Confirmation of Gaseous Hydrocarbons from AVO Study Over Shallow Gas Prospects – A Case History

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Summary

In recent years most oil-related seismic surveys have been 3D surveys. But there has also been an increasing interest in obtaining more sophisticated 2D profiles. The high amplitude reflections were very successful in early seventies for direct detection of gas. The AVO technique later emerged as a powerful tool in seismic industry for direct detection of gas in clastic reservoirs. The change in ratio of P wave velocity to S wave velocity causes the partitioning of the incident wave to differ for the case of a gas-sand/shale or gas-sand/wet –sand reflectors from that of most other reflectors. This anomalous behavior of gas-sands is clearly noticed in seismic data sets and interpreted as AVO indication which consists of an examination of reflections at varying incident angles (at varying source–receiver offsets). The present paper deals with AVO study carried over a 2D seismic profile based on 1D model derived from petro physical properties corresponding to gas bearing sand in the well where the AVO anomaly was confirmed by different AVO attributes. The sand encountered at a depth of 626 m (669 ms) is gas bearing which is confirmed by the production testing results. AVO study confirms with the production testing results. The study was extended to shallower zones (200-400 mS) where high amplitude anomaly observed in seismic section. The AVO attributes and subsequent inversion of normal incidence reflectivity confirms the lowering of acoustic impedance corresponding to this high amplitude anomaly which needs validation by production results

Introduction

The solutions for depositional model, tectonic frame work and other aspects related to petroleum system of the Miocene reservoirs are in sight. But the requirement of AVO study has been envisaged as an important G&G options for accurate delineation of the gas pools. The present work has been carried out on a 2D seismic profile over the southern part of Cambay basin of India **(Fig-1**).

The model based AVO study has confirmed the presence of AVO anomaly corresponding to gas bearing sand in A-23 well The wells A-2, A-4 and the recently drilled well A-23 are gas bearing. The well A-23 is projected on the above 2D seismic line. PSTM gathers were pre-conditioned by taking into consideration of source and receiver array, surface consistent scaling, Q correction, amplitude calibration, frequency filtering and geometrical spreading etc. The maximum angle was kept 45 deg. The RMS velocity derived from migrated gathers was used for Pre-stack time migration and AVO study. This involves AVO modeling and generation of synthetic gathers, calibration of seismic data using synthetic seismogram, AVO inversion and generation of AVO attributes, cross plotting and analysis of AVO results. The AVO technique being a very powerful tool analyzes the change in the offset dependent reflectivity along an interface and predicts the presence of gaseous hydrocarbons in the area.

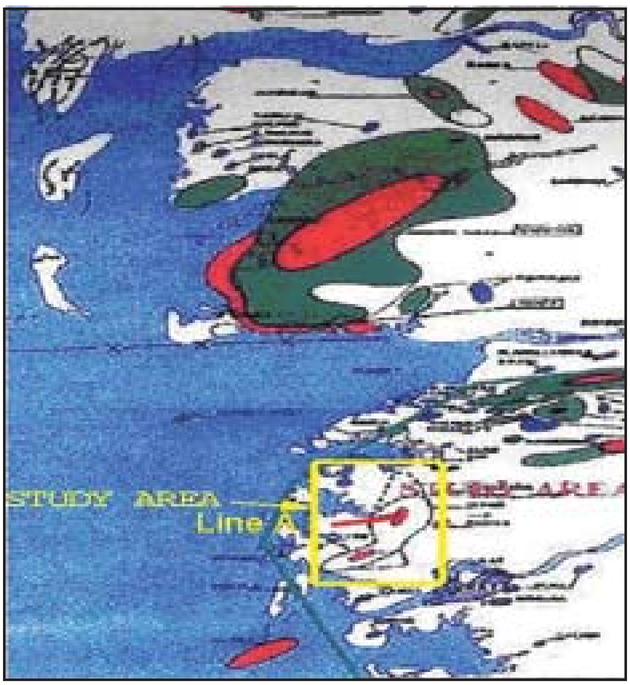

Fig-1 Location map of the area

Classification of AVO anomaly

The classification of AVO anomaly is based on the presence of oil and gas within the embedded sand. Class-I anomaly is a high impedance sand anomaly. It has positive

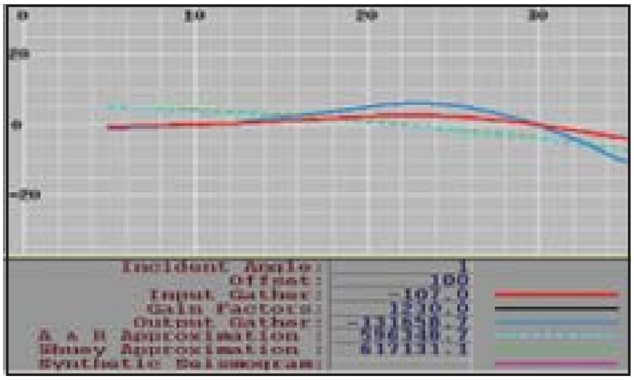

Fig.2: Observed anomaly at TWT 669 mS exhibits Class-II anomaly with phase reversal

normal incidence reflectivity which becomes smaller at larger offsets. In case of Class-II anomaly the normal incidence reflectivity value has either a small positive or small negative values which become more negative towards higher offset. It may exhibit phase reversal. Class-III anomaly has negative normal incidence reflectivity (the gas sands having low impedance ñv, gives typical bright spots in stack data.

Methodology

AVO Modeling & Generation of Synthetic gathers

AVO modeling was carried out using sonic, density and T-D log values from VSP data. The drilled depth of the well is about 800 m. One dimensional model using petro-physical parameters viz., density, interval velocity, slowness of P waves besides T/D curve at A-23 well was generated. The shear wave log was not available and hence mud rock line was used to derive the Vs values from P wave sonic log. The one dimensional model of the smoothened petro-physical values were displayed in **Fig-3**. The top of the main gas bearing Zone is observed at 626 m.

The synthetic gather **(Fig-4)** was generated using ray tracing technique with 1D interval velocity (as derived from sonic log). The reflection coefficient was calculated as a function of angle of incident using the Zoeppritz relation for each sample (considering plane wave propagation). Zero phase Ricker wavelet of peak frequency 35 Hz was chosen for synthetic response.

Calibration of Seismic data

The sonic log & synthetic seismogram were used at the well location for calibration. The sonic log was written in time domain using T-D curve. The top of the Main gas sand is

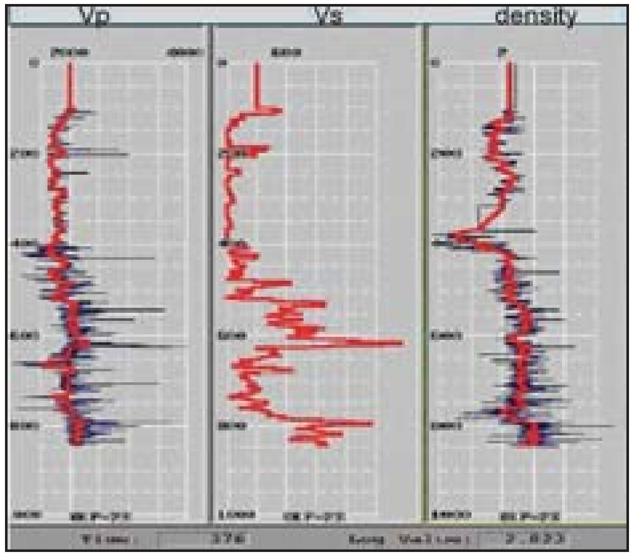

Fig-3: One dimensional model derived from well logs at well location

626 m (669 mS, TWT). For improving the correlation between synthetic seismogram & amplitude preserved stack section, the wavelet was selected from sonic log and the phase rotation on the wavelet was applied. As a result, a reasonably good improvement was observed in the correlation of synthetics and seismic, especially across the gas pay (**Fig-5**).

AVO Inversion

The angular envelope of the pre-conditioned gathers was computed by ray tracing of the modeled gather. The traces falling within the respective angular envelope of each CDP are stacked to generate the angle stack attributes. The angle stacks generally give the first hand AVO indication about the presence of AVO anomaly. AVO inversion provides solution of P and S wave velocity reflectivity coefficients “(Vp)/ Vp and “ (Vs)/ Vs, the ray tracing gives the computation of angle •i from offset Xi.

In Aki, Richard’s inversion scheme the attributes are:

a) P- wave velocity reflectivity
b) S- wave velocity reflectivity
c) Pseudo-poisson reflectivity, expressed by the normalized change in pseudo Poisson’s ratio.
d) Fluid Factor $F = —\Delta (Vp)/ Vp) - (1/ \sigma) * Vs/Vp*\Delta (Vs)/ Vs$

In Shuey’s scheme, the attributes are:

a) Normal Incidence section (Rp)
b) Gradient stack (G)

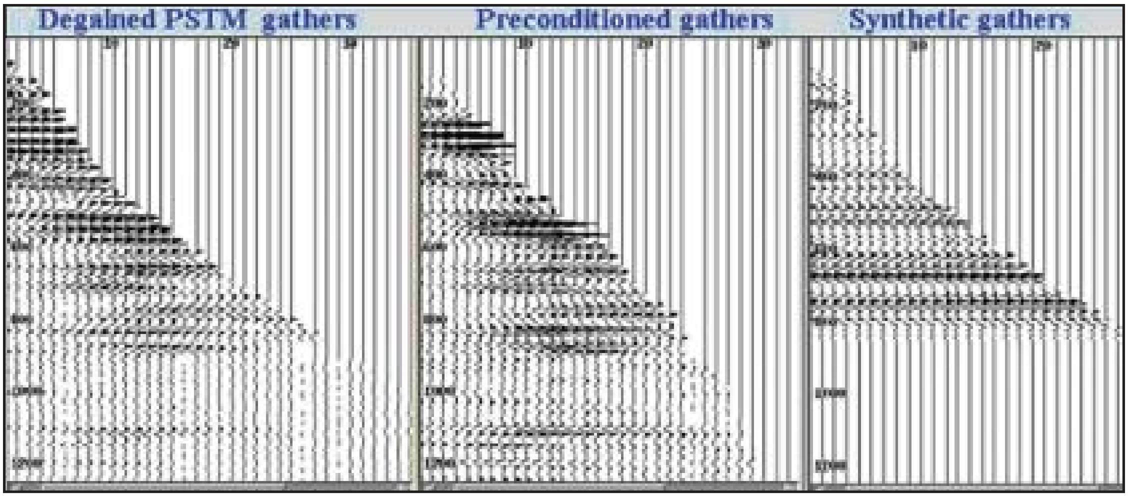

Fig-4: Preconditioned and synthetic gathers

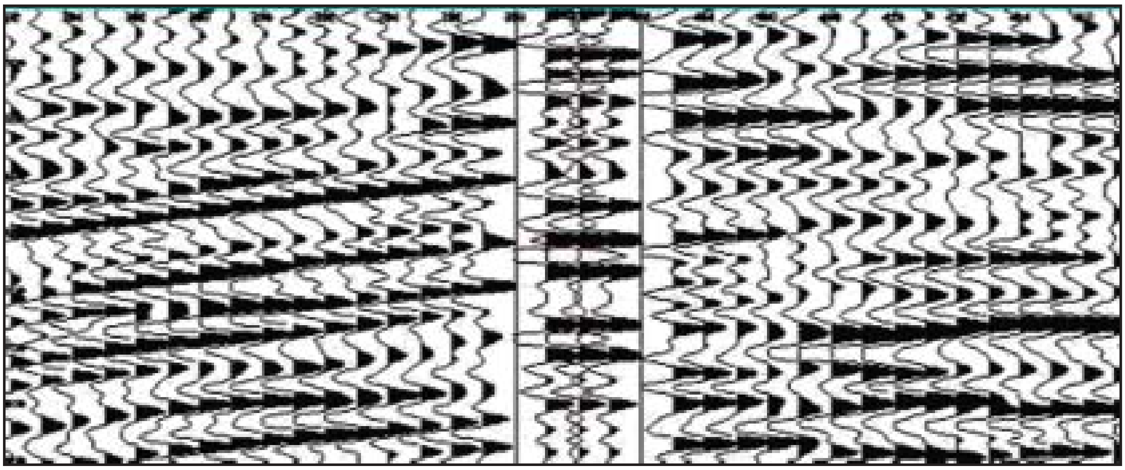

Fig.5: Correlation of synthetic seismogram with stack section after phase adjustment.

c) Sin Rp * G stack section

d) Pseudo Poisson's reflectivity section —$\Delta\sigma$ $[1-\sigma]^2$ = P + G, Where P = Normal incident reflectivity/ along intercept axis and G = Gradient, σ = Poisson's ratio.

The Aki & Richards Inversion's method and Shuey's method can be applied to invert angle stack to derive elastic impedance. Some of the AVO attributes based on above schemes are shown at **Fig-6**

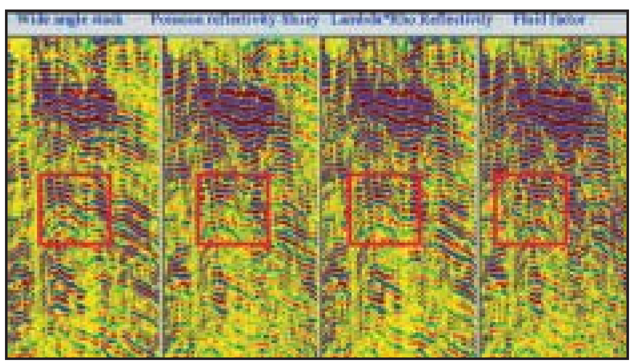

Fig.6: Integrated display of selective AVO Attributes

Cross plotting

The cross plotting facilitates meaningful interpretation of AVO anomalies. Any relationship between the two physical properties under certain geological reasons may follow a definite trend. The cross plotting methodology allows the mapping of the deviations from the mud rock line on the section and thereby pin points the probable locations of gas pools or high amplitude litho-facies. Different classes of AVO anomalies fall in different quadrant of the plot and could easily be distinguished. It is a powerful aid for interpretation of AVO response. The cross plot corresponding to this pay sand with the class II anomaly was very well mapped at TWT 669 mS.(**Fig-7).**

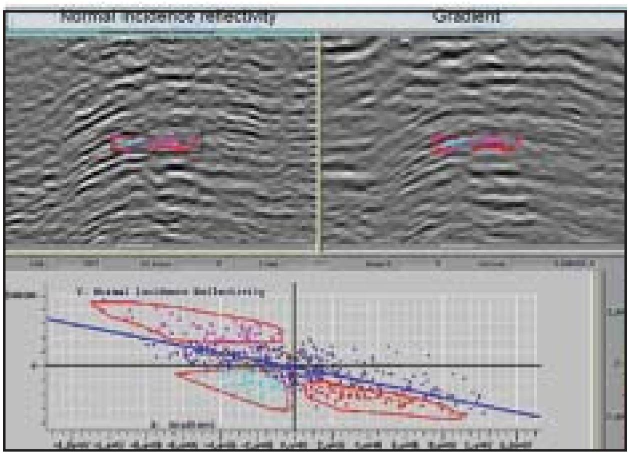

Fig.7: Cross plot at pay sand in well A-23, TWT=669 mS confirms the class II phase reversal anomaly

Results and Discussion

The stratigraphic sequence encountered in the well gives the overall idea about the lithology of the area. The two objects were tested during production testing. The object-II of well (TWT 669 ms) produced gas. This pay sand corresponds to a reflection at 669 mS., at the projected well location. This reflection in pre-conditioned gather exhibited class-II anomaly which was also supported by its counter part in synthetic gather (model response) as illustrated in **Fig-8 & 9**.

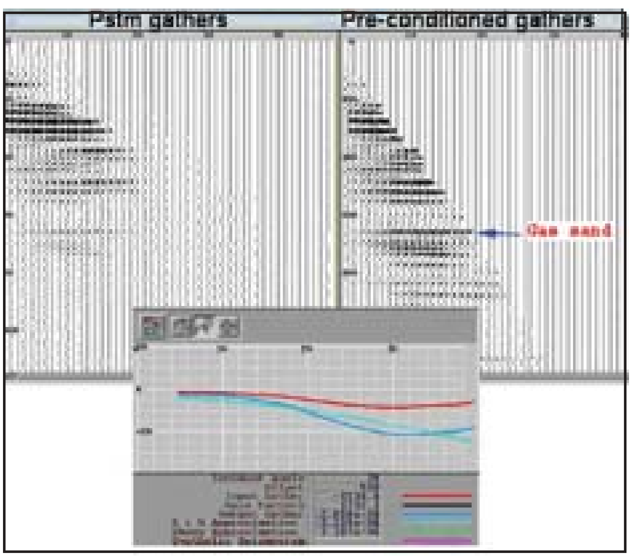

Fig.8: Observed anomaly corresponding to pay sands

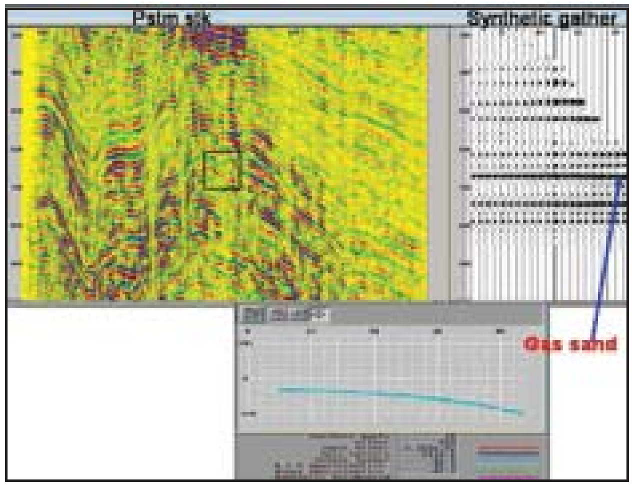

Fig.9: Synthetic gather response at pay sands derived using 1D model at well location

However, the event is stronger in synthetic gather. A small phase shift was observed which may be attributed to using a zero phase wavelet for preparing synthetic.

While all AVO attribute sections support this AVO anomaly. The prominent AVO anomalies were noticed in the sections of Lambda-Rho, Poisson's reflectivity and Gradient stack section, corresponding to this pay (**Fig-6**).

The class-II phase reversal anomaly is well supported by AVO cross plot produced gas during production testing and mapped at TWT 669 mS.(**Fig-7).**

High amplitude AVO anomalies were observed at various locations of this amplitude preserved angle stack section (**Fig-10**). The pre-conditioned gathers falling in these zones were analyzed to examine the variation of reflectivity with offset (AVO) (**Fig-11**).

The high amplitude anomaly shown in **Fig-11** falls under class II type. Most of the reflections in these zones exhibit class-II or class-II phase reversal type anomalies. The observations are well supported by cross plots (**Fig-12**).

The inversion of normal incidence reflectivity confirms a lowering of acoustic impedance (**Fig-13**) corresponding to high amplitude anomaly and thus may be attributed to the presence of gaseous hydrocarbon within the formation corresponding to the shallower zone

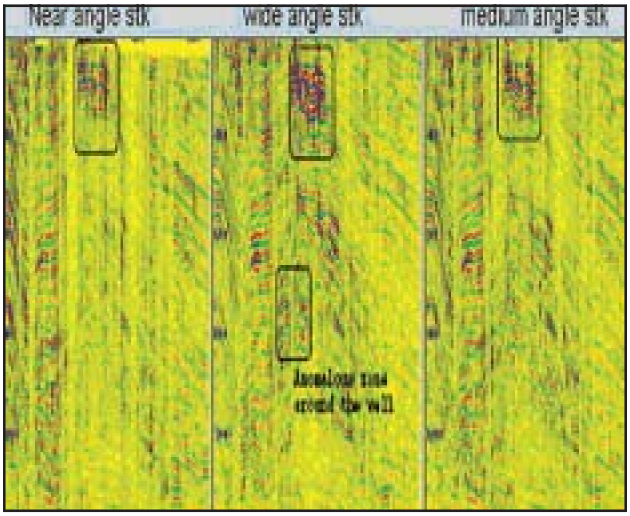

Fig.10: Integrated display of angle stacks showing anomalous zones.

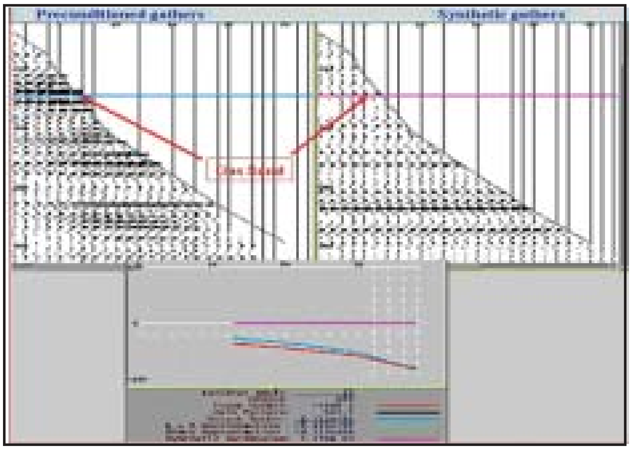

Fig.11: AVO response of pre-conditioned & synthetic gathers in shallower zone

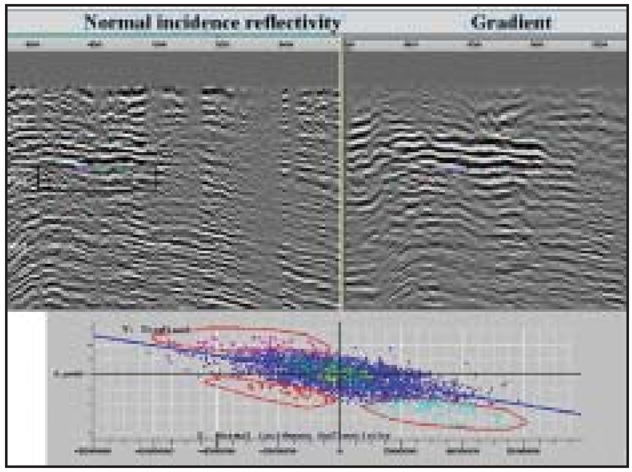

Fig.12: Class II anomaly is well mapped in AVO attribute section through cross plot in shallower zone

Conclusion

1. The efficacy of AVO analysis on the line-A is encouraging despite the limitations of the input data in respect of resolution and noise contamination.
2. The AVO response of the synthetic gathers, derived from well log data of A-23 conform well with the AVO effect of the event at 669 m sec at the level of pay sand .
3. The presence of other high amplitude anomaly on 2D seismic section could be a probable indication of shallow gas corresponding to 200-400 mS (within 200-500 m) in the area. AVO inversion as well as cross plots support the anomaly at shallower level where

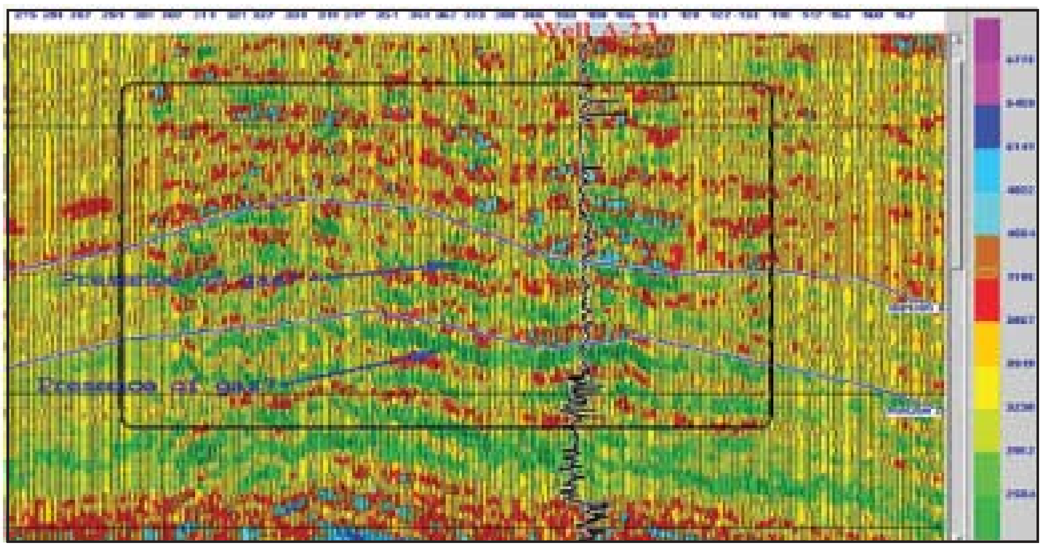

Fig.13: Inversion of normal incidence reflectivity confirms the lowering of acoustic impedance within the anomalous zone (shallow high amplitude anomaly)

production testing is not available which on testing may lead to shallow gas prospects in the area.

4. The extensive AVO analysis of more 2D seismic lines (dip lines and strike lines) is therefore recommended for enhanced reserve accretion of gaseous hydrocarbon, in these areas.

Acknowledgement

Authors acknowledge the infrastructural facilities provided by ONGC Ltd for carrying out this work. Authors are thankful to Director (E) for according the approval for presenting the results of the present work in SPG'06 conference. Authors wish to express their sincere thanks to Dr. C.H.Mehta, former Head GEOPIC, Sri S.K.Das GM (Geophy) & Head GEOPIC and Shri K Niyogi, Dy GM (Geophy) & Head Processing for their valuable guidance & encouragement during the course of work.

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