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# Pre-stack seismic data analysis for gas hydrate characterization: An example from Krishna Godavari ultra-deep-water

## Abstract

Gas hydrate reservoir characterization is in principal no different from the traditional hydrocarbon reservoir characterization. Therefore technologies developed for identification of pore fluid can be applied to gas hydrate as well. As Gas hydrates exhibit enhanced acoustic impedance due to relatively high P/S wave velocities and typical Amplitude Vs. Offset (AVO) effects. In this paper, study of pre stack seismic data duly reprocessed for AVO is analysed and presented for AVO effect at the site where thick gas hydrate section has been discovered. The AVO analysis preferentially targeted at a shallow "bright spot" that is interpreted to mark the top of gas hydrate above base of the gas hydrate stability zone. The AVO analysis at the site (Water depth >2500 mts) in a Krishna Godavari offshore shows results that also corroborates the observation from well and core data and suitable as proxy for a medium with presence of substantial gas hydrates over underlying free gas. Based on the analysis of AVO parameters like intercept/gradient and cross plot analysis at the study site, it is inferred that highly concentrated gas hydrate bearing sediments above a poorly gas saturated sediments exist in the depth interval of 272 to 291 (mbsf).

## Introduction

Gas hydrate is an ice like crystalline solid formed from water molecules that encase and trap gas molecules. Gas Hydrate mainly develops and is stable at high pressure and low temperature conditions in the marine sediments of ocean basins and ice covered arctic regions. Common seismic representation of methane hydrate is a bottom-simulating reflector (BSR) caused by the impedance variation between sediment containing solid gas hydrate and underlying sediment containing free gas. A BSR is often correlated with the base of the gas-hydrate stability zone, below which the temperature is too high for gas hydrate to exist.

Recently conducted Gas hydrate research in India has proven that gas hydrate has great potential as future energy source. Worldwide production tests also encourages possible commercial realization and has prompted a recent increase in hydrate research in India and worldwide.

India is in the forefront of developing this resource under National Gas Hydrate Program (NGHP) known as NGHP. India has completed two expeditions so far, first expedition NGHP-01 in 2006 and second expedition NGHP-02 in 2015. Several gas hydrate prospective sites were identified in Krishna Godavari offshore area for the second expedition of National Gas Hydrate Program (NGHP-02) of India (Shukla et al 2011). One of these sites discovered highly saturated gas hydrate particularly at site-A (Kumar et al 2016). In view of a study is undertaken to correlate the well log and pre-stack seismic response using amplitude behaviour with the lateral offset. It is also intended in the study to find the AVO response in established (proven) gas hydrate section at site- A (Figure-1) to analyse the efficacy of AVO as a gas hydrate identification and characterization method.

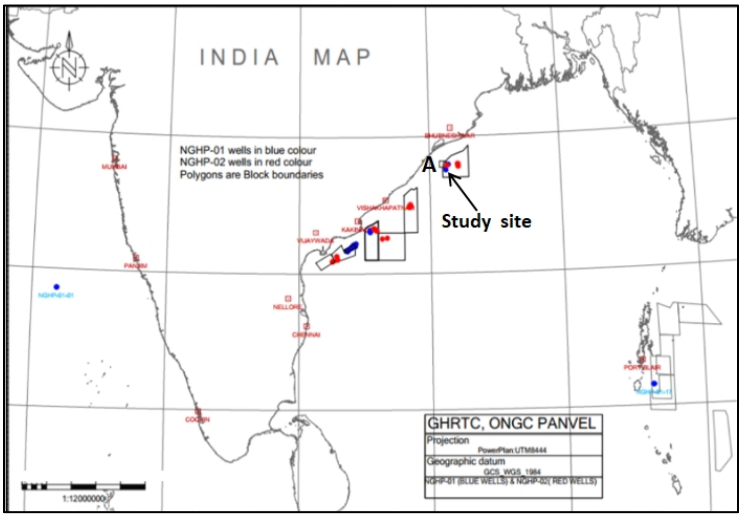


Figure 1: Map showing study site-A for AVO analysis.

## Integrated well and pre-stack seismic studies for AVO analysis

In the AVO/Inversion studies of pre-stack seismic attributes requires generation of synthetic model through integration of the seismic and well data. Integration of seismic and well data also required to calibrate and tie up the seismic events and log features. Once seismic event and log features are correlated using appropriate P-wave velocity profile then it is possible to estimate S-wave velocity using appropriate Castagna transform (Castagna et al, 1997). Recorded P-wave velocity and estimated S wave velocity are the essential component for characterization of rock fluid constituents in AVO and inversion attribute studies. In general such studies are more suitable for gas/oil saturated sediments, as shear waver are more sensitive to them than gas hydrate and non-gas hydrate sediments. Therefore AVO/Inversion studies in gas hydrate exploration is mainly carried to infer about the presence of free gas below gas hydrate sediments which is also seismically characterized by the bottom simulated response (BSR) in seismic data. In view of this mostly AVO studies are carried for bright events related to BSR using pre-stack seismic gather.
As Effectiveness of AVO studies is thereby depending upon quality of pre-stack seismic data. For this reason, seismic data acquired in 2003-04 for conventional oil and gas prospects in deeper sediments has been reprocessed. The reprocessing efforts were mainly aimed to generate AVO suitable gather and stack volume for shallow sedimentary section where gas hydrate occurs.
The processing efforts were carried out at SPIC, ONGC, Panvel. This reprocessed seismic data along with gas hydrate well data obtained during NGHP-02 Expedition was populated in the database of Hampson Russel 10.2.1 software. Hampson Russel software is most suitable and widely used for AVO and inversion studies.

## Pre stack data Processing for preparation of AVO suitable gathers

In the study area, 3D seismic data volume acquired by M/V CGG Amadeus during 2003-04 for conventional hydrocarbon exploration with an objective to identified deeper hydrocarbon plays. Moreover the available data volume covers large area about 1200 sq.km. Therefore to trim the data volume to cover the study area and generate AVO suitable gather for shallow depths, basic reprocessing work was carried out at SPIC (ONGC) Panvel.

Following are the key processes and optimized parameter used in basic reprocessing pre-stack data for AVO studies -

1- Input: Navigation merged raw gather segy data
1. De-signature
2. Zero phase
3. Deghosting
4. Offset regularisation from 100m to 6100m at 200m interval
5. Deconvolution (TX) PD:16ms, OL:240 ms
6. Q Compensation (phase only): 200

7. RMS velocity analysis (250m*250m) on target line migrated gathers
8. Fourth order eta picking (250m*250m)
9. PSTM Anisotropic aperture 2500m
10. Residual move out picking and gather flattening
11. Mute and stack
12. Spectral balancing and TVF( filter 6-90 HZ) 3dB-12dB

Part of an inline passing through study site- A from processed PSTM gather is displayed in figure 2.

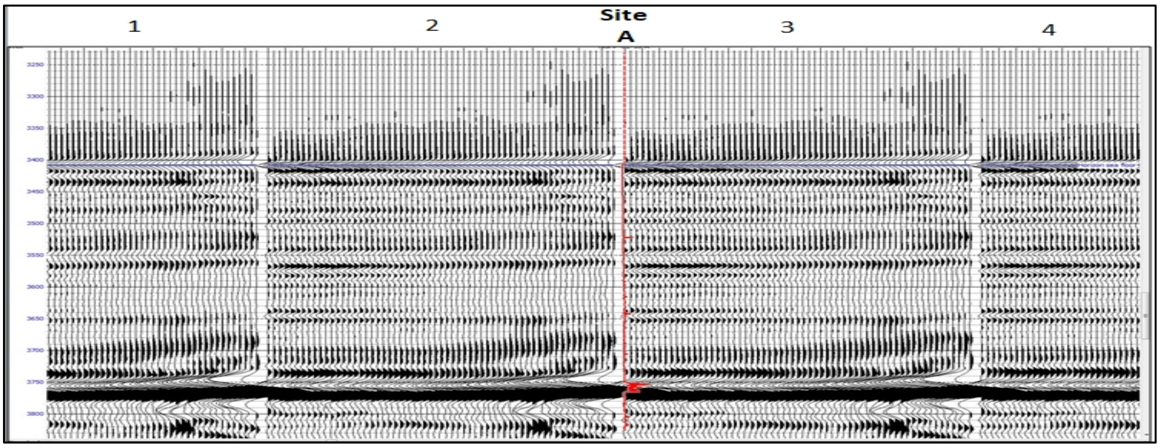


Figure-2: Inline PSTM Gathers (1,2,3,4) passing through gas hydrate well site-A. P wave velocity curve is posted at gather (well location). Blue line is correlated with sea floor.

## Pre-stack Seismic AVO Method

In general, AVO and inversion studies has been used by the petroleum industry in the last two decades in order to determine rock's fluid content, porosity, density or seismic velocity. AVO refers to the dependency of the seismic amplitude with the distance between the source and receiver (the offset) and is based on the relationship between the reflection coefficient and the angle of incidence based on the Zoeppritz equations.

Conventional AVO (amplitude variation withoffset) analysis is based on the well-known Knott-Zoeppritz equations (Knott, 1899, and Zoeppritz, 1919). For a planar interface between two homogeneous isotropic elastic half spaces in welded contact, these equations describe the various reflection and transmission coefficients for plane waves as a function of angle of incidence. Therefore pre-stack seismic data can be studied for amplitude changes with the offset caused by host fluid or gas hydrate.

AVO program usually requires an offset-dependent synthetic seismogram using the P-wave sonic log, density log, and created S-wave log. To create a synthetic seismogram we needs the following -

(1) **The seismic wavelet:** the seismic wavelet can be a modeled Ricker wavelet with a dominant frequency equal to some average value for the wavelet derived from seismic. Result from statistical wavelet Extraction from processed super gather along Inline adjacent gathers at site-A is shown in figure 3. Amplitude spectrum shows band of frequencies ranging from 5 Hz to 50 Htz are usable amplitude studies. Dominant amplitude is in 20 to 30 Hz, which covers the zone of real interest.

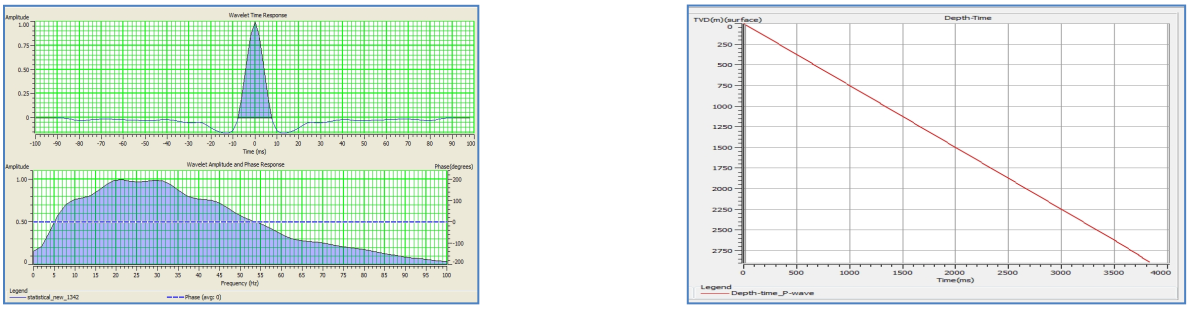


Figure 3: Wavelet response with time (top) and frequency (bottom) in the left side and Depth-time (TWT) relation profile is shown by red line

(2) **The seismic geometry**: It needs correct near and far offsets which is available in CDP gather data set. In our study gather data is ranges from 200 to 6200 mts offset.

(3) **The depth-to-time conversion**: This is obtained from a sonic log to accurately tie observed seismic data. If any deviation between log and seismic feature appears than it is to be corrected. Depth-time curve optimized for present work at well site-A, is shown in figure 3.

## AVO analysis on pre-stack seismic gathers

AVO refers to the dependency of the seismic amplitude with the distance between the source and receiver (the offset) and is based on the relationship between the reflection coefficient and the angle of incidence based on the Zoeppritz equations. A large part of current industry practice in AVO analysis involves what is referred to as intercept/gradient analysis. To understand the basics of this procedure, there are three key topics:

1. **The basic approximations of the Zoeppritz equations**: Zoeppritz equations and Shuey's equation (Shuey RT, 1985) are dependent upon the angle of incidence at which the seismic ray strikes the horizon of interest (figure-4).
2. **Transforming our data from the constant offset to the constant angle domain:** However, we record seismic data as a function of offset. While offset and angle are roughly similar, there is a nonlinear relationship between them, which must first be accounted for in processing and analysis schemes which require that angle be used instead of offset. We term this type of analysis AVA (amplitude versus angle) rather than AVO. An example of such a transform is shown in Figure 5. an offset gather is shown in Figure 5(a), and the equivalent angle gather is shown in Figure 5(b). At the top of each gather is shown a schematic of the ray-path geometry assumed for the reflected events in a particular trace of each gather. Notice that the angle of incidence for a constant offset trace decreases with depth, whereas the angle remains constant with depth for a constant angle trace. In the present study also, an offset and angle gather extracted which are shown in figure 6 at inline gathers transacting through study site -A.

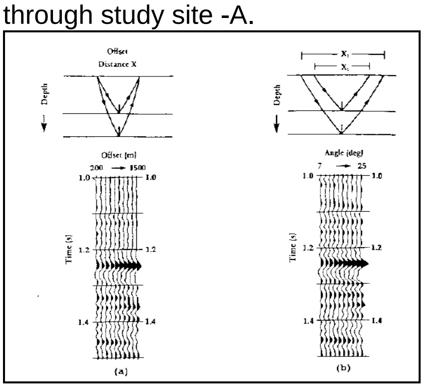


Figure 5. (a) shows AVO response and (b) shows transform of (a) in AVA (amplitude versus angle) response

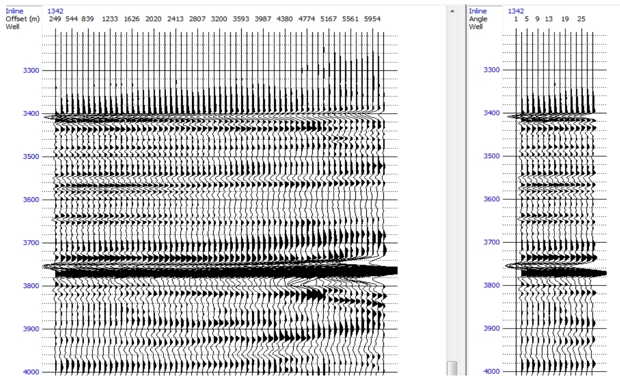

Figure 6. shows gather showing amplitude variation with offset response (Left) and amplitude versus angle response (Right), at well site-A

3. **Pre-synthetic model:** Fluid replacement by oil/gas: AVO program in Hampson Russel have provision to replace fluid in the pore space to generate model for oil/gas presence. One can observe that pre synthetic model curve for oil or gas is not matching with recorded at well site –A. It implies that the fluid contained is other than oil or gas i.e gas hydrate. As AVO program still not includes the gas hydrate as it is solid not the fluid.

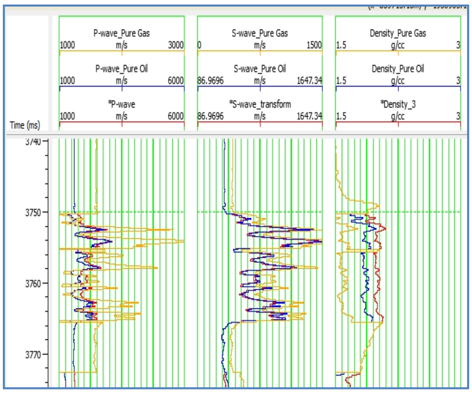


Figure 7: Pre-synthetic model curve for P-wave, S-wave and density are shown for Gas (yellow), Oil (red) and recorded at well (blue).

**AVO intercept and gradient study:** Intercept and gradient are widely used two important AVO attributes. These attributes are extracted by plotting the seismic amplitude of the signal related to a reflector (horizon) of interest against the offset/angle of the trace. The "Intercept" provides the trend of the amplitude measurements that meets the plot at zero-offset line. The plot also yields the radient or slope of the curve made by the plot points.

In the current study AVO response curve is extracted for two events, event-1, well site-A is positioned. The bright spot event-1 occurs at 3752 ms (TWT) as indicated by P-wave curve plotted on super angle gather (figure-9). The detailed analysis and parameters of both events are given below -

*Analysis Volume: Angle Gather at well site-A and Gradient Curves: A/B (Two Term Aki-Richards)*

Event 1: Time= 3764 ms, Correlation= 0.68, A= 76522, B=-95026, Max Angle= 29 degs

*Event 2: Time= 3752 ms, Correlation= 0.96 A=-450750, B= 275291 Max Angle= 29.00 degs*

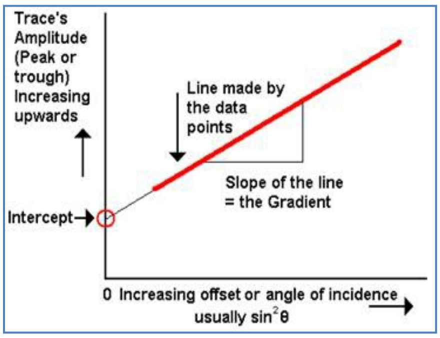


Figure 8: Schematic diagram showing intercept and gradient measurements. Red line shows the Amplitude trend with trace offset. (source: HRS tutorial)

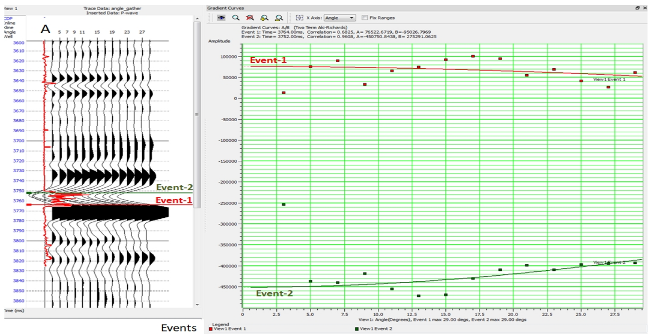


Figure 9: AVO response curve of a seismic event-1 and event-2 at site- A. Variations of reflection coefficient with incident angle for event-1 is exhibiting zero or low saturation gas hydrate whereas event-2 is exhibiting very high gas hydrate saturation.

It can be observed from figure 9, that event-1 has weak AVO response for low gas hydrate saturation and event 2 is clearly exhibiting strong AVO anomaly as it has low reflection coefficient in zero offset and then a steeply increasing reflection coefficient in middle and far offsets.

In practice, it is the sums or differences of these gradients and intercept values that is being used for mapping AVO anomalies.

## Conclusions

The AVO analysis shows results consistent with evidence for free gas underlying a medium with higher P-wave and S-wave velocities such as gas hydrates. Based on study of AVO parameters like intercept/gradient at site - A, it is inferred that highly concentrated gas hydrate bearing sediments above a poorly gas saturated sediments exist in the depth interval of 272 to 291 mts below sea floor.

The study also demonstrates that pre-stack seismic data analysis using AVO method is suitable for gas hydrate characterization in identified bright spot in shallow sediment section. AVO analysis is therefore preferably utilized as proxy to confirm the presence of gas hydrate prior to drilling.

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