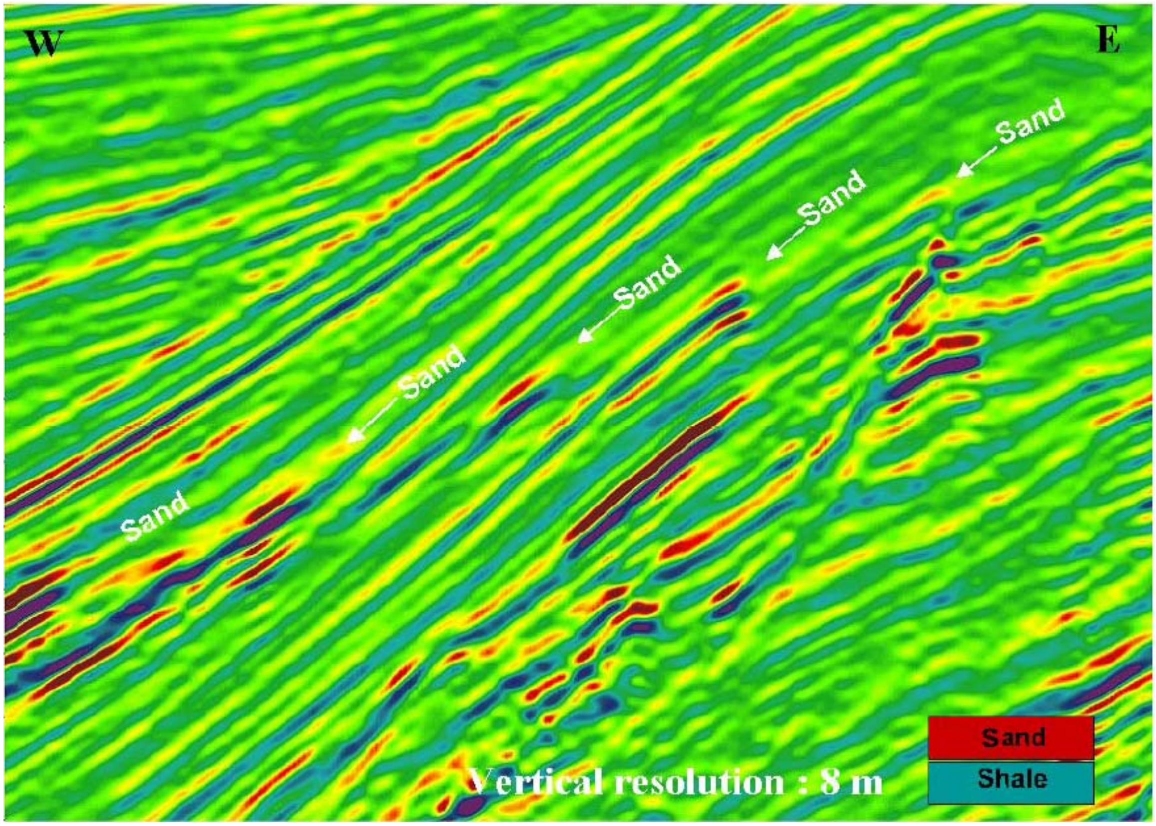

Figure 3. Keathley Canyon line from the 3D PSTM volume showing BSR interpreted along the terminations of high amplitude free gas within the sand-rich layers. Sand and shale are inferred from seismic amplitude analysis and known shallow stratigraphy of the GOM.

Atwater Valley

The Atwater Valley study area is located in the middle of the Mississippi Canyon paleo-channel system and contains numerous features interpreted to be hydrate mounds (Figure 4). Although no evidence of a regional BSR can be seen, most mounds show strong seismic indicators of hydrates including gas chimneys, amplitude "wipe-out" zones, and near-seafloor reversed-polarity seismic waveforms. Figures 5 and 6 show a northwest-southeast-trending seismic traverse through mounds "D" and "F", and illustrate two different hydrate mound types. A WesternGeco reprocessed 3D PSTM random line is shown in Figure 5 and the USGS high-resolution 2D MCS line of the same orientation is shown in Figure 6. The areas beneath both mounds reveal an amplitude disturbance within the upper 300 m of the section, free gas velocity anomalies and reverse polarity seismic events interpreted as shallow localized BSRs. However, the difference in depth of the BSR below each mound indicates dissimilarities and suggests something about the amount of hydrate present. For example, the very near-seafloor high-amplitude BSR at location "D" suggests that a hydrate crustal mound, possibly 60 m to 80 m in diameter, is exposed at the seafloor. It is probable that only free gas, and not hydrate, exists below this mound. The BSR at mound "F", about 50 m below the surface, is better defined and deeper than at mound “D”. This indicates a different fluid-gas flux or chemical composition and probable thicker concentration of hydrate below the seafloor. As distance increases away from the center of the mound where the high flux is interpreted, the BSR plunges downward toward the deeper section with a bell-shaped geometry (Figure 5). This suggests rapid pressure-temperature-chemical re-equilibration with the surrounding sediment.

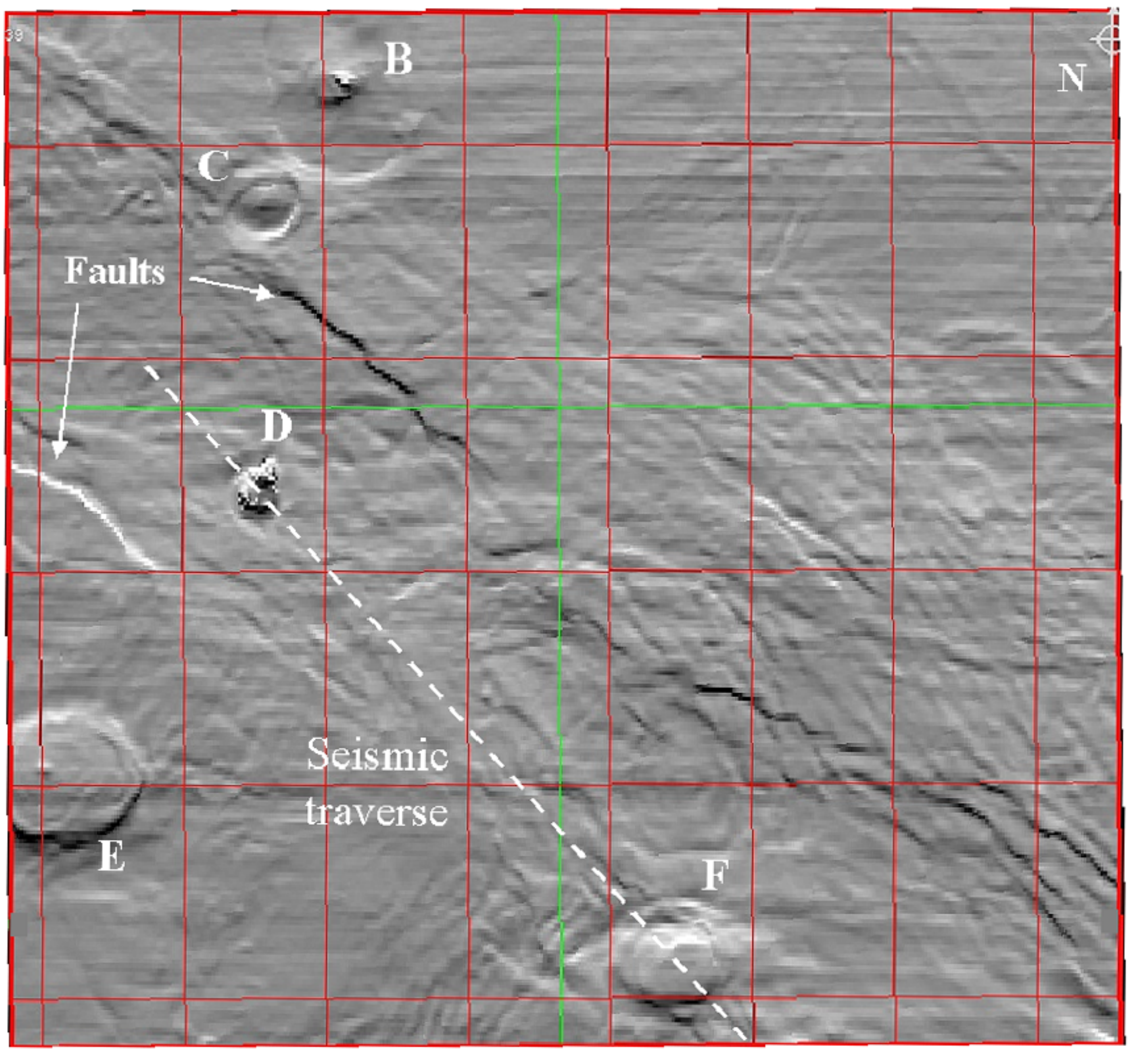

Figure 4. Atwater Valley water bottom reflectivity and shaded relief showing gas hydrate mounds B through F and structural features. Note mound “E” with possible gas vent or mud volcano. Dashed line indicates orientation of profiles in Figures 5 and 6.

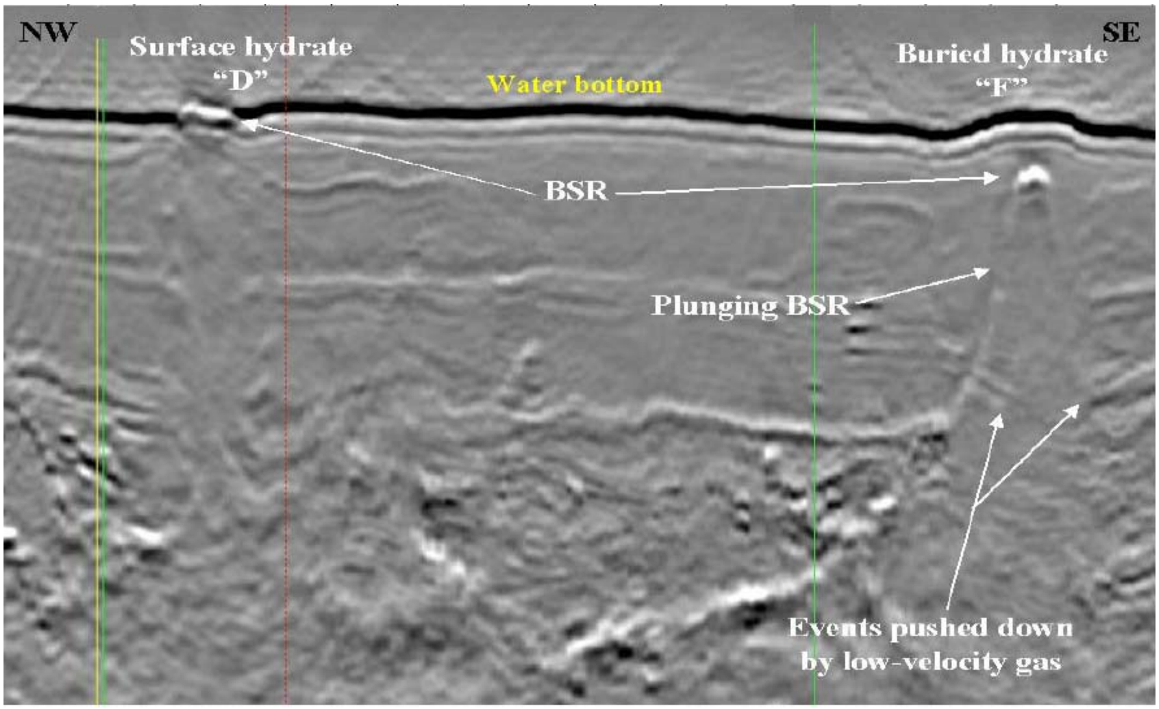

Figure 5. Atwater Valley WesternGeco 3D PSTM line through mounds "D" and "F".

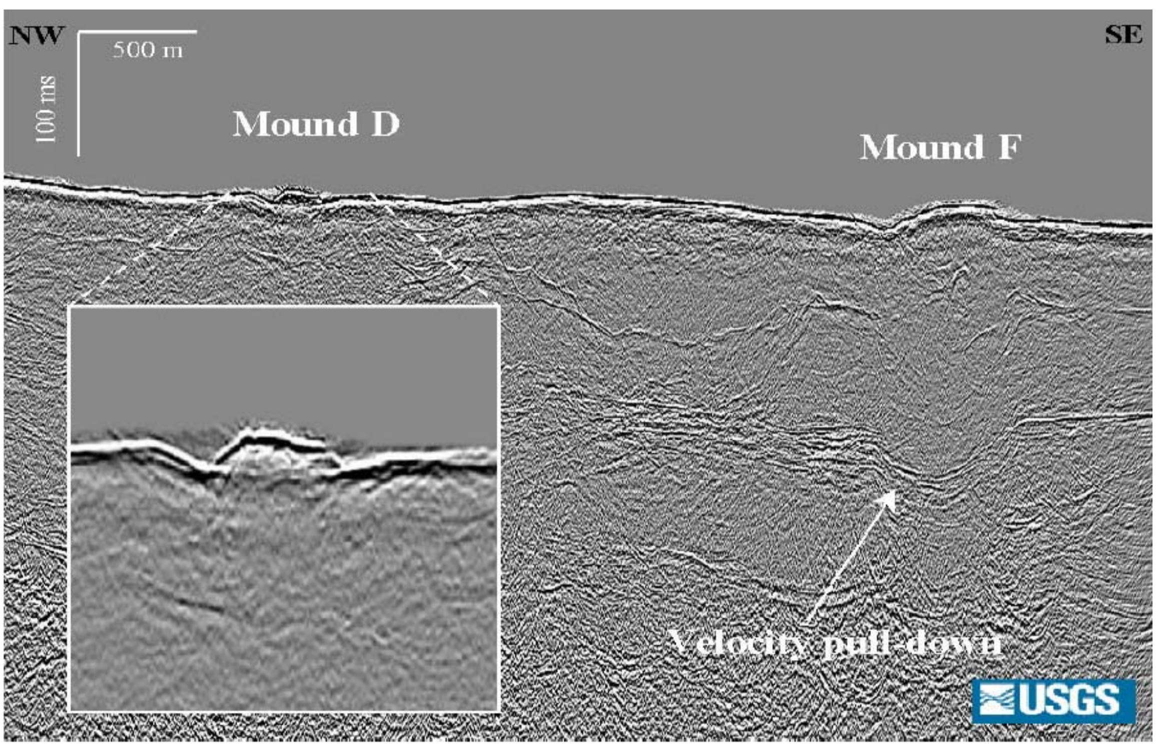

Figure 6. Atwater Valley USGS 2D MCS high-resolution line through mounds "D" and "F".

Concluding Remarks

Natural gas hydrate occurrences within northern GOM deepwater areas are often complex and diverse. Differences in lithologic, thermal, and geochemical regimes can create variations in hydrate formation and concentration levels. In addition, the presence of low permeability, fine-grained sediments in the shallow section reduces gas migration except in proximity to fault or fracture systems. These and other factors serve to make seismic detection of hydrates challenging. However, these two study areas have shown that high quality seismic data and detailed stratigraphic interpretation can be used to find and delineate gas hydrate concentrations, whether with the aid of a prominent BSR or by other distinctive hydrate characteristics. Drilling through the gas hydrate zone within these two areas in 2004, for research purposes, will test these ideas of hydrate occurrences.

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