Gas Hydrate Characterization from Seismic and Well Log Data: Krishna-Godavari Basin

Anju K. Joshi, Laxmi Pandey, Arun K.P., Kalachand Sain

CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad-500007, India

anju841991@gmail.com

Abstract

The Bottom Simulating Reflector (BSR) is the main marker of gas hydrates in seismic data. In the present study the BSR is identified by analyzing the well log data at site NGHP-01-11A and the lateral extent is delineated in the corresponding 2D seismic data in Krishna-Godavari basin, which passes through the well. As a next step, we estimated the gas hydrate concentration at the well location using three phase weighted equation and compared with the concentration values obtained using Archie's law.

Introduction

Gas hydrates are ice, like solid crystalline substances in which gas molecules (mainly methane) are trapped inside the water molecules by a clathrate structure (Sloan, 1998; Kumar et al, 2009). The formation of gas hydrates depends on the optimum pressure and temperature conditions, supply of free gas and pore fluid chemistry. Gas hydrates are reserves of immense amount of natural gas (Collet, 2002), which can meet the energy requirement of India for future. They are found in ocean floor sediments at a shallow depth and permafrost regions. BSR is the main marker of gas hydrates which shows several characteristics in seismic section, like mimicking the seafloor, cross cutting the sedimentary strata, and reversed polarity with seafloor reflections.

Krishna- Godavari basin is a proven reserve of gas hydrates in which 15 sites are drilled in the expedition NGHP-01 which was conducted in 2006. The present study deals with the delineation of BSR along the 2D seismic data (Figure 1) of K-G basin which passes through site NGHP-01-11A and further estimation of saturation at the site. The presence of gas hydrate in sediments alters the physical and mechanical properties of sediments and the change can be clearly identified from well log data. The gas hydrate stability zone and BSR can be marked laterally along the seismic data using model based acoustic impedance inversion, as impedance is an attribute which alters drastically with the presence of gas hydrates.

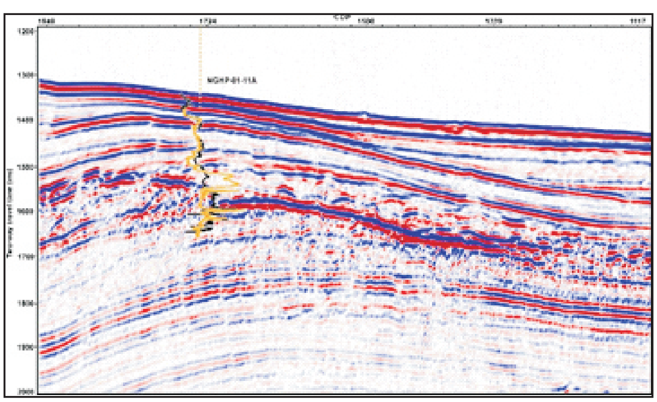

Fig. 1: Post stack 2D seismic data superimposed with sonic (black) and resistivity (orange) logs.

In this paper, the properties like electrical resistivity and P-wave velocity are used to estimate the gas hydrate saturation at the well location. The obtained saturation is then converted into gas hydrate concentration which represents the amount of hydrate as volumetric fraction in sediments. The P-wave velocity of gas hydrate bearing sediments are modeled using three-phase weighted equation and the obtained concentration is compared with the results acquired using electrical resistivity data.

Theory and method

Well log data gives the in situ variations in physical properties throughout the depth of well. The presence of gas hydrates alters the trend of compressional wave velocity and resistivity without much change in density. The P-wave velocity and resistivity increases with the presence of gas hydrates. A thorough analysis of sonic, resistivity and density logs provide information about the gas hydrate stability zone as well as the depth of BSR.

Post stack impedance inversion

The post stack impedance inversion transforms the input seismic data into an inverted acoustic impedance section which provides layer information (Lee et al, 2013). The model based acoustic impedance inversion constrained with well data uses the density log, sonic log and interpreted horizons from seismic data as inputs. The method is based on the convolution of a source wavelet with earth's reflectivity series (Lu and McMechan, 2002). The wavelet is extracted from seismic data using well logs. The P-wave reflectivity series is related to the acoustic impedance derived from density and sonic logs. The seismic to well tie is performed using the synthetic trace generated by convolution of extracted wavelet with the reflectivity series. The initial low frequency model is constructed using well logs and interpreted horizons. The inverted impedance section gives the clear boundary of gas hydrates and free gas, as high impedance above and low impedance below, and thus the BSR can be delineated along the data.

Three-phase weighted equation

Three-phase weighted equation is the weighted mean of the three-phase time average and Wood equation and it is applied to derive the relationship between the compressional wave velocity and amount of hydrates filling the pore space (Lee et al., 1996).

Time average equation: In time average equation (Wyllie et al.,1958), the slowness is taken as the weighted sum of fluid and matrix of rock. The three phase time average equation is given as:

$$\frac{1}{V_p} = \frac{\varphi\,(1-S)}{V_w} + \frac{\varphi S}{V_h} + \frac{1-\varphi}{V_m} \qquad (1)$$

where, V_p is the compressional velocity of hydrated sediment, V_h is the compressional velocity of pure hydrate, V_w is the compressional velocity of the fluid, V_m is the compressional velocity of matrix, φ is the porosity as fraction and S is the hydrate saturation in pore space as fraction.

Wood Equation: *Wood* [1941] equation is approximately valid for particles in suspension and the three phase wood equation for hydrated sediments is defined as:

$$\frac{1}{\rho V_p^2} = \frac{\varphi\,(1-S)}{\rho_w V_w^2} + \frac{\varphi S}{\rho_h V_h^2} + \frac{1-\varphi}{\rho_m V_m^2} \qquad (2)$$

where, ρ is the bulk density of sediments, ρ_w is the density of fluid , ρ_m is the density of matrix, ρ_h is the density of pure hydrate.

Three phase weighted equation: *Lee et al,* 1996 proposed that the interval velocity for hydrated deep marine sediment can be estimated from a weighted mean (Pearson et al., 1983) three phase time average equation and the three phase wood equations, following the approach of *Nobeset al*. [1986]. It is given as:

$$\frac{1}{V_P} = \frac{W\varphi\,(1-S)^n}{V_{p1}} + \frac{1-W\varphi\,(1-S)^n}{V_{p2}} \qquad (3)$$

where, V_{p1} is the P-wave velocity by the wood equation, V_{p2} is the P-wave velocity by the time average equation, W is the weighting factor and n is a constant simulating the rate of lithification with hydrate concentration. The value of W is derived from regression analysis of V_p in hydrate-free sediments. The gas hydrate saturation is estimated for which modeled velocity best matches with measured velocity. The volumetric fraction of gas hydrate in sediments which is called the concentration (Kumar et.al,2009) of gas hydrate S_{hyd} is calculated as:

$$S_{hyd} = \varphi S \qquad (4)$$

Archie's law

The electrical resistivity of water saturated sediments R_0 is expressed using Archie equation (Archie,1942) as

$$R_0 = \frac{aR_w}{\varphi^m} \qquad (5)$$

where, R_w is the resistivity of connate water, a and m are the Archie constants and φ is the porosity. R_w is calculated using the equation of state of seawater (Fofonoff,1985). Using the calculated R_w and measured resistivity from well log R_t, the formation factor (F) is calculated. The Archie coefficients are determined from a cross plot between the formation factor and density porosity (Lee and Collet,2009). The parameter n varies between 1.715 (unconsolidated sediments) and 2.1661 (sandstone) (Pearson et al.,1983). In the present study, we use n=2. Then the gas hydrate saturation is estimated using the formula.

$$S_h = 1 - \left(\frac{aR_w}{\varphi^m R_t}\right)^{\frac{1}{n}} \qquad (6)$$

The gas hydrate concentration is estimated using equation 4.

Results and Discussion

The gas hydrate bearing sediments shows a high in compressional wave velocity and resistivity without much change in density. The porosity is decreasing at this region which can be inferred as the presence of gas hydrates. By thorough analysis of well log, the depth of BSR is fixed at 150 meters and gas hydrate stability zone is inferred at a range of 113m to 150m. Figure 2 shows the level of BSR marked from well logs.

The model based acoustic impedance inversion yields an inverted impedance volume from which the lateral extent of BSR is delineated as a boundary with high impedance above and low impedance below.Figure 3 shows that the level of BSR identified from the inverted section is clearly agreeing with well logs.

Gas hydrate concentration from velocity

As BSR is confirmed along the seismic section, the three-phase weighted equation is used to model the compressional velocity at the well site NGHP-01-11A for the estimation of gas hydrate saturation. The weighting factor W is determined by the regression analysis of compressional velocity of hydrate free sediments and is fixed at W=1.5. The figure 4 gives the similarity between computed P-wave

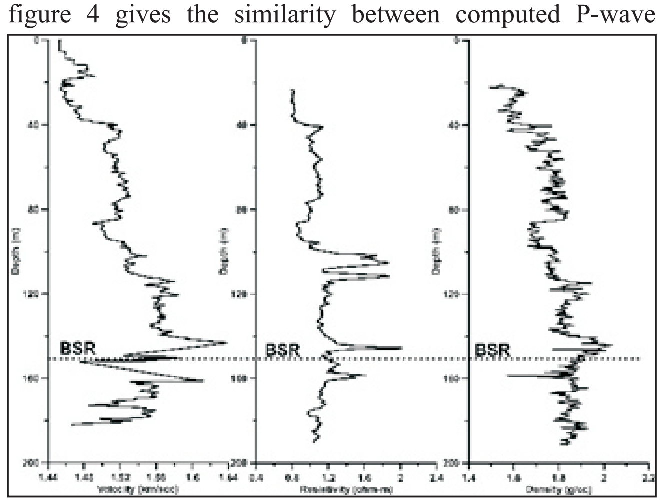

Fig. 2: Well log data at NGHP-01-11A

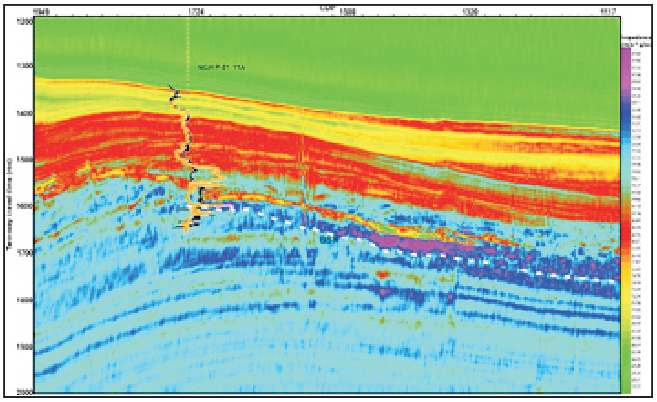

Fig. 3: Inverted acoustic impedance section superimposed with velocity (black) and resistivity (orange) logs.

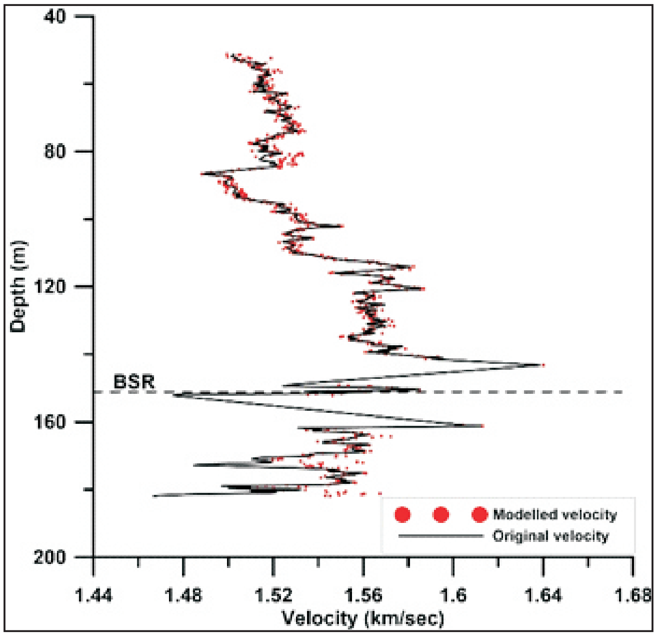

Fig. 4: Modeled and measured velocities of NGHP-01-11A using three phase weighted equation.

velocity and measured P-wave velocity for NGHP-01-11A. The saturation is estimated within the minimum error between modeled and measured velocity. The obtained saturation is converted into gas hydrate concentration in sediment and is found to have a maximum of ~5% at 137m.

Gas hydrate concentration from resistivity

The gas hydrate saturation is estimated using the relation between resistivity of gas hydrate bearing sediments and water saturated sediments. The high resolution LWD resistivity log data is used for the study. The formation factor (F) is calculated using the formula,

$$F = \frac{R_t}{R_w} \tag{7}$$

The value of Archie parameters, tortuosity factor a =1.3952 and cementation factor m=1.68 is determined from a cross plot between formation factor and density porosity of water saturated sediments. The figure 5 shows the difference between water saturated resistivity R_0 and measured in situ resistivity R_t and we can see that the R_0 is close enough with the R_t for water saturated sediments.

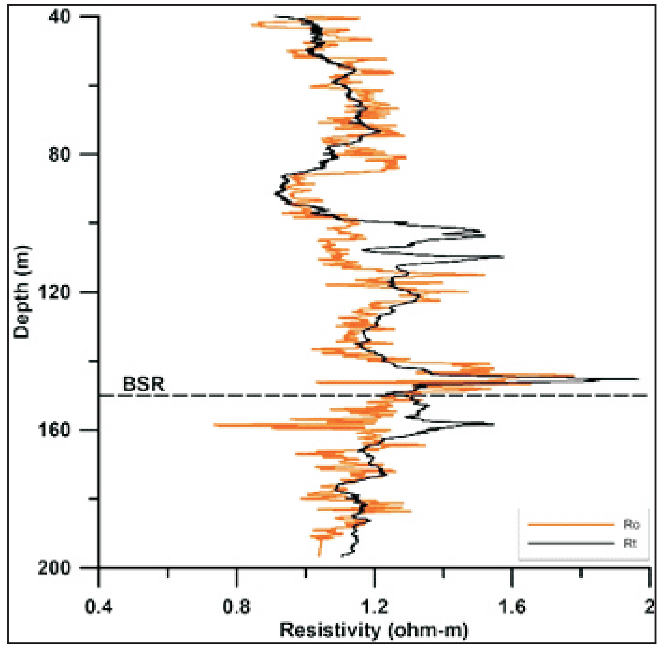

Fig. 5: Measured LWD resistivity and calculated water saturated resistivity determined from Archie's analysis.

On analysis of resistivity log, an anomalous increase in resistivity is found out at a depth range of 95m to 115 m without any significant increase in velocity. Hence the concentration values obtained from resistivity log at this depth range cannot be attributed to that of gas hydrates. So in the present study, the maximum concentration obtained from resistivity method is ~12% at depth 146m.

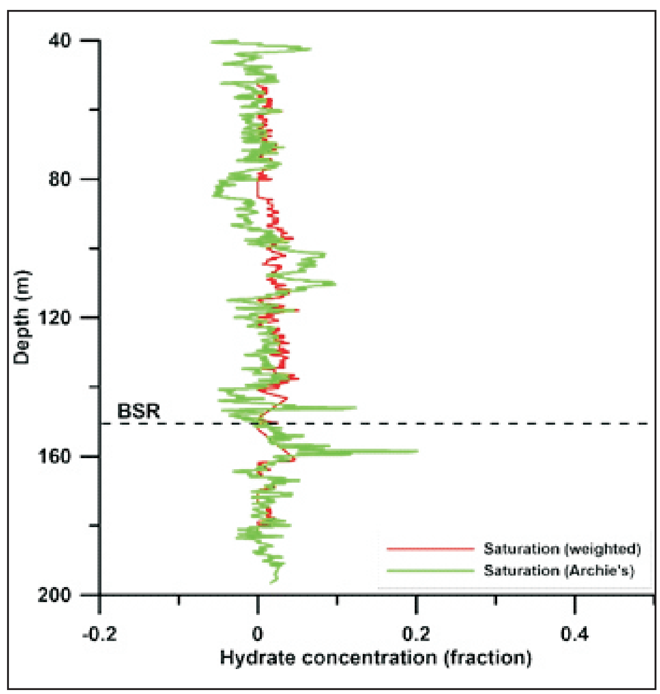

Fig. 6: Concentration of gas hydrate estimated from velocity log (red) and resistivity log (green) at site NGHP-01-11A.

The gas hydrate concentrations estimated using above two methods are given in figure 6.

At a depth range of 144m-147m, the velocity values are not available in the LWD log data and hence cannot validate the amount of gas hydrate obtained at this location. The concentration of gas hydrate estimated from both velocity log and electrical resistivity log are close enough at the range of 113 m to 150m. However, the results from velocity modeling show comparatively lower S_{hyd} values. Since, pressure core data is not available at this site, further validation is not possible. Taking account to all the above discussions, the overall maximum gas hydrate concentration of site NGHP-01-11A is found out within a range of 5% to 12%.

Conclusions

We have used the well log data at site NGHP-01-11A for the identification of BSR level at log location. Model based acoustic impedance inversion constrained with well data is performed to delineate the lateral extent of BSR along the 2D data in KG basin. The BSR is marked as a clear boundary between a high impedance above and low impedance below and is confirmed by superposing the well logs on the impedance section. The gas hydrate concentration is estimated both from LWD P wave-velocity log using three phase weighted equation and LWD resistivity log using Archie's equation. The maximum amount of gas hydrate obtained was ~5% to 12% in the sediment.

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