Gas Hydrates saturation estimation using geophysical methods - An application to Krishna-Godavari basin, India

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ABSTRACT

Gas hydrates are an unconventional energy resource. They may become an important possible source of energy for India and some other countries in the future energy scenario. Although a technology for economic production of gas hydrates does not currently exist, much effort is being made to explore and quantify gas hydrate saturation. The goal of this work is to present a new technique to estimate the quantity and location of gas hydrates. The region of study for the project is the Krishna-Godavari basin located on the eastern offshore of India. A 2D seismic line and well data were used for the study. The method to estimate gas hydrates saturation uses a combination of seismic inversion and seismic attributes. This includes stacked and migrated data along with well logs to perform poststack seismic inversion to obtain impedance volumes. These volumes were combined with multi-attribute analysis using a neural network method to predict anisotropic resistivity and porosity logs at the well location. Transform equations relating the seismic attributes to the well measurements predicted the petrophysical properties throughout the desired zone of interest. By using neural networks for multi-attribute analysis a statistical method for the prediction gas hydrates saturation along the complete seismic profile was obtained. The results suggest gas hydrates saturation in the range of 50–80% in the region. The estimated saturation of gas hydrates matches up very closely with the saturation readings obtained from the cores recovered during coring. Hence, the method provides a very accurate method of quantification of gas hydrates by making use of seismic and well log data.

INTRODUCTION

Gas hydrates or clathrates are naturally occurring chemical substances that form by the inclusion of different molecules in the molecular structure of another molecule (Giavarini and Keith, 2011). In case of methane hydrates, methane gas molecule is trapped within a cage like structure made of water molecules, which are bonded together by hydrogen bonds. Three necessary conditions for the formation of gas hydrates (Giavarini and Keith (2011) are: 1) presence of sufficient water, 2) the presence of guest molecules such as methane, ethane, carbon dioxide, etc., 3) a thermodynamically stable range of pressure and temperature conditions for the occurrence of has hydrates, which are typically high pressure and low temperature values. The depth range over which gas-hydrates is stable is known as the gas-hydrates stability zone (GHSZ). These conditions are typically found in permafrost and marine environments (Riedel et al., 2010). Ocean drilling projects carried out by the national gas hydrates exploration programs in India (Collett et al., 2008) have shown the presence of gas hydrates in continental slopes along the eastern margin of India and in the Andaman Islands.

Geophysical methods have become an important tool for exploration of gas hydrates. Some of the reasons that justify the importance of using geophysical exploration methods are (Riedel et al., 2010): indirect assessment of the resource potential of gas hydrates (concentration of gas hydrates), mapping the geographical extent of gas hydrates reserves in a region (depth and area), understanding the physical conditions required for gas hydrates formation (depth and temperature), and investigation of the reservoir character (lithology, porosity etc.). Gas hydrates have anomalous physical properties, which make them readily detectable using surface geophysical techniques. The P-wave velocity and density of pure synthetic methane hydrates from laboratory experiments are respectively 3300 m/s and 0.90 g/cc (Waite et al., 2000). Formation of gas hydrates replaces water from the pore space of sediments with solid gas hydrates, which causes reduction in porosity and a significant increase in the elastic moduli of the bulk host rock. This causes an increase of the compressional and shear seismic wave velocities (Yuan et al., 1996). An alternate explanation that has been proposed for the mechanism explains the increase in velocities of sediments with gas hydrates is when gas hydrates act as cementing material for the grains of the rock, thus becoming a part of the load bearing frame of the rock leading to an increase in bulk and shear moduli of the rock (for example, Helgerud et al., 1999; and Chand et al., 2006).

Surface seismic and bore-hole well log based observations are commonly used geophysical methods for the identification of gas hydrates. One of the most prominent markers in surface seismic observations for gas hydrates in marine sediments is the bottom simulating reflector (BSR) on the seismic reflection section (Figure 2). It is a physical boundary across which there is a major change in the physical properties and hence the seismic propagation velocity of the pore filling fluids (gas hydrates and gas). The BSR can be identified as the reflection event which cuts across the geological reflectors on the section. The BSR has the unusual characteristic of mimicking the bathymetry of seafloor. The BSR also has a polarity opposite to that of the seafloor reflection.

Well log data are also useful in demarcating gas hydrate zones. Figure 3 shows some of logging while drilling (LWD) well logs recorded in the region of present study. Borehole data from LWD technology uses sensors placed on the drill bit to collect data at regular intervals from a borehole during the drilling operation (Evans, 1991). They provide in situ measurements of physical properties of the sediments containing gas hydrates. Some of the LWD logs used commonly for identification of gas hydrates are the porosity, resistivity and sonic velocity (Riedel et al., 2010). Commonly used well log properties as indicators for presence of gas hydrates are augmented electrical resistivity and high P-wave velocity (Mathews, 1986; Collett, 1993; Goldberg, 1997). Since gas hydrates are highly resistive to the flow of electrical current (Makogon, 1997), their presence is conspicuous in the resistivity logs. A comparison of resistivity well logs in the Figure 3 shows clear deflection in the electrical resistivity in the gas hydrates stability zone (GHSZ). The region with gas hydrates has electrical resistivity of at least two orders greater than overlying and underlying sediments. Gas hydrates have considerably higher bulk and shear moduli than water (Helgerud et al., 2009), hence their presence increases the P- and S-wave velocities of the sediments in which they are formed. An example of this is depicted in Figure 3 where a major change in the P-wave velocity obtained from the sonic log can be observed.

Gas hydrates with their worldwide presence, are increasingly gaining importance as a future energy resource (Kvenvolden, 1993).The determination of the quantity of gas hydrates is an important step in the process of the exploration of gas hydrates since it would help in understanding of gas hydrates energy supply potential.. Accurate methods of quantification of gas hydrates in this scenario become important as the present estimates of total in place methane resources from laboratory and field studies have great uncertainties (Milkov, 2004). Different methods have been used to estimate gas hydrates saturation. Some of these methods are based on estimating gas hydrates saturation from seismic velocities, described, in detail, in a review paper by Sain et al. (2008; 2012). Some of the examples of this type of approach are found in Wood et al.,(1994), Yuan et al., (1996), Lee et al., (1993,1996). The drawback of these methods is that the relationship used to relate the gas hydrates saturation to velocity does not have a physical basis (Ecker et al., 2000). Some other approaches use rock physics models to predict saturation, for example. Ecker et al., (2000). Rock physics models do not always correctly estimate the gas hydrates saturation since the effect of gas hydrates on elastic properties of the host rocks is not well understood (Lu, McMechan,2002).Well logs have been used for quantification of gas hydrates by Collet (2000), Lee and Collett (2009), Lee and Waite (2008). Some of the drawbacks of the aforementioned methods are: well log based for quantification of gas hydrates are limited to the estimation of gas hydrates saturation at the well location, they do not consider anisotropy as a factor affecting the saturation estimation. The current study in gas hydrate quantification is an attempt to address these issues.

In the present study, a novel method using both surface seismic and well log data has been used to estimate gas hydrates saturation. The salient features of the present study include the use of statistical methods for saturation estimation and also the inclusion of anisotropic behavior of electrical resistivity in Archie's law (Archie, 1942) to predict gas hydrates saturation. The present method uses P-impedance and S-impedance obtained from inversion of surface seismic data and the subsequent use of them in a multi-attribute analysis to predict equivalent log properties at all trace locations on the seismic profile. The idea is based on finding a statistical relationship between the multiple attributes obtained from the surface seismic data and the desired property derived from log data at the well location using neural network. The transform equations are then applied to predict the log property at all trace locations on the seismic profile. The log properties that are predicted along the seismic profile are resistivity and porosity. To include anisotropy as a factor affecting gas hydrates saturation, the work done by Lee and Collett (2009) on estimation of gas hydrates saturation at the well location using an anisotropic Archie's law (Archie, 1942) is extended to the estimation of gas hydrates saturation along the whole seismic section.

REGION OF STUDY

The region of study for present study is the Krishna-Godavari basin located in the eastern margin of India (Figure 1). The Krishna-Godavari (KG) basin is a passive rift margin on the eastern coast of India. It developed as a result of the rifting and drifting of the Indian plate from the Antarctica-Australian plate during the late Jurassic and Early Cretaceous. (Shastri et al., 1981). It covers an area of 24,000 km^2 on the onshore and 145,000 km^2 in the offshore region. The NE-SW trending horsts and graben fault systems from the late Jurassic rift cut across the older NW-SE trending Permian-Triassic Gondwana grabens which include the Mahanadi and Pranhita-Godavari grabens (Shastri et al., 1981). Mahanadi and Godavari rivers transport huge amount of sediments in the Bay of Bengal, resulting in one of world's largest accumulation of sediments.

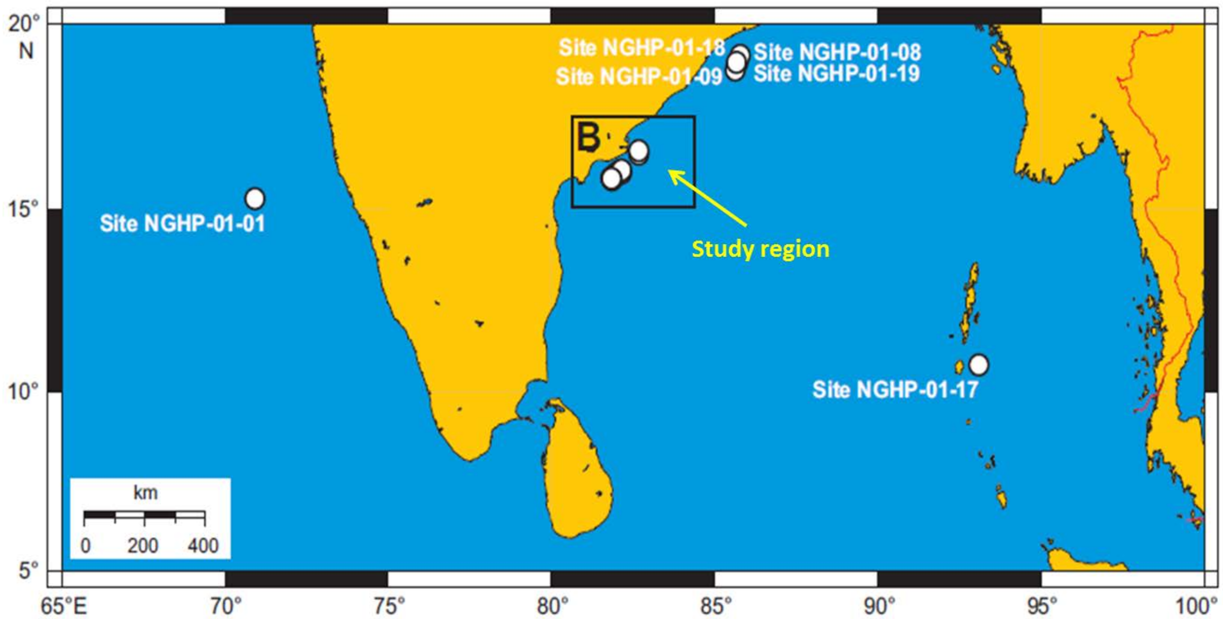

Figure 1. Map showing the region of study in the Krishna-Godavari basin in the Eastern offshore, India. The white dots are the drilling locations during the NGHP Expedition 01. The arrow marked black box denotes the study region. (Collett et al., 2008)

DATA

Both surface seismic reflection and well log data were used in the present study. The surface seismic data used here is a high resolution NW-SE 2D seismic line in the Krishna- Godavari basin (Figure 2). The data were provided by the gas-hydrate group at National Geophysical Research Institute (NGRI). The 2D seismic line consists of 1200 common depth points (CDP) with a CDP spacing of 12.5 m. The data has a sampling interval of 2ms. BSR can be identified with its characteristic bright amplitude and a polarity opposite to that of the seafloor, cutting across the dipping reflectors in the NE section of the profile. BSR is not clear in the mid-section of the seismic profile but a careful viewing of the data reveals faint signature of the BSR in the SW section of the seismic line.

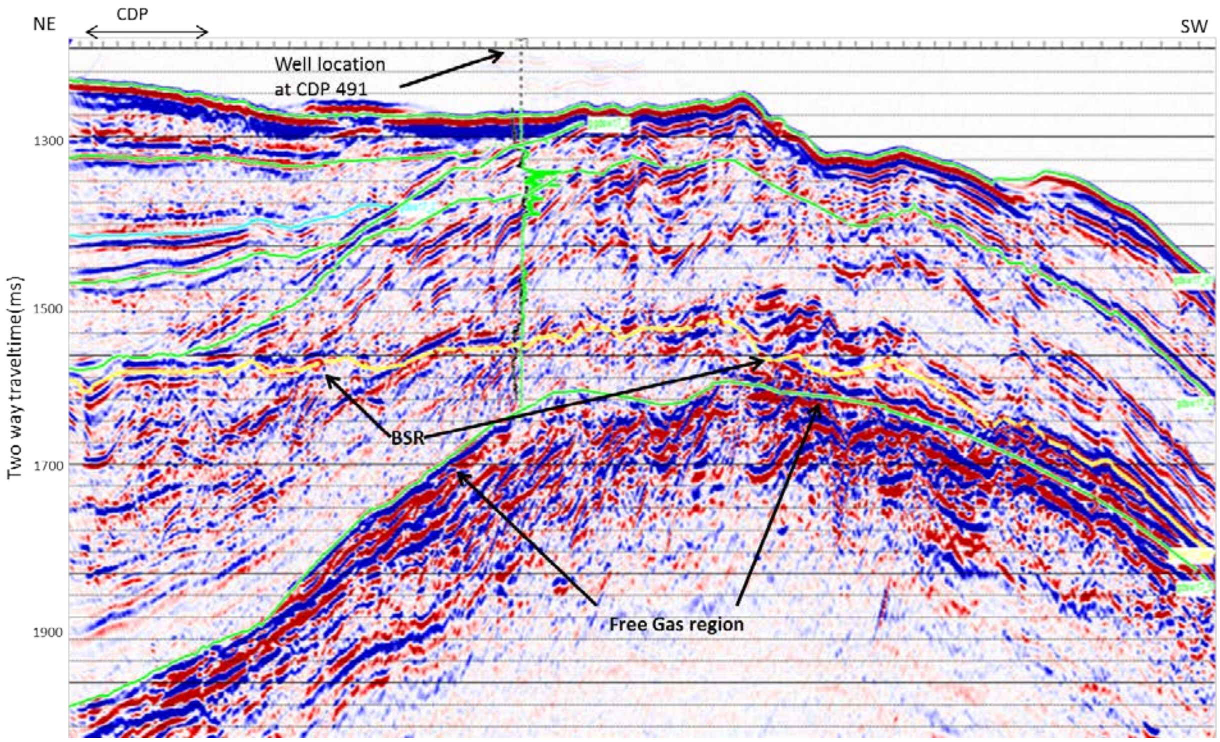

Figure 2. Processed 2D seismic section of the study region (Krishna-Godavari basin) with well location on the seismic section. The section also shows the interpreted Bottom simulating reflector (BSR) as the yellow horizon, the top of the free gas (green horizon). The well although not located exactly on the seismic profile, has its location closest to CDP 491 on the seismic profile.

The logs used for the present study are from a well drilled during the NHGP Expedition 01 (Figure 3). It is not exactly situated along the seismic line used for the present study. It has its nearest location to CDP 491 on the 2D seismic line (Figure 4). Logging while drilling (LWD) was done starting from a depth of 1049m logged upto a total depth of 1054.5m. Although many log measurements were taken during well logging, only sonic, resistivity (deep), neutron porosity, and density logs for the purpose of present study.

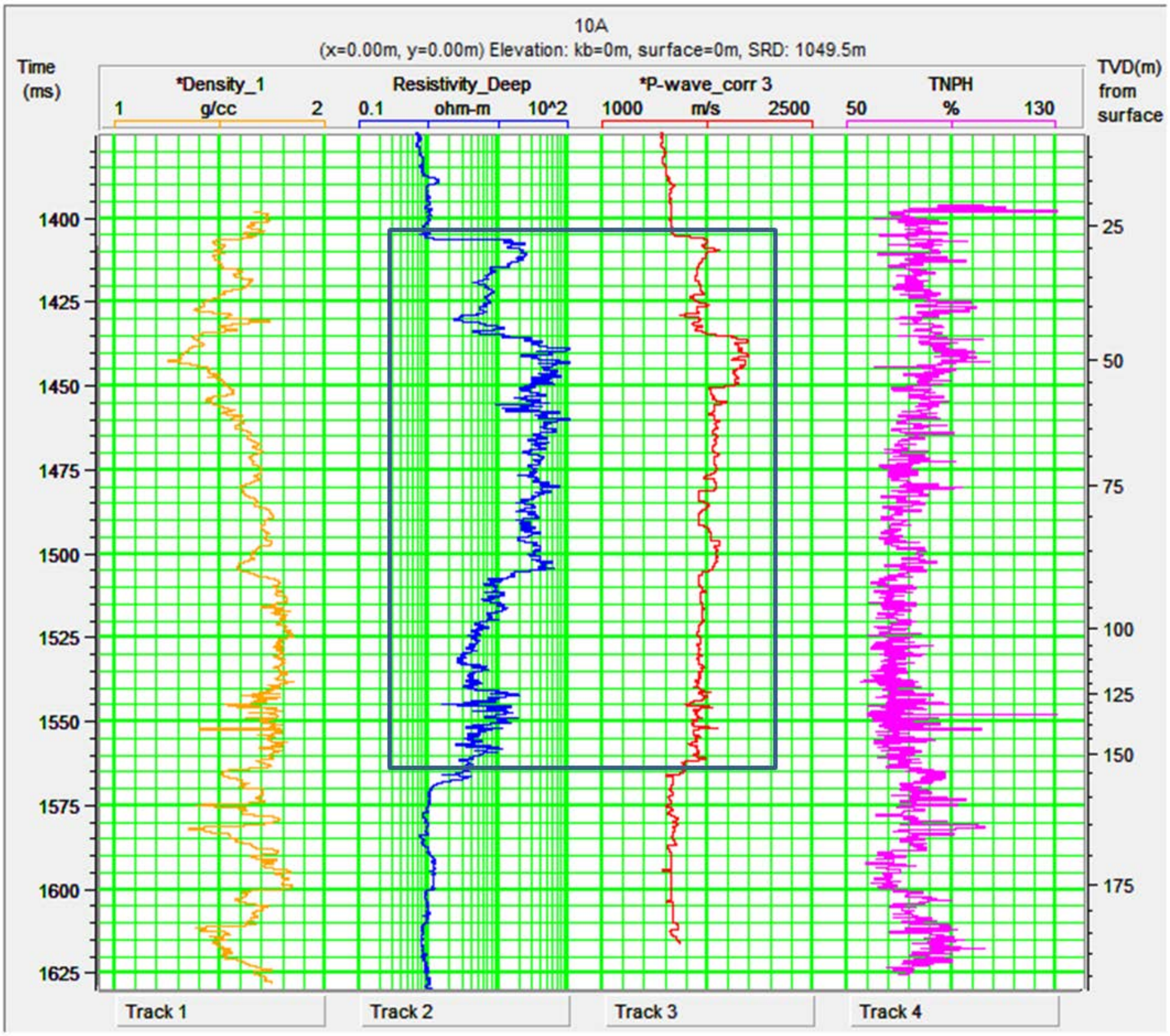

Figure 3. Borehole well logs displayed in two way traveltime from the sea floor. The Gas hydrates stability zone (GHSZ) is emphasized in a box. Major change in resistivity is observed at around 1405 ms which is the top of gas hydrate bearing sediments and 1570 ms which is the base of the GHSZ. In the same zone considerable change in P-wave velocity is also observed (Collett et al., 2008). Density and neutron porosity do not show any significant change but are displayed here as they are used in the study.

THEORY AND METHOD

The methodology can be broadly divided into three main steps: 1) Impedance inversion to obtain seismic impedance attributes 2) Using the impedance attributes for well log prediction 3) Using the predicted pseudo well logs to estimate gas hydrates saturation along the seismic profile.

Impedance inversion

Impedance inversion is the process of obtaining P-impedance from seismic data (Lindseth, 1979; Oldenburg et al, 1983). Both poststack impedance inversion and pre-stack impedance inversion is carried out. The purpose of carrying out inversion using these two methods is to compare the results obtained using each of these methods.

Poststack impedance inversion

The goal of poststack impedance inversion is to invert poststack seismic data to obtain P-impedance. Poststack seismic data is an approximation of the response of the layered earth to a perpendicularly incident plane wave (Sen, 2006). Since the formulation of the poststack inversion problem is based on the premise that incident wave is perpendicular to the reflector (Sen, 2006), this assumption is realized through the stacking of normal moveout (NMO) corrected, common depth point (CDP) gathers (Figure 2). The processing steps used to remove noise from the data and obtain a migrated stacked seismic section are as follows:

1. Filtering of bad traces to prevent instability in inversion,
2. Application of trapezoidal bandpass to filter out noise,
3. Velocity analysis,
4. NMO correction,
5. CDP stacking, and
6. Poststack time migration (Kirchoff migration).

The processing of seismic data is done on a workstation using Paradigm Focus®, industrial seismic data processing software. As a result of the above processing steps the seismic data can be treated as a series of reflectors in their true physical locations with the seismic waves perpendicularly incident and reflected back from them. Once this has been achieved the resultant data is ready to be used for impedance inversion.

Impedance inversion using poststack seismic data has been extensively used in geophysics (for example, (Lindseth, 1979; Oldenburg et al, 1983). It is a favored method of inversion because of its simple assumptions and robustness (Russell and Hampson, 1991). Poststack inversion tackles three types of problems (Sen, 2006) Wavelet estimation when reflection coefficient, 2) Reflection coefficient or impedance inversion given the seismic wavelet is known, 3) Inverting simultaneously for impedance and wavelet. Poststack inversion methods are classifiable in three broad categories robustness (Russell and Hampson, 1991): 1) The recursive inversion method, in which if the impedance of one layer is known, for example the seafloor in case of marine seismic data, then the impedance of other layers can be solved recursively (for example, Cooke and Schneider, 1983), 2) Sparse spike inversion is an inversion method in which a sparse set of reflection coefficients determined from seismic data is constrained with a model based on geological constraints (for example, Torres-Verdín et al., 1999). 3) Model based method, which are based on perturbing an initial model based on geological constraints, until the synthetic matches the observed seismic data within the acceptable error tolerance. In the present studies, STRATA® module available in Hampson-Russell®, industrial inversion software has been used for the inversion of seismic data. It involves inversion for impedance given that the seismic wavelet is known. It is a model based method of poststack inversion.

Model based methods of inversion are preferred because they overcome the challenges of removing the source wavelet completely, removal of all noise, accounting for spherical divergence and transmission losses and inclusion out of plane reflections, which are encountered in other inversion methods (Sen, 2006, p. 74). A basic flow of model based inversion is shown in Figure 4. The model based poststack inversion of Hampson-Russell® can be put down in the following steps:

1. Extraction of wavelet,
2. Identification of main reflectors from seismic data,
3. Tying well log to seismic data,
4. Building initial model,
5. Inversion analysis at well location, and
6. Model based inversion for the complete poststack seismic section.

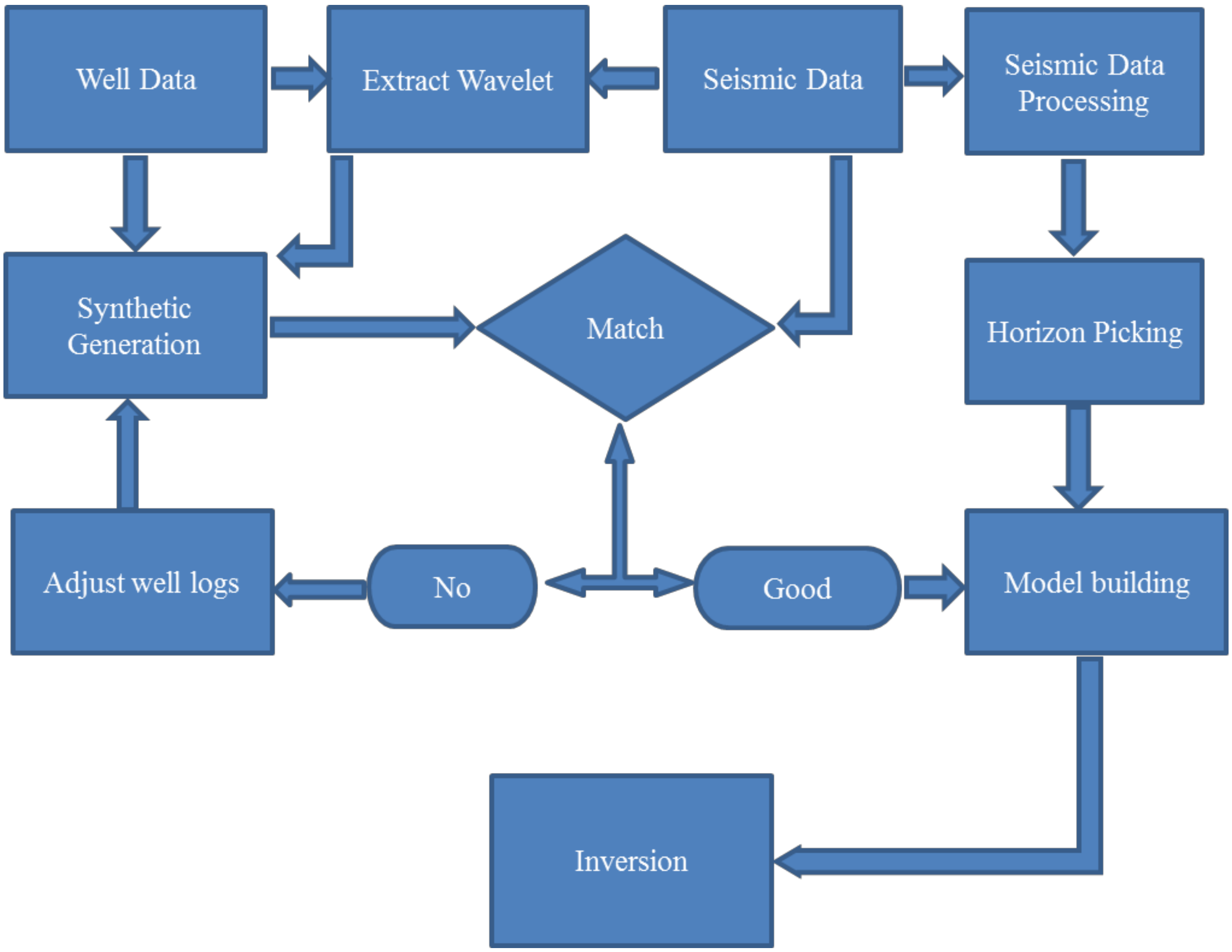

Figure 4. Flowchart of model based post-stack impedance inversion (adapted from Sen, 2006)

Prestack impedance inversion

Prestack inversion is the method of impedance inversion, which uses reflection amplitude, traveltime and waveform information of the prestack seismic data to invert for multiple inversion attributes such as acoustic impedance and Poisson's ratio (Sen, 2006, p.85). Prestack inversion has been used to invert for P and S-impedances (Goodway et al., 1997). It is also an important tool for lithology and fluid discrimination (Goodway et al., 1997; Burianyk, 2000). Several approaches have been adopted for prestack inversion. Generalized linear inversion (GLI) is one class of such methods for prestack inversion(Tarantola, 1986; Pan et al., 1994). Global optimization based methods such as simulated annealing (SA) and genetic algorithm (GA) are another class of prestack seismic inversion that have also been used to obtain multiple impedance attributes from seismic data (Sen and Stoffa, 1991; Mallick, 1995). For the purpose of the present study, Hampson-Russell®, industrial inversion software is used for carrying out prestack inversion. This process of inversion is based on the simultaneous inversion of pre-stack seismic data suggested by Hampson and Russell (2005). The inversion process is called so since P-impedance (Z_p) and S-impedance (Z_s) are inverted for simultaneously along with density (ρ) (Hampson and Russell, 2005).

Well log prediction

The present methodology of gas saturation estimation requires resistivity and porosity values at all trace locations. In the method presented here pseudo resistivity and porosity logs are predicted at all trace locations using seismic attributes. Seismic attributes have been used to predict well logs (for example, Schultz et al., 1994; Hampson et al., 2001). These methods are based on finding empirical relationships between porosity and impedance obtained from inversion. These methods have the drawback of being deterministic, as the relationship between the reservoir property and seismic data may not always be deterministic (Todorov et. al., 1998). Since such methods do not have the ability to consider the non-linearity in the relationship to predict reservoir properties, statistical methods are more useful in predicting the non-linear behavior of a reservoir property as a function of seismic attributes (Hampson et. al., 2001). There are numerous examples of prediction of reservoir properties using geostatistical methods, such as multi-attribute analysis and neural networks (for example, Russell et al., 1997; Schuelke and Quirein, 1998; Hart and Balch, 2000). Although these methods have been questioned about their validity, since they do not have a geological basis of reservoir property prediction, some applications on these methods (Ronen et al., 1994; Hirsche et al., 1997) have proven that geostatistical methods are indeed useful in reservoir property prediction. Geostatistical methods have the advantage of not only presenting a framework to link petrophysical and the more error prone seismic data but also being able to characterize the uncertainty in the predicted reservoir property (Hirsche et al. 1997).

Hampson et. al., (2001) have suggested using multi-attribute analysis to predict well logs away from the well. Multi-attribute analysis as the name suggests, uses multiple seismic attributes from the seismic data. The purpose of this method is to find a suitable relationship that connects the input (seismic attributes) and the output (well log to be predicted at the well location). This relationship is found out by using statistical methods. The statistical relationship between the input and the desired output can be linear or non-linear. Some of the examples of using linear statistical relationship for prediction of reservoir property are Gastaldi et al., (1997); Russell et al., (1997); Hampson et al., (2001). A linear relationship between the log properties and seismic attributes means that when the log property is cross plotted against the seismic attribute, a linear equation is solved to obtain the coefficients of the linear regression fit. The coefficients of a linear relationship can be obtained using the method of least-squares. This idea of linear regression can be extended to include multiple seismic attributes and the coefficients of the transform equation can be obtained by solving for the least squares problem of fitting the desired log property as a function of the input seismic attributes.

However multi-attribute analysis considers only linear behavior between the seismic attributes and the well log properties. To include non-linearity in the transform relationship between seismic attributes and well log properties, Hampson et al., (2001) suggest the use of neural networks. Artificial neural networks have been used for log property prediction (for example, Himmer and Link, 1997; McCormack, 1991; Schultz et al., 1994). There are two approaches for using neural networks to predict well logs. The first one is called the multilayer feed-forward neural network (MLFN) the description of which can be found in many textbooks (for example, Masters, 1994). MLFN has been used for well log prediction by Liu and Liu (1998). The network consists of three layers, the input layer comprised of all the seismic attributes connected to a layer of weights through as many nodes as attributes and a third layer, the output layer which has a single node representing the log being predicted and a hidden layer which lies in between the input and the output layer. The number of nodes for the hidden layer is decided by experimentation. The process of finding the optimum weights between different nodes is called training of the neural network (Hampson et al., 2001). The weights are estimated using a non-linear optimization technique. A second type of neural network is called probabilistic neural network (PNN) (Masters, 1994). It is based on mathematical interpolation techniques using neural networks to predict well logs. It is an easier method to understand than the MLFN whose nodes' weighing method is like a black box (Hampson et. al., 2001). In the present studies EMERGE® the log prediction module in Hampson-Russell®, is used for statistical prediction of well logs**.** It is based on the PNN approach of neural networks.

Gas hydrates saturation estimation

Using multi-attribute analyses and neural networks, pseudo resistivity and porosity logs are obtained at each trace location along the complete seismic profile. The method to estimate gas hydrates saturation is based on Archie's law (Archie, 1942), which connects water saturation to resistivity and porosity as

$$S_w = \left(\frac{aR_w}{\Phi^m R_t}\right)^{1/n} \tag{1}$$

where R_w is resistivity of water, R_t is the true formation resistivity which is the deep resistivity log data where invasion of drilling fluids is minimum, *a* and *m* are called Archie's parameters,*m* is also known as cementation factor, *n* is the saturation exponent. The value of *m* varies between 1.3 to 2 for sandstones (Archie, 1942) and that of n varies between 1.715 and 2.1661 (Pearson et al., 1983). The values of the Archie's constants calculated in these works have been done assuming an isotropic medium (Lee and Collet, 2009). These values may not be appropriate for a medium containing gas hydrates. In the presence of gas hydrates the pore shape and pore space is changed. It has been shown in Collett et al., (2008) that there are fractures present in the Krishna-Godavari basin based on the X-ray images of the cores. Considering that the presence of factures may introduce anisotropy in rocks, Lee and Collett (2009) suggested the following values for anisotropic medium as $m=2$ and $n=3$ be used in Archie's relation. R_w is calculated using Arp's formula (Arp, 1953),

$$R_{w2} = R_{w1}(T_1 + 7)/(T_2 + 7) \tag{2}$$

where R_{w2}, R_{w1} are water resistivity at temperatures T_2 and T_1 respectively. In the present studies the reference resistivity R_{w1} and the temperature T_1 are the values at the sea floor. The gas hydrates saturation based on resistivity was given by Lee and Collett, (2009) as

$$S_h = 1 - S_w \tag{3}$$

where S_w is defined in Equation 1.

RESULTS

Figure 5a shows the P-impedance obtained from poststack seismic inversion. The impedance ranges from 2200 g.m/s.cc to 3200 g.m/s.cc. Observe that the cooler colors are the regions of high impedance, which is as expected, since the presence of gas hydrates increases the P-impedance of the host rocks. The impedance values right beneath the gas hydrates zone shows low impedance, as expected from the impedance of free gas zone. Impedance inversion is done only up to the top of the gas layer since the well logs do not extend beyond that depth. Hence the impedance values of inverted section of two way traveltime greater than the two way traveltime of the well bottom are not taken into consideration.

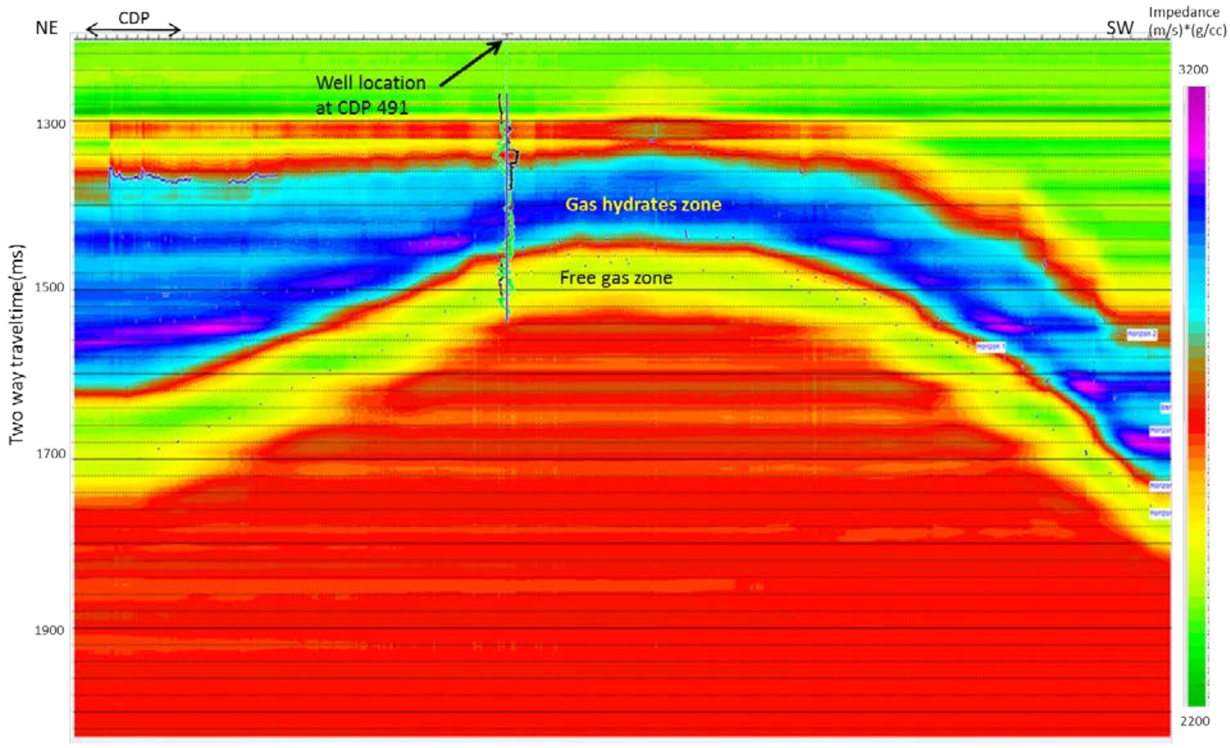

Figure 5. a) Inverted P-impedance of the whole seismic section obtained after 50 iterations. The colorbar indicating the impedance values ranging from 2200 to 3200 g/cc*m/s is shown to the right of the image. The lower of end of the colorbar (green) indicates low impedance and the upper end (purple) indicated high impedance. The resistivity log (black) and the density log (black) are also shown. The blue zone represents the gas hydrates stability zone, a region of high resistivity.

Figure 5b is the P-impedance obtained from prestack impedance inversion. Comparing with the poststack inversion results it is observed that there is a significant improvement in the resolvability of the geologic features in the prestack impedance inversion results. The inverted P-impedance values have a range of 2046 (m/s)*(g/cc) to 3082 (m/s)*(g/cc). The high P-impedance zone is the gas hydrates region. The low P- impedance zone may correspond to free gas, which is generally expected from marine gas hydrate regions. Again, the results are realistic only upto the two-way traveltime of the logged depth which is around 1500 milliseconds at CDP 491.

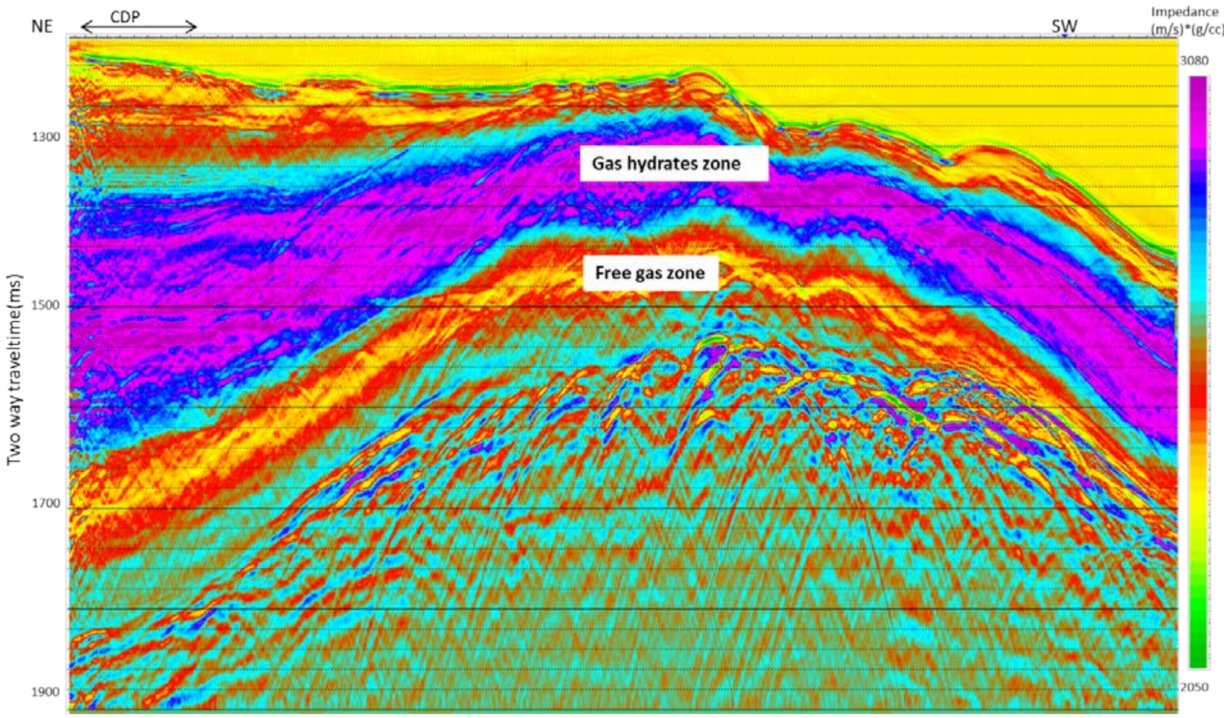

Figure 5. b) Inverted P-impedance. The range of impedance is 2050(g/cc)(m/s) the green end to 3050 (g/cc)(m/s) the purple end. The gas hydrates region (purple color) has the highest impedance. The free gas zone beneath the gas hydrates zone, has low impedance.

Figure 6a shows the predicted resistivity along the profile of the 2D seismic line used in the present study. It can be observed from the predicted resistivity section that the electrical resistivity high corresponds to the region above the BSR consisting of gas hydrates. It is as expected since the presence of gas hydrates increases the resistivity of the formation. Figure 6b shows the predicted porosity section. It can be observed that the region corresponding to the gas hydrates stability zone has reduced porosity. This is in agreement with the fact that the gas hydrates reduce pore space (Yuan et al., 1996).

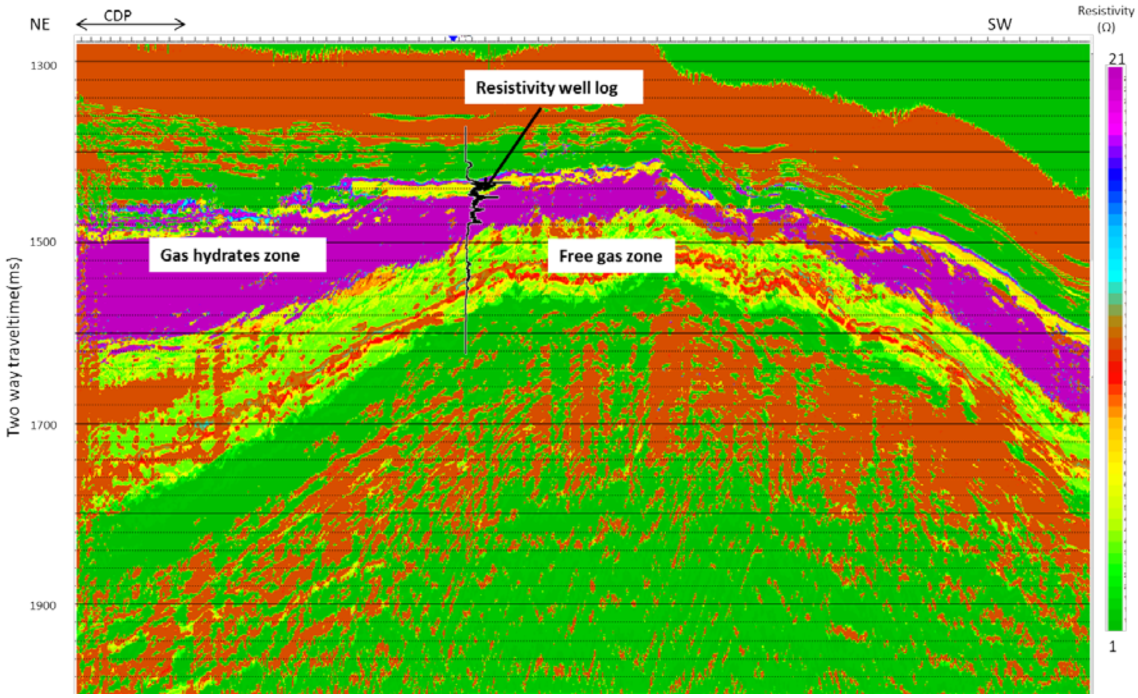

Figure 6. a) Predicted resistivity along the section. The gas hydrates zone is highly resistive. The original well log (black) is superimposed on the predicted resistivity section. The colorbar shows the resistivity range. The lower end (green) is 1Ωm and the upper end (purple) is 21Ωm.

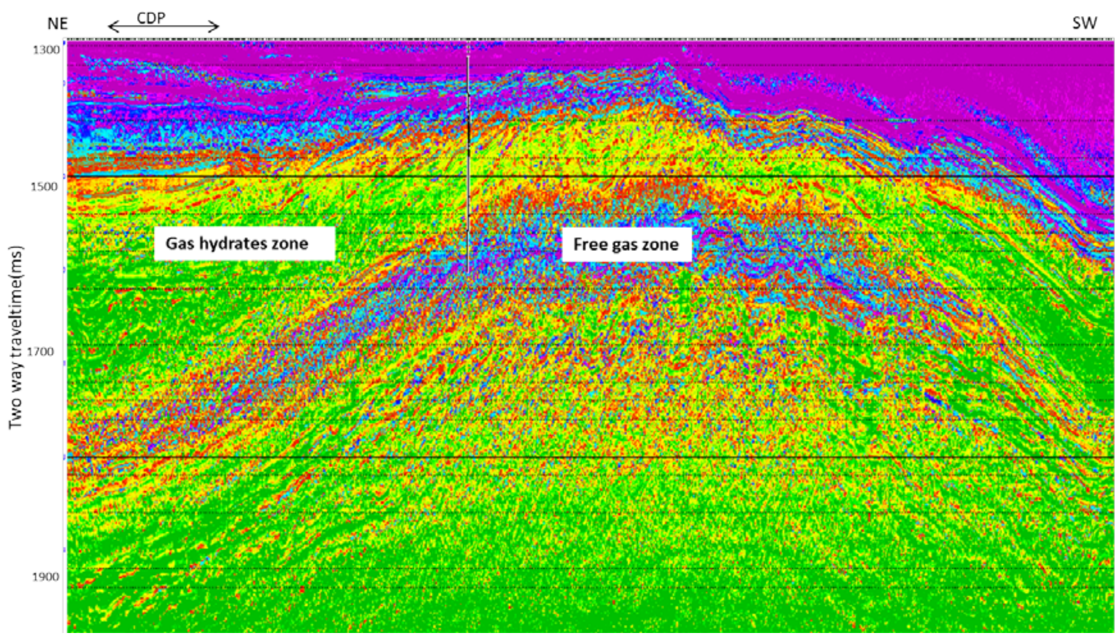

Figure 6. b) Predicted porosity along the section. The lower limit of porosity is 40% (green color) upper limit is 80 % (purple).

Figure 7a shows the estimated gas hydrates saturation at the well location using the pseudo resistivity and porosity logs plugged in Equation3. Comparing with the saturations obtained from core measurements, it was observed that the estimated saturation matched very closely at two of the four depth locations, with another point being very close to the estimated saturation. Figure 7b shows the estimated saturation along the complete seismic profile. The estimation of gas hydrates saturation at all trace locations is done based on the same principles that are used for estimation of gas hydrates saturation at well location. Since the values of well log properties that are obtained from multi-attribute analysis and neural networks give the resistivity and porosity values at all trace locations, saturation estimation is extended to the whole seismic section. The warm colors are the region with greater gas hydrates saturation. Saturation of gas hydrates varies between 50-70 %. Since the saturation has been predicted using predicted well logs the saturation at depths greater than the depth of the well logs (the blue region in Figure 7b) is not to be considered.

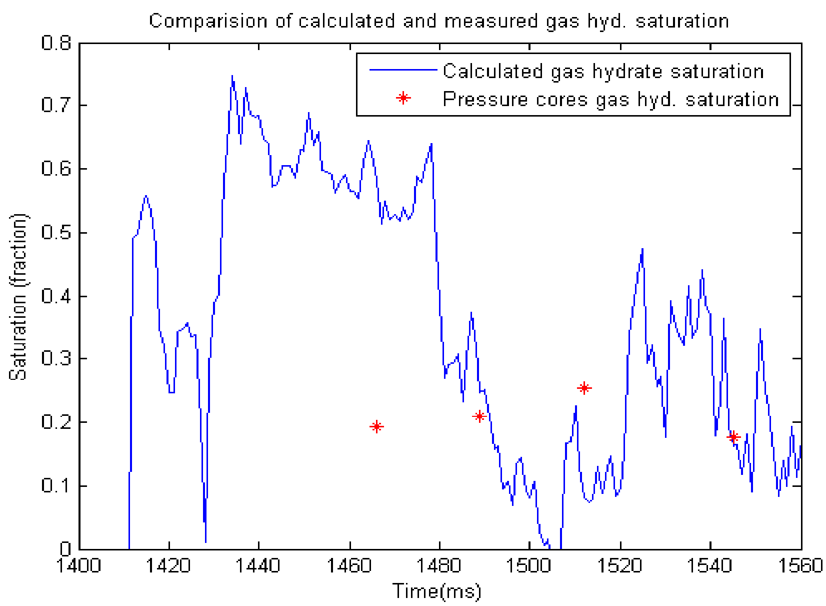

Figure 7. a) Estimated saturation (blue line) against the measured saturation (red stars) from cores.

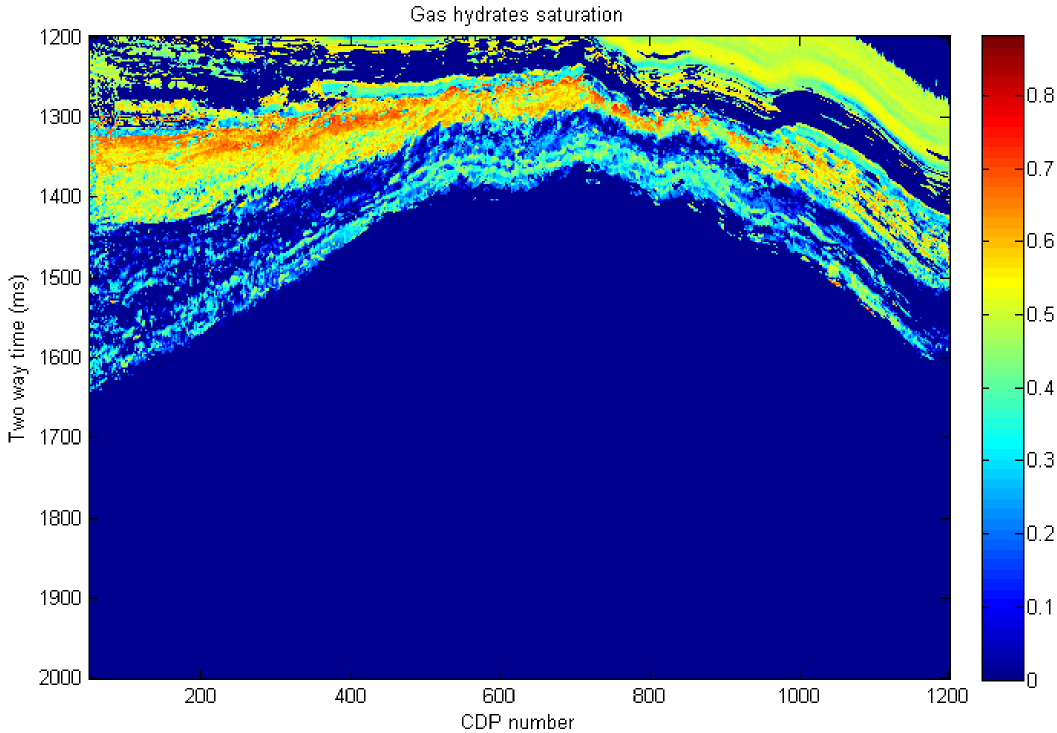

Figure 7. b) Gas hydrates saturation estimation at all trace locations. The warm colours indicate higher concentrations of gas hydrates. Since the estimation of gas hydrates is limited only to the well log depths the estimated saturation values are shown as zero in the depths greater than the logged depths.

CONCLUSIONS

Prestack inversion provides with better results compared to poststack inversion results. Since the resolvability of geologic features was poor in poststack impedance inversion results, prestack inversion was used to invert seismic data for P-impedance. Better resolvability from the impedance attributes is important because they are used for determination of gas hydrates saturation. The better the resolution of the impedance result, the better will be the delineation of the gas hydrates saturated zone.

The methodology to estimate gas hydrates saturation considers anisotropy as an influencing factor, hence is expected to give better saturation estimates as compared to isotropic Archie'e equations. This method for saturation estimation is applicable when both seismic data and the requisite well logs are available. Since the present method uses well logs, saturation can only be estimated in the section where logging has been done. The use of statistical methods for prediction of well logs rather than using empirical relationships increases the quality of results as the transform relationships between the well log properties and the seismic data are generally non-linear. The mismatch in the saturation estimated from core measurements and present method may be caused due to the fact that the cores were not from the same well as used for the present study.

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