Estimation of porosity using post-stack seismic and well log data at site NGHP-01-9A in the Mahanadi offshore basin - a case study.

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Keywords

Gas hydrate, Mahanadi Basin, Impedance inversion, Porosity.

Summary

We perform the post stack acoustic impedance inversion along a 2D seismic line passing through site NGHP-01-9A in the Mahanadi offshore with a view to deriving reservoir properties such as the porosity that can be used for the estimation of gas-hydrates. We have used the density derived porosity ranging from 50% to 75%, in the depth interval of 1935 to 2258 m, as an input for porosity inversion from post-stack seismic data, where BSR (marker for gas-hydrates) are observed. A very good correlation (0.8) between the acoustic impedance and porosity is observed. The lateral extent of porosity along the 2D seismic line varies from 52% to 68% for water bearing silt/clay sediments below the sea floor; 55% to 68% for gas-hydrates zone; and maximum of 70% for gas bearing sediments below the BSR.

Introduction

Gas hydrates, ice-like crystalline substances found along the outer continental margins and permafrost regions, are considered as major future unconventional energy resources of India. The BSR is the main marker for gas-hydrates, and is often associated with the base of gas-hydrate stability zone with free gas underneath (Sain et al., 2011). The well logs are widely used to characterize in situ gas-hydrates. Several inversion techniques are used to extract additional information from seismic data (Veeken and Da Silva, 2004). Post stack model based acoustic impedance inversion constrained with the density and velocity logs is one of the important methodologies generally used for characterization of reservoir properties such as the porosity, permeability, lithology, fluid saturations etc. The study is carried out along a 2D multichannel post-stack seismic data with the density and velocity logs from a well NGHP-01-9A passing through the line (Figure 1) in the Mahanadi (MN) offshore. Being one of the major sedimentary basins in India, the MN basin is characterized by a thick accumulation of about 8 to 10 km sediments (Collett et al., 2008). The basin is also characterized by bathymetry, sediment thickness, rate of sedimentation, TOC content and geothermal gradient ranging from 40-51^{0} C/km (Sain et al., 2011). Studies of geophysical data in this basin have shown BSRs on seismic sections.

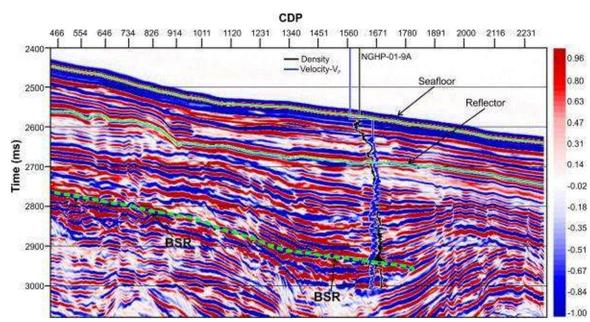

Figure 1: Post stack seismic data superimposed by density and velocity logs at site NGHP-01-9A in the MN basin.

The aim of the present study is to (i) perform the model based inversion along the 2D seismic line to derive acoustic impedance and (b) establish a relation between acoustic impedance and density derived porosity for transformation of seismically-derived acoustic impedance into porosity.

Theory and Methodology

Post stack model based inversion is widely used to predict reservoir properties away from the well control. The acoustic impedance (AI), obtained from post-stack inversion of seismic data, is usually used for the delineation of reservoir properties such as the porosity, etc by establishing a relation between acoustic impedance and porosity. Porosity is derived from the density logs available from the well at site NGHP-01-9A in the MN basin.

Model based acoustic impedance inversion

Petrophysical properties like the porosity of rocks can be predicted from core samples using log data or integration of well log and seismic data such as acoustic impedance (AI) using multivariate statistics modeling or non-linear methods including the neural network (e.g. Hampson et al., 2001; Leiphart and Hart, 2001; Walls et al., 2002; Pramanik et al., 2004; Calderon and Castagna, 2007; Singha and Chatterjee, 2014; Singha et al., 2014). The model-based acoustic impedance inversion involves derivation of acoustic impedance along a seismic line and high frequency information can be obtained from well logs (Lindseth, 1979). The well log data provides in-situ measurement of gas-hydrates using the sonic, density and density derived porosity logs. A suite of well logs (Figure 2) from the site NGHP-01-9A that include the (a) sonic P-wave velocity (b) bulk density (RHOB) and (c) density derived porosity log. The density measurements during the LWD at site NGHP-01-9A well was used to calculate the sediment porosities (φ) with a standard formula that relates density with the porosity as $\varphi = (\rho_g - \rho_b)/(\rho_g - \rho_w)$. The parameters chosen for deriving porosity from bulk density (ρ_b) are constant water density (ρ_w) of 1.03 g/cm^3 and average matrix density (ρ_g) of 2.75 g/cm^3. Higher matrix density may be due to presence of carbonate content that has slightly higher grain density. Therefore, for a particular lithologic unit, matrix density can be higher but as a whole the rock may have low density. This has resulted into higher porosity for the target zone. The estimated porosity along the seismic line is comparable to the density (RHOB) log derived porosity.The model-based inversion along the 2D seismic line is achieved from a low frequency acoustic impedance model by correlating well and seismic data. After detailed analysis of well logs, seismic to well tie is performed using the synthetic trace generated by convolution of extracted wavelet with the derived p-impedance.

Then a low frequency acoustic impedance model is generated by incorporating well logs and the geologically interpreted horizons. The acoustic impedance (Figure 3) is computed from seismic data with the help of model based post-stack inversion (Russell and Hampson, 1991), which can be used as one of the major seismic attributes to estimate spatial distribution of porosity.

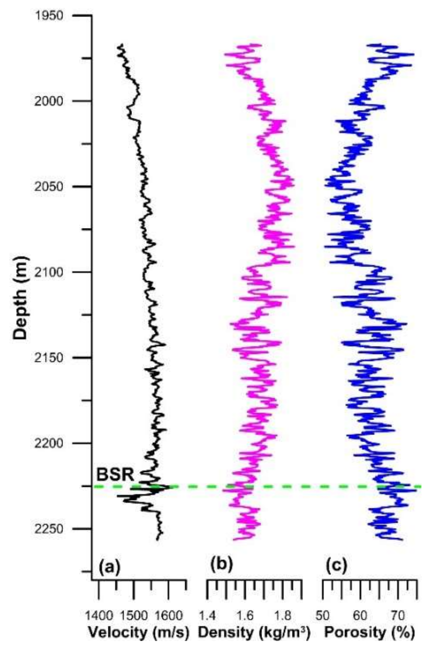

Figure 2: Suite of logs from site NGHP-01-9A, including (a) Sonic P-wave velocity (b) Bulk density (RHOB) (c) Porosity log.

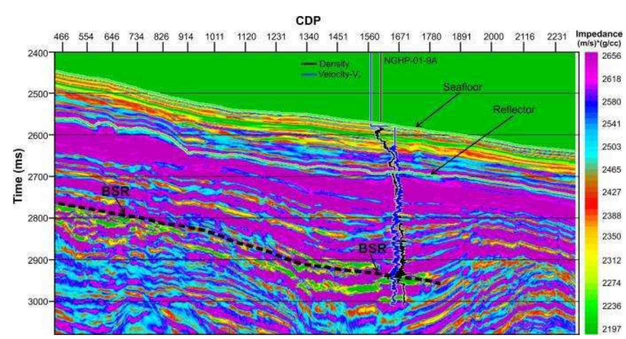

Figure 3: Acoustic impedance (AI) section superimposed by density and velocity logs at site NGHP-01-9A in MN basin.

Porosity evaluation in Mahanadi basin

The seismic velocity and acoustic impedance are sensitive to changes in rock porosity and lithology. Integration of 2D seismic data with the porosity at well can significantly improve the spatial distribution of porosity. However, it is necessary to understand the relation between bulk rock properties and seismic acoustic properties (velocity, acoustic impedance). The presence of gas-hydrates and free gas changes the bulk reservoir properties of marine sediments.

A common way to extract porosity from seismic data is to employ acoustic impedance inversion (Kumar et al., 2016). First, the porosity is derived from density log from the well NGHP-01-9A. This density derived porosity and the acoustic impedance at the well are plotted (Figure 4). The best linear fit with a correlation of 0.87 is established between the acoustic impedance (AI) and the density-derived porosity. The inverted acoustic impedance from seismic data is then transformed into porosity using the established relation as follows

$$\varphi = -0.0003470743156(AI) + 1.5181391$$

where, φ is the density derived porosity and AI is the acoustic impedance (m/s*g/cc).

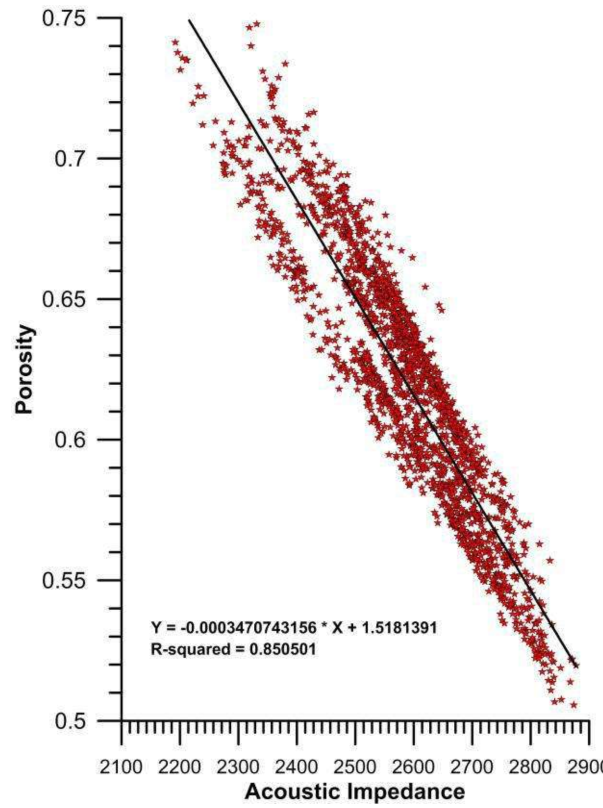

Figure 4: Crossplot between Acoustic impedance (AI) and density derived porosity for well at site NGHP-01-9A in MN basin.

Results and Conclusion

The model-based inversion, which is a robust inversion method that accounts for the well data and seismic interpretation can provide a spatial distribution of reservoir properties such as the acoustic impedance. Since the reservoir properties are altered due to the presence of gas-hydrates and free gas, the acoustic impedance can be used for ascertaining a reflector as a BSR and hence for delineation of gas-hydrates. The well log data displays high velocity above the BSR and low velocity below the BSR without much variation in density and porosity (Figure 2). The post-stack model based inversion has been performed up to the well drilled control region. It shows a good correlation between the measured seismic and synthetic seismic traces. The inverted impedance section shows high impedance above the BSR due to gas hydrates (Figure 3). The enhanced seismic reflections with low impedance values are observed below the BSR due to the presence of free-gas. The BSR mimics the shape of seafloor topography.

The Acoustic impedance (AI) is often used for porosity estimation from post-stack seismic data, this approach of predicting porosity from post-stack seismic has been employed in the MN basin. Excellent linear fit with a correlation of 0.87 is observed between the acoustic impedance (AI) and the porosity from the crossplot (Figure 4). The single linear trend is due to unconsolidated clay/silt sediments present below the seafloor in the MN basin. It can be seen from (Figures 3) and (Figure5) that acoustic impedance and porosity varies from 2550 to 2650 m/s*g/cc and 55 to 68% respectively in gas hydrate bearing zone, whereas lower acoustic impedance of 2350 m/s*g/c and higher porosity of 70% are observed for the free gas zone below the BSR. Since acoustic impedance is a rock property rather than interface property as reflected from seismic data, we can obtain significant information on porosity of the reservoir. This aspect requires a detailed knowledge about the geology of a particular target zone that helps in approximating a linear relationship for each lithological unit by stating a lithology dependent empirical relation between acoustic impedance (AI) and porosity (φ). Thus acoustic impedance, being a product of velocity and density, is directly related to rock properties like porosity, which may be higher due to low density of a rock unit with higher matrix density variation**.**

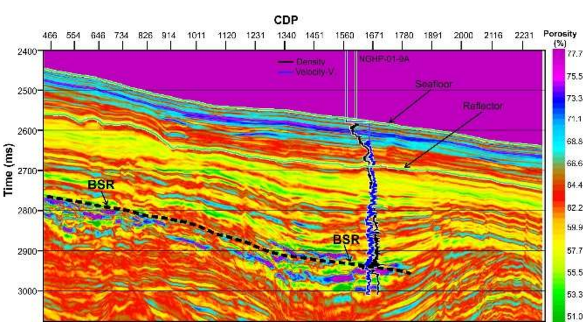

Figure 5: Inverted porosity section for post-stack seismic data of MN basin.

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