Seismic interpretation of gas hydrate based on physical properties of sediments

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Summary

This paper analyzes amplitude behavior of gas hydrate from stacked seismic data, based on rock physics properties of hydrate-saturated sediments, gas saturated sediments, and water saturated sediments. Gas hydrate is likely to occur in suitable gas hydrate occurrence environment. Velocity of hydrate saturated sediments increases as gas hydrate replaces water in pore space of the sediment. In contrast, velocity of gas filling sediment decreases. The different patterns that consist of low concentrated gas hydrate, high concentrated gas hydrate, water and/or gas produce Dim out and Bright spots. The two gas hydrate indicators are illustrated in a 3D seismic data from the Green Canyon area of the Gulf of Mexico.

Introduction

Gas hydrates are ice-like solid composed of gas molecules enclosed in cages of water molecules. Under favorable conditions, they occur in marine sediments in deep water.

Gas hydrates can be detected from seismic data by observations of Bottom-Simulating Reflectors (BSR). A BSR is parallel to the seafloor reflector and has the opposite polarity. In sediments, gas hydrate usually grows in the pore space. Pure gas hydrate has a P-wave velocity of 3.65-3.75 km/s (Helgerud et al. 1999). Because gas hydrate has higher velocity than those of pore-filling fluids, gas hydrate saturated sediment exhibits relatively high velocity compared to water filling sediment. Below the BSR, a low velocity layer about 1.2-1.5 km/s is often observed, which is caused by that gas displaces water in the pore space. However, Numerous expeditions have shown that the presence of a BSR does not correlate to high concentrations of gas hydrate above the BSR (Lu and McMechan, 2002; Tréhu et al., 2003). On the other hand, gas hydrate has been detected in some areas without BSR such as Gulf of Mexico. In the paper, we interpret a 3D seismic data on Gulf of Mexico by within a suitable gas hydrate occurrence environment and physical properties of sediments. Our results show two gas hydrate indicators in sands: dim out and bright spots.

Geologic setting and Data set

The study area is in the eastern Green Canyon area on the upper continental slope off Texas and Louisiana where near-surface geology is dominated by active salt tectonics and rapid sea-level-driven sedimentation. The mobile salt has extensively fractured the overlying sediments with regional growth faults and associated fault types. These faults act as conduits for the migration of hydrocarbons from deep layers to the shallow section. The terrigenous coarse-grained sediments in the upper continental slope are mainly deposited during sea level lowstands.

The data used for this study is a poststack Kirchhoff time-migrated 3D seismic acquired by WesterGeco. The data was processed for hydrocarbon exploration purposes, and is sufficient for a shallow gas hydrate study. The frequency of the seismic data in the shallow section ranges from 40 to 60 Hz. Inlines are spaced 40 m (131.2 ft) apart; crosslines are spaced 25 m (81.02ft) apart.

Suitable gas hydrate occurrence environment

Recent studies suggest a concept of gas hydrate petroleum systems to identify the occurrence of gas hydrate in coarse grained sandy deposits (Hutchinson et al., 2008; Jones et al., 2008). The concept emphasizes the sandy deposits within gas hydrate stability zone, a gas source close to the deposits; and a migration pathway which can transport gas into the deposits (Ruppel et al., 2008).

Gas can flow upward from the deeper source rock due to driving forces (i.e. buoyancy, geopressure, and hydrodynamics). It moves through some permeable conduits into the gas hydrate stability zone. Faults and fractures are important for the gas migration and accumulation. They act as pathways to conduct gas into a reservoir within gas hydrate stability zone. The reservoir consists of relatively porous and permeable rock.

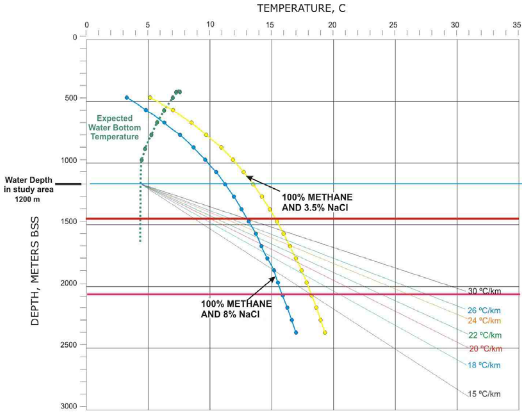

Figure 1: Predicted base of hydrate stability zone in study area. Red lines are possible upper limit and low limit of base of hydrate stability zone.

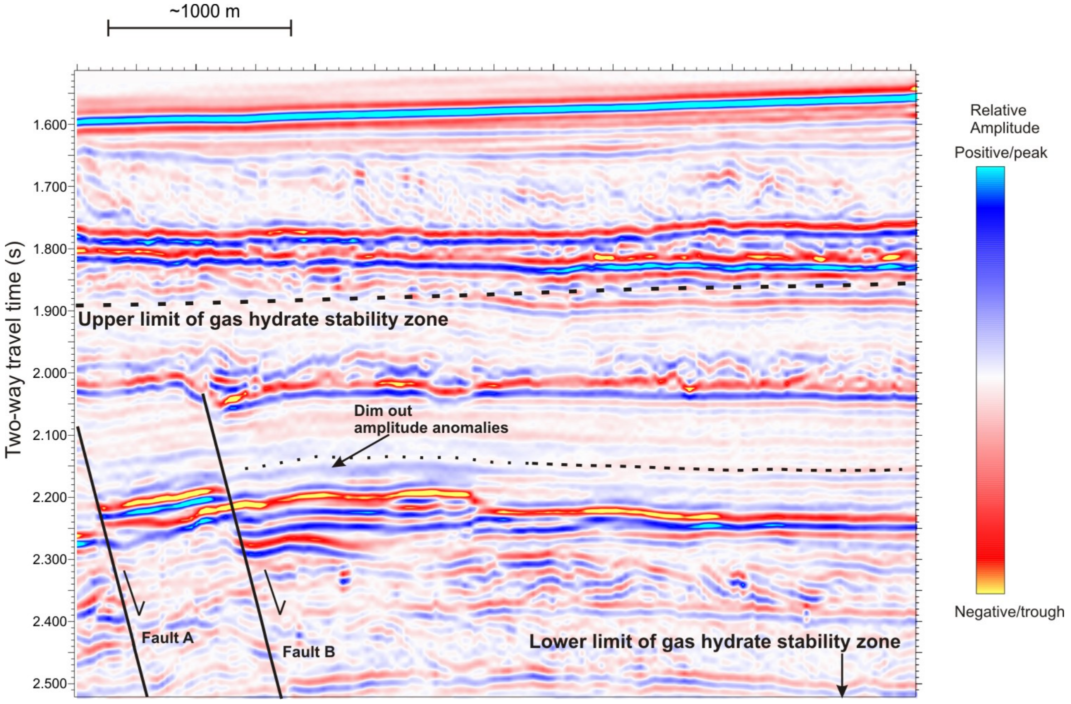

Figure 2: Stacked seismic data illustrates Dim out amplitude anomalies. The reflector at 1.6 s is seafloor.

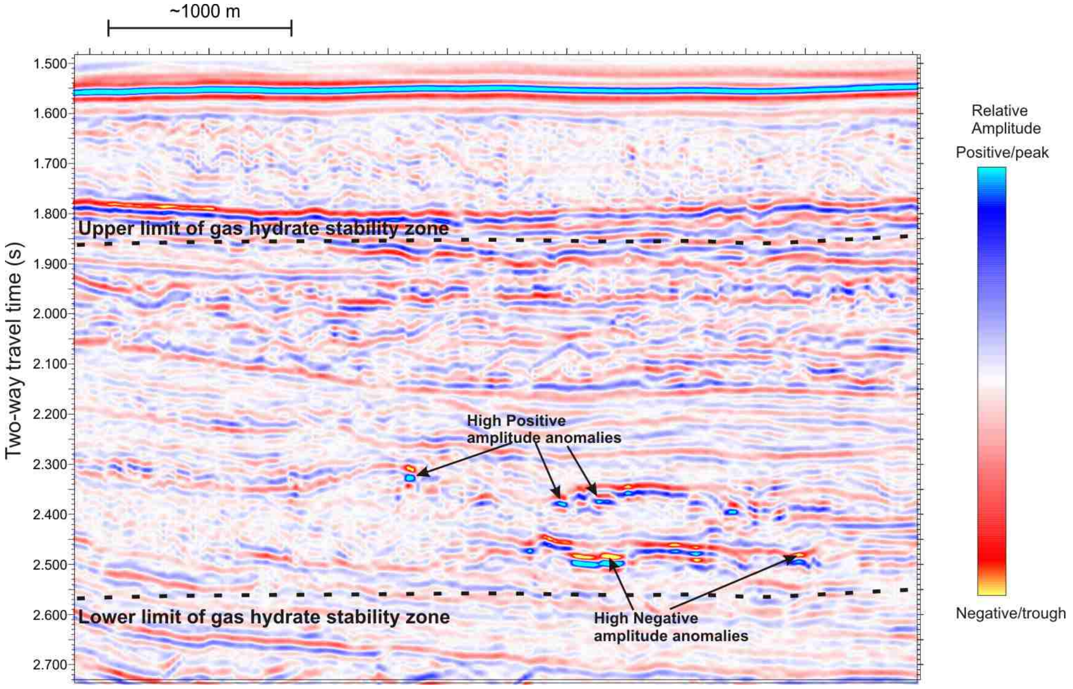

Figure 3: Stacked seismic data illustrates bright spots amplitude anomalies. The reflector at 1.57 s is seafloor. High positive amplitude anomalies are interpreted to be gas hydrate; high negative amplitude anomalies are interpreted to be free gas.

The formation of gas hydrate in deep marine deposits, given gas-saturated fluids in the sediment pore space, is mainly controlled by temperature, pressure, and pore water salinity (Figure 1). However, local variations in physical properties of deep marine sediments may be sufficient to produce localized thermodynamic non-equilibrium conditions whereby gas hydrate does not form within gas hydrate stability zone. These local variations may include local geotherms, local isobars, local flux rates, and local salinities etc within the gas hydrate stability zone. Localized conditions may exist whereby gas is present with the gas hydrate stability zone. Likewise gas may not reach the base of hydrate stability zone.

We estimate the conditions for gas hydrate formation using the CSMHYD program (Sloan, 1998). The geothermal gradients from 15˚ C/km to 30˚ C/km are used in the Figure 1. Assuming the bottom water temperature of 4.4˚, the base of gas hydrate stability zone is expected to range from upper limit at approximately 250m BML to lower limit at approximately 830 m BML in the area.

Seismic interpretation

Two large normal faults are shown clearly in Figure 2 (Faults A and B). The presence of these faults is very important for the vertical migration of free gas. The tops of these burial faults are located in approximately 2 s Two-way Travel Time (TWT) (360m BML). Channel systems and lobes are relatively common in the area. The sand-prone deposits are located within the computed base hydrate stability zone. These buried faults cut sand-prone channel levee deposits at approximately 2.25 s TWT (~520 m BML) in Figure 2.

High negative amplitude anomalies are interpreted to be gas saturated sediments at 2.25 s (Figure 2). The weak amplitudes can be seen above the gassy sediments. Dash line at 2.15 s shows negative reflections partially disappear in the zone (Figure 2). The Dim out anomalies are interpreted be low concentrated gas hydrate within the sand prone deposits.

Some bright spots with high positive amplitude anomalies are found at about 2.35 s and some bright spots with high negative amplitude anomalies are found at about 2.45 s in Figure 3. The high positive amplitudes are interpreted to be gas hydrate and high negative amplitudes are interpreted to be free gas.

It could be caused by local variations that dim out and bright spots occur in different depth. In general, they occur in the depths about 500 m BML to 700 m BML, which are corresponded to geothermal gradients below 20˚ C/km in P-T condition in Figure 1.

Physical properties interpretation

Rock physics depth trends can be very complicated depending on lithology, mineralogy, fluid properties, and pressure. In general, acoustic impedance of shallow sediments increases with depth due to compaction (Figure 4). In the zone close to the seafloor, clays tend to have higher porosity than sands. The porosity of clays decreases faster than that of sand in the shallow section because clays tend to compact more easily than sands during early burial. Thus, the impedance of clays tends to increase more quickly than that of sand. Within the gas hydrate occurrence zone, the acoustic impedance of sands may or may not be less than that of clays, depends on porosity (Figure 4).

The smooth clay baseline curve shows porosity decreases and impedance increases with increasing depth in Figure 4. We divide shallow sediments into water saturated sediments, gas hydrate saturated sediments, and gas saturated sediments. At any given depth, the sum of water, gas hydrate and free gas volume fractions is equal to the total porosity of sediment. The difference between these sediments is the gas hydrate and gas content in the pore space. When the water saturation decreases, resulting from gas hydrate filling the pore space, impedance increases. Therefore, we can see higher impedance in gas hydrate saturated sediments than water saturated sediments (Figure 4). Similarly, if free gas fills the pore space, impedance decreases (Figure 4).

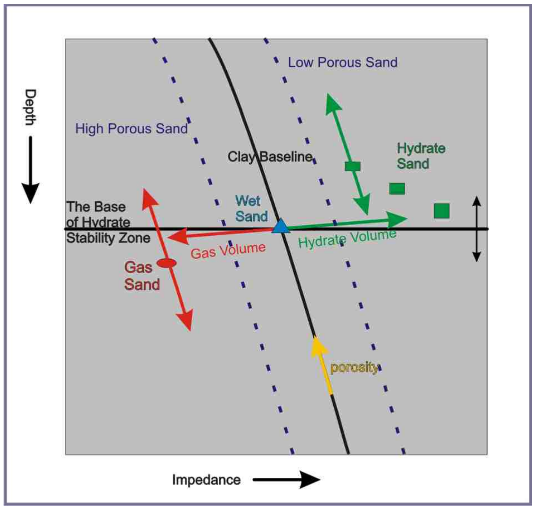

Figure 4: Pore fluid, clay baseline, wet sand, porosity, and the base of hydrate stability zone variations.

The effect of fluids and rock mineralogy on seismic velocity tends to determine the seismic response of gas hydrate shown in Figure 5. The top of free gas is consistent with base of hydrate stability zone in traditional BSR. The impedance contrasts in the case are caused by low concentrated gas hydrate over free gas, high concentrated gas hydrate over free gas or only high concentrated gas hydrate (Figure 5).

Fluid is likely to move in high porous sediments within gas hydrate stability zone. In general, low porous sediments have higher velocity than high porous sediments. The velocity contract decreases when some gas hydrates form in high porous sediments. This could lead to a dim out (Figures 2 and 5).

The gas saturated sediment is well known to be identified by high trough amplitude reflections because of low velocity (Figure 4); high concentrated gas hydrate saturated sediment may be identified by high peak amplitude reflections because of high velocity (Figure 4). These strong reflections are called bright spots (although in typical usage, a "bright spot" is a low impedance reflector. We include the high impedance anomaly as another kind of "bright spot") (Figure 5). The gas and gas hydrate separation and lateral variation could cause a series of bright spots (Figure 3).

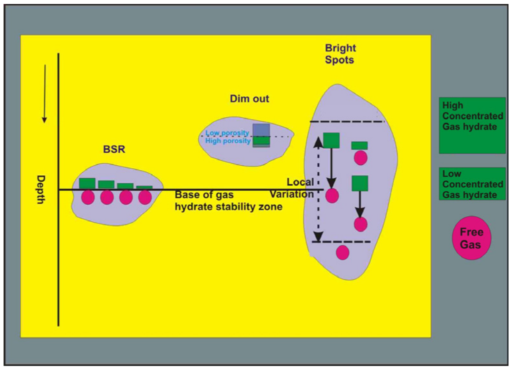

Figure 5: Analysis of BSR, Dim out, and Bright spots based on physical properties of sediments.

Discussions

In the study, interpretation of gas hydrate is based mainly on there being a favorable environment for gas hydrate occurrence. Gas hydrate indicators provide additional information to guide the interpretation.

The Dim out anomalies have the following main characteristics:

- Amplitude on the stack section is weaker for the hydrate saturated sediments than for equivalent water saturated sediments.
- Reflection shows a relatively thick zone in hydrate saturated sediments compared with equivalent water saturated sediments.
- Wavelet character may or may not be peak-trough.
- Dim out occurs certain distances above the base of gas hydrate stability zone. Unless carefully interpreted, it is not obviously distinguished from background amplitude.
- Dim out is associated with moderate to high fluid flux in our study area.

The Bright spots anomalies have the following main characteristics:

- Amplitude on the stack section is much stronger for the hydrate saturated sediments than for equivalent water saturated sediments.
- Chaotic or dis-continuous reflection shows in water saturated sediments. The reflection may or may not trough-dominated.
- Wavelet character may be peak-trough or trough-peak.
- Bright spots occur within local variations of gas hydrate stability zone. Free gas and gas hydrate may co-exist within the zone, hence both high peak-dominated and trough-dominated anomalies can be obviously distinguished from background amplitude.
- Bright spots are associated with low to moderate fluid flux in our study area.

Conclusions

Detailed examination of reflections on seismic stack section can provide important information about the presence of gas hydrate. Bright spots and Dim out may be useful indicators to identify gas hydrate from seismic, provided that a suitable gas hydrate environment is understood to be present. Amplitude, wavelet, and reflection thickness need to be considered when the gas hydrate indicators are interpreted. Amplitude anomalies caused by free gas can aid in identifying potential gas hydrate.

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2010 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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