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# Free gas/gas hydrate inference in Krishna–Godavari basin using seismic and well log data

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ABSTRACT

Amplitude Variation with Offset (AVO) technique is applied to marine seismic data in Krishna-Godavari (KG) basin to identify the distribution of gas hydrate/free gas below the Bottom Stimulating Reflector (BSR). The seismic data is used in conjunction with the well log data at two different locations on the profile to study the influence of lateral heterogeneity on occurrence of free gas/gas hydrates. AVO cross-plot predicts two different AVO classes at the two log locations. The attributes derived from intercept, gradient, and Poisson's ratio show the spatial distribution of gas-hydrates/free gas in the region.


## 1. Introduction

Gas hydrate forms an ice like crystalline lattice of water molecules with gas molecules trapped inside. Under favorable conditions of pressure and temperature and the availability of methane and water, gas hydrates are formed and remain stable (Sloan and Dekker, 1990). Gas hydrates are commonly identified on seismic section by observing a specific reflection mimicking the seafloor and crosscutting the general stratigraphic trend. This reflection is called as Bottom Simulating Reflection (BSR), and it forms at the base of gas hydrate stability zone. The BSR is caused by the acoustic impedance contrast between the free gas bearing sediments overlying the gas hydrate bearing sediments (Stoll and Bryan, 1979; Hyndman and Spence, 1992) and would cause an increase in the seismic amplitude with an increase in offset if the gas saturation is appreciable. This phenomenon is often termed as AVO.

Presence of gas hydrate/free gas can be very well characterized at isolated bore hole locations and the saturations of gas hydrate and free gas are derived using various rock physics theories. However, it maybe envisaged that the rock properties do not necessarily remain same at locations away from the borehole and therefore, lateral heterogeneity is not reasonably addressed. The only way to look at lateral heterogeneity is to use the 2D/3D seismic data over a distance. In this paper we use the concept of AVO to study and understand the effect of lateral heterogeneity (varying structures) on the occurrence of free gas. The seismic data used here is calibrated using the well log locations that are at a distance of ~9 km apart and the main objective is to qualitatively interpret the changes in gas saturations along the line.

AVO analysis is a powerful geophysical method that aids the direct detection of gas from seismic records. It is widely used in hydrocarbon detection, lithology identification and fluid parameter analysis (in terms of thickness, porosity, density), as the seismic amplitudes at layer boundaries are affected by the variations of physical properties just above and below the boundaries (Tinivella and Accaino, 2000). The pre-stack amplitudes of the seismic data are mostly chosen for the AVO analysis and hence AVO is sometimes called as PSSA (Pre Stack Seismic Amplitude). Though we are using pre-stack amplitudes in our study, we refer to term AVO in subsequent sections for the sake of simplicity. From a given AVO anomaly, the reflection coefficients are calculated by carrying out AVO modeling and Inversion (Zoeppritz, 1919). Subsequently the elastic parameters can be determined from these reflection coefficients. Derived AVO attributes on the other hand, give a clear picture of the presence of free gas in the sediments underlying the BSR (Smith and Gidlow, 1987). In the present work, the AVO attributes have been calculated for identifying BSR/free gas zones and thereby establish a spatial relation between the BSR/free gas

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occurrences at two different locations on a seismic traverse. The primary attributes, i.e., AVO intercept, AVO gradient are cross plotted against each other to identify the gas bearing zones and by noticing a trend that deviates from the background trend. AVO is very sensitive to the rock properties, primarily the Vp/Vs and a change in amplitude is noticed when there is a change in the rock properties. This paper examines the changes in AVO at two different locations and then use them to understand the spatial distribution of free gas along the seismic profile.

The occurrence of gas hydrates in the fractured sediment (Collett et al., 2010) and also in sands (Riedel et al., 2011) of KG basin was established primarily by using the log data at two different sites, NGHP-01-10 and NGHP-01-15, respectively. These two are located at a distance from each other and are not connected by a seismic line, making it difficult to draw an inference about the lateral variation in gas hydrate/free gas occurrences in the region. Also, gas hydrate saturations were estimated at two specific log locations (Riedel and Umashankar, 2012) that are again not connected by a seismic line and thus do not address the aspect of heterogeneity. Regional estimates of gas hydrate saturation have been made in the deeper part of the basin (Satyavani and Sain, 2014), but they suffer from the non-availability of log data on the same seismic line and therefore an extrapolation of gas hydrate saturation vis-a-vis sediment character was not attempted. Analysis of 3D seismic data from the same basin (Shukla et al., 2012) has helped in identification of gas hydrate prone regions but does not focus on the aspect of heterogeneity. The present study makes an attempt in this direction and tries to address the effect of lateral heterogeneity on the occurrence of free gas. This is achieved by considering two different locations on the same seismic line and by making simultaneous use of bore hole and seismic data at each location.

The AVO technique is applied to the seismic and log data in the Krishna-Godavari basin. Two sets of log data (L1 and L2) spaced at a distance of ~9 km on the same survey line are used in this study. The gradient analysis is carried out at these two locations and the class of AVO is then established. As a next step, the derived attributes like product of intercept and gradient, signed product of intercept and gradient, Poisson's ratio are computed using the log and seismic datasets at each location.

### *1.1. Study area*

The study area (Fig. 1) is located in the Krishna–Godavari (KG) basin within the water depth of ~895 m. The KG Basin, situated in a classic passive-margin setting, has a lateral extent of ~500 km, and extends more than 200 km from the coast into the deep sea. This basin is formed by two major rivers of Eastern India, namely Krishna and Godavari that deposit the bulk of detrital sediment. The KG basin has a sediment thickness extending to ~8 km in some of the depocenters (Prabhakar and Zutshi, 1993) and is endowed with petroleum systems. The stratigraphy contains sediments ranging from Cretaceous to Recent times (Mangipudi et al., 2014). The deeper sections of this basin are characterized by thick sediment accumulation with a good potential to generate hydrocarbons (Max, 2000). The characteristic feature of this basin is the shale tectonism, caused by the growth faults that generate anticlinal structures in the shale sequences (Ramana et al., 2009). Due to this deformation tectonics, several bathymetric mounds are formed that are associated with normal faults and toe-thrust faults. These toe-thrusts may serve as preferred pathways for the migration of deeper fluids into the gas hydrate stability zone (Riedel et al., 2008), eventually causing gas hydrate emplacement. Deep mini-basins are formed between the individual thrust faults trapping significant amounts of sediment for potential accumulation of gas hydrates.

### *1.2. Seismic and log data*

The data used in this work is collected by National Geophysical Research Institute (NGRI) in 2010 with the objective of identifying and quantifying the gas hydrate reserves in the region. Multi-Channel seismic data were acquired in the Krishna Godavari basin during April–June 2010 on board M/V "Akademik Fersman". The data used in the study were obtained along the line shown in Fig. 1 with a 1500 in$^3$ tuned air gun source and a 4500 m long streamer with 360 channels. The shot and group interval are both at 12.5 m (near offset of 150 m) and the data were recorded till 8 s with a sampling interval of 2 ms. The seismic data was processed at NGRI and the resulting image (Fig. 2) shows the typical sediment sequence of basin and ridge observed throughout the KG Basin and each ridge appears to be associated with a deep-rooted fault. The basin sequence is well developed on the down thrown side of the fault extending towards south east. The basin is characterized by seafloor-parallel to sub-parallel, sedimentary sequences, whereas the ridge flanks are dominated by layers of large south easterly dips and somewhat brighter reflection amplitude, especially below the BSR that is well developed along this line.

The log data used in this work is obtained from two sites of the NGHP Expedition −01, namely NGHP-01-14 (L1) and NGHP-01-06 (L2). This data was acquired by NGHP with an objective of studying the gas hydrate occurrences and to calibrate the seismic data with wire line logs for time-depth modeling. The first location, L1 is at a distance of ~1.2 km from the seismic line and its projection on the seismic line is approximately around CDP 1900 while second location, L2 lies on the seismic line intersecting at CDP 3350. Water depth at L1 is ~895 m while at L2, it is ~1160 m. The operations at L1 are limited to a total depth of mbsf (meters below the seafloor) and the BSR is found at 109 mbsf. At L2 the operations are limited to 350 mbsf and the BSR is found at a depth of 210 mbsf.

The imprint of the BSR is noticed very clearly at L1 while at L2 it is diffused and does not appear as clear cross cutting event. BSR appears as a distinct reflection almost throughout the section but can be best visualized where it cross cuts the steeply dipping reflector, at L1. The P-wave, S-wave, density and resistivity logs available at L1 (Fig. 3a) are used for carrying out the AVO studies at L1. However, at L2 only P-wave and density logs are available (Fig. 3b) and hence an S-wave log was created using Castagna mud rock relationship.

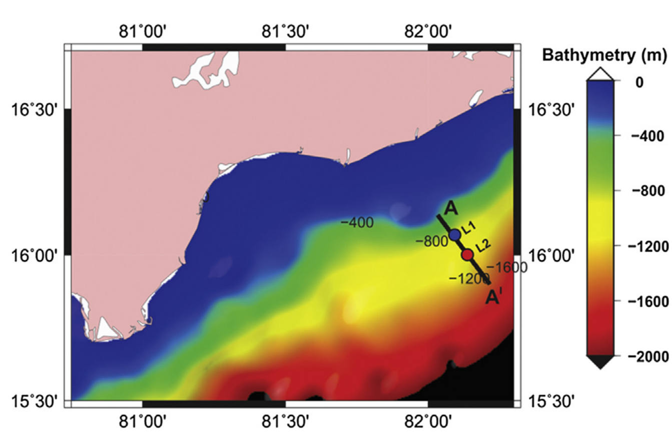


**Fig. 1.** Map of study area in Krishna–Godavari (KG) basin. The black line shows the seismic profile. Blue and Red dots indicate the two well locations namely NGHP-01-14 (L1) and NGHP-01-06 (L2) respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)