Use of Seismic Attributes and Modeling in Gas Hydrate Reservoir Interpretation, North Slope, Alaska

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Abstract

Gas clathrates, commonly known as methane or gas hydrates, are an ice-like crystalline solid composed of water and natural gas, primarily methane. Gas hydrates occur in the shallow subsurface where both water and gas are present within low-temperature and moderate-pressure regimes. The shallow subsurface geology of the North Slope of Alaska is structurally dominated by a broad antiform, known as the Barrow Arch, and is riddled with a myriad of high angle normal faults trending roughly north south and east-west. In addition to the complex structure, the hydrate-bearing units are predominantly fluvial and northward prograding deltaic strata. The complexity of the local geology, coupled with the lack of a consistent amplitude anomaly associated with hydrate occurrences, make simple horizon interpretation of hydrates difficult. In order to gain a better understanding of the hydrate distribution as well as a clearer picture of the structural geology, seismic attributes are used in conjuncti on with traditional horizon-to-well-tie interpretation techniques. Several of the attributes, based on the Hilbert Transform, can yield information about the physical properties of the hydrate-bearing units. For example hydrate layers may have an anomalous frequency response based on their relatively high acoustic velocity. Delineation of high-angle faults and possible channel deposits are aided by the use of calculated event similarity prediction (ESP) volumes. ESP volumes are essentially a measure of trace-to-trace similarity, so discontinuities in the seismic data are brought into better focus. The use of these attributes, as well as others, yields a clearer picture of hydrate distribution as well as a more accurate structural model.

Location

The general survey location for this project is the Prudhoe Bay region of the North Slope of Alaska. More specifically this project focuses on the Milne Point and Northwest Prudhoe Bay lease blocks, (Figure 1).

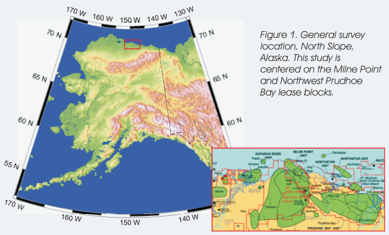


Figure 1. General survey location, North Slope, Alaska. This study is centered on the Milne Point and Northwest Prudhoe Bay lease blocks.

Modeling

Finite-difference modeling was done to predict and explain characteristic features of the seismic data for use in hydrate and free-gas identification. Simple geologic models of planar layers with gas-water contacts as well as hydrate-gas contacts were constructed and tested using Promax 2D software. In order to approximate a stacked section, an "exploding reflector" was used in creating the synthetic seismic data. The synthetic seismic data were then compared to the stacked seismic data from theNorth Slope to try to identify potential gas-hydrate and free-gas occurrences where well control was unavailable.

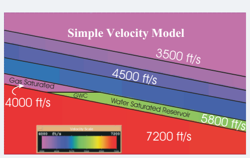


Figure 2. A simple velocity model was created to simulate the seismic response characteristic of a free-gas-to-water contact. Velocities increase with depth, except for the gas-saturated reservoir. A strongly negative-amplitude reflection is expected to be associated with free gas occurrences based on the relatively low velocity of the layer. Velocities shown are RMS velocities in units of feet per second.

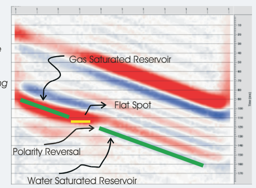


Figure 3. The velocity model from Figure 2 was modeled using a finite difference modeling technique.. The finite difference technique uses a numerical solution to the wave equation to estimate the seismic response. From this model it can be seen that the gas-saturated reservoir has a strong negative amplitude anomaly as well as a polarity reversal along the horizon. This model has been migrated, and has had random noise added.

Real Data Comparisons

Once the seismic response for the model was computed, the output was compared to the North Slope data to see if similar anomalies were present. Events in the seismic data with similar anomalies can be considered candidates for free-gas or hydrate occurrences.

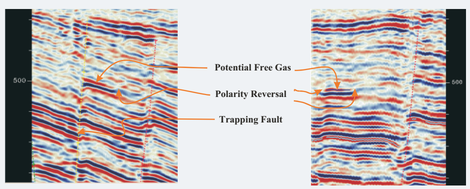
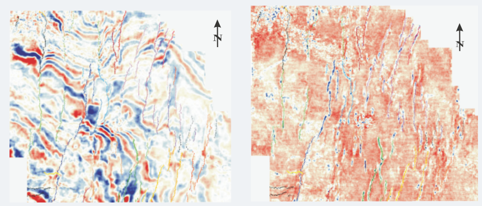


Figure 4. Real data example. The figure above is a real data example showing a strong negative amplitude event truncated by a polarity reversal. This response is similar to that found in the modeled seismic data, and is considered a candidate for free-gas accumulation. The area where the seismic data were acquired has sparse well coverage in the shallow subsurface, so seismic attributes and modeling become very important in delineating potential gas-hydrate and free-gas accumulations.

Seismic Attributes, Structural Interpretation

The North Slope of Alaska is riddled with normal faults with the dominant trends NNE-SSW and NW-SE. Many of the faults have small offsets and are generally very high angle. In order to more accurately interpret the faults and determine their strike, an Event Similarity Prediction (ESP) attribute cube was calculated. The ESP attribute essentially measures trace-to-trace dis-similarity using semblance calculations between adjacent traces and their resulting Manhattan distances. Eight adjacent trac es are scanned about a center trace; the trace with the minimum trace-to-trace semblance then has it's Manhattan distance calculated.

In the figures below, regions of high dis-similarity are represented by blue, and regions of relatively low dis-similarity (more uniform geology) are represented by red. The ESP attribute cube clearly delineates the major fault trends and is a significant improvement in aiding fault interpretation compared to conventional 3D seismic data in time-slice view.



[Time Slice Seismic Data, Map View] [Time Slice ESP Data, Map View]

Figure 6. Using the Event Similarity Prediction (ESP) attribute, a more accurate fault map was created. As seen above (right), faults and their trends are more obvious than on conventional time-slice seismic data (above left). The dominant fault trend was found to be NNE-SSW, in contrast to the Prudhoe bay and Kuparuk regions where the major faults trend NW-SE.

Seismic Attributes in Stratigraphic Interpretation

The instantaneous phase attribute is considered a good indicator of continuity of seismic data, and so is useful in identifying and interpreting sequence boundaries. The figure below is an example of the use of the instantaneous phase attribute used to better define a flooding surface.

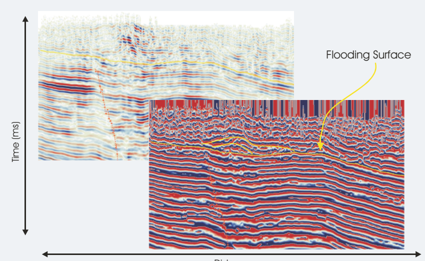


Figure 7. The flooding surface on this seismic line is more clear using an instantaneous phase display. The instantaneous phase attribute is a good indicator of continuity. Here semi-continuous horizons terminate at the flooding surface, exhibiting onlap and downlap.

Instantaneous Frequency

The instantaneous frequency attribute is considered a good tool for lateral seismic character correlation. In the past, a low instantaneous frequency anomaly has been used to predict conventional hydrocarbons (oil & gas) accumulations in the oil industry. In this case we expect to see a high-frequency anomaly due to the relatively high velocity of the gas hydrates.

Calculating Seismic Attributes

The <u>Manhattan distance</u> is given by the following equation;

$$M_d = 100 * \frac{\sum_{K=N-n/2}^{K=N+n/2} |G_k - H_{k+d}|}{\sum_{K=N\ n/2}^{K=N+n/2} (|G_k| + |H_{k+d}|)}$$

Where:

Gk = Center Trace
Hk = Target Trace
Md = Manhattan Distance
n = number of samples in the wavelet
d = integer sample shift
N = Center sample of the reference trace
100 = Scalar used for display purposes

<u>Instantaneous phase</u> is a seismic attribute based on the Hilbert transform, and is given by the equation;

$$\Phi(t) = \arctan(\mathrm{Im}(G_k(t))/\mathrm{Re}(G_k(t)))$$

Where $\Phi(t)$ is the instantaneous phase value at time t, arctan is the inverse tangent, $G_k(t)$ is the value of the seismic trace at time t, Re is the real or recorded part of the seismic trace, and Im is the imaginary part of the seismic trace determined by the Hilbert transform.

<u>Instantaneous frequency</u> is also based on the Hilbert transform and is given by the derivative of the instantaneous phase;

$$f(t) = \frac{d(\Phi(t))}{d(t)}$$

Where () is the instantaneous frequency, and () is the instantaneous phase

We expect to see a high frequency anomaly associated with gas hydrate accumulations based on the relatively high acoustic velocity of hydrates compared to surrounding strata.

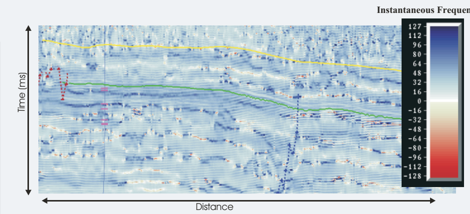


Figure 8. The above figure shows a potential correlation of gas hydrate picks by Tim Collett (USGS), with high instantaneous frequency values. Low instantaneous frequency anomalies have been used in the past to help identify free gas. In the case of gas hydrates, the difference in instantaneous frequency is probably due to the difference in elastic properties.

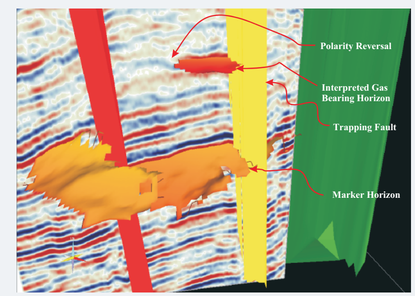


Figure 8. The above figure is a 3D model of what may be a small gas reservoir. In this 3D environment, volumes of seismic and/or attributed data can be selected based on amplitude or attribute characteristics to yield accurate volumetric calculations and a more complete picture of the reservoir. This image was created using Landmark Graphics software (EarthCube).

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