Acoustic to Elastic Impedance –A New Tool for Reservoir Characterisation

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Summary

Elastic Impedance (EI) is an art of technology and sophisticated tool which allows us to visualise AVO effect approximately with routinely processed 3-D seismic data and interpret the data without any special requirement of software for AVO and with less efforts .Quantitative AVO information such as Poisson's ratio, fluid substitution etc. can be extracted approximately from 3-D seismic data.

For viewing the effect of AVO or elastic impedance (EI) , an attempt has been made in this paper with the help of well data where S wave, P wave and density log have been recorded with other logs and 3-D seismic data volume of the North Mumbai High Field. Elastic impedance at different angles, V_p / V_s and Poisson's ratio were computed and seismic data was enhanced for the study. Finally, the enhanced seismic data has been converted into EI volume via acoustic inversion attribute (AI) with the help of well data and multiattributes analysis.

The layered structure of the acoustic /elastic impedance cubes form an ideal visualization for mapping the variations between wells and enable the reservoir engineers and geologists to upgrade the reservoir model for the optimisation of oil recovery through development or redevelopment plan of the field by lithology discrimination, depth imaging, petrophysical mapping and geosteering .

Introduction

Porosity and fluid discrimination from seismic using elastic inversion techniques is currently an area of interest for oil and gas exploration as well as development of the field. Since the formulation of impedance (Connolly 1999) many workers have been evaluating the possibility of combining the benefits of elastic impedance to provide enhanced discrimination of fluid and lithology .

Recently, Whitcombe et.al. (2001) formulated the attributes called GI (projection of elastic impedance) and showed that projection of AIGI cross plot can be used to differentiate fluid or lithology .

In most of case, only stack seismic data is available and it is felt to do AVO or its equivalent analysis to enhance the study. In such case as in the present study, a relation has been established between EI and AI and the compete 3-D seismic volume has been converted into elastic impedance.

Study area and data set

Log data

A data set from the well N-11-5 was chosen from the North Mumbai High field as the well is having all the log. Having these logs, calculation of EI and different angle based on Connolly formula becomes easy for including shear wave sonic log, P wave and density log. V_p / V_s ratio and Poisson's ratio etc. were calculated mathematically and logs were generated for comparing the different attributes any lithological interval .Cross plot correlation of AI and EI also becomes easier. All other wells were taken for reference for the present study. Most of the wells have sonic, Gamma ray, resistivity and density logs.

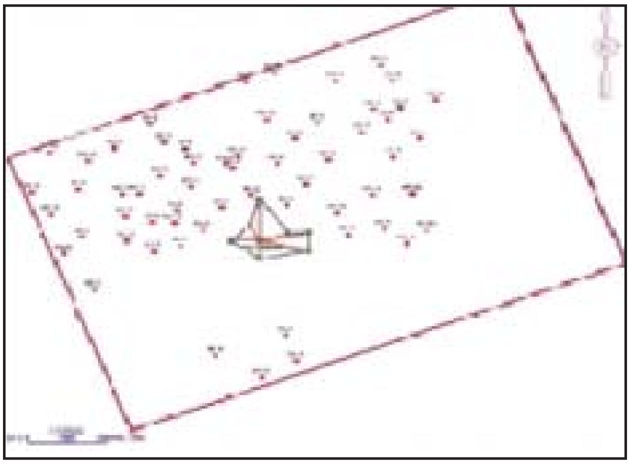
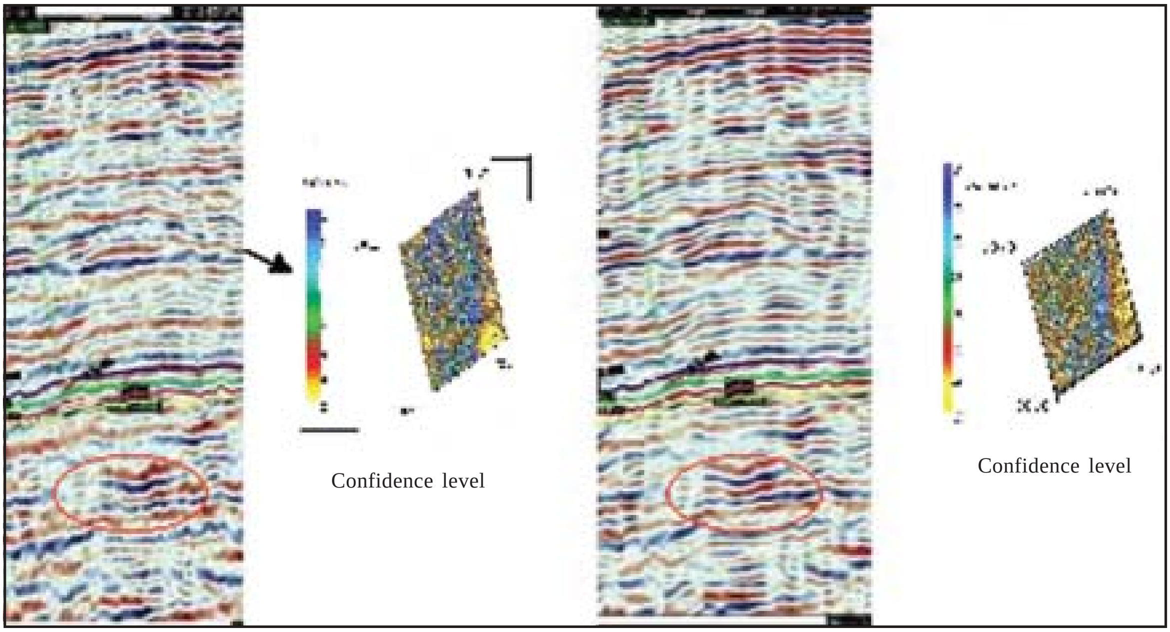


Fig. 1: Location map of Study area with platforms

Seismic data

3-D seismic data acquired with OBC technique during year 1998 was selected for the present study. The area is covered by good quality OBC seismic survey with close



Before data enhancement

After data enhancement

Fig. 2: Seismic section with corresponding confidence map showing data enhancement

grid of 12.5x25mts.VSP data is available in N11-5 for depth to time relationship. The N11 platform area, covering 400sq.kms and falling within one of the oil field of western offshore basin as shown in **Figure**1 was taken for the present study. The main carbonate reservoir L-III (Early Miocene) is divided into ten layers from A1 (top of reservoir) to C layer. The reservoir has a series of stacked limestone and shale with excellent reservoir quality in limestone. The stack of layers have been deposited under intra tidal to supra tidal environment. The upper layer contributing to production and having prominent GOC and OWC, was selected for the study so that fluid effect on seismic property could be studied during analysis. New platforms are likely to be taken up in and around northern part of the N11 platform.

Methodology

Data enhancement

First step is to examine the data quality before proceeding for computation of any attribute or inversion of seismic data because most of data is processed for structural interpretation using minimum phase wavelets and a gain to enhance structural surfaces. Fortunately, 3-D seismic data of Bombay High field is processed for stratigraphic interpretation with zero phase wavelets. However, some more efforts have been applied for processing of post stack data through the utility of data enhancement package of Land mark. **Figure 2**. indicates the seismic data before and after data enhancement Seismic data was conditioned and enhanced through dip scan stacking, a powerful data enhancement tool, and random noise was attenuated Testing was performed on a single line with trace mixing, F-K filter and coherence filter etc. Finally dip scan was applied to the 3-D volume. Frequency content and continuity increased significantly as shown in the figure. Confidence maps were generated on the basis of phase shift, amplitude variation and continuity of the seismic event and put on the right side of seismic section. Corresponding maps as shown in figure 2 indicates the enhancement in the confidence factor. Color bar is shown in left side of maps. Yellow color indicates 100% as maximum and blue color as 65% as minimum confidence factor. After the enhancement, the level of 65% increases to around 80%. Low confidence factor is localized near fault zone. Confidence maps indicate the reliability of the data for horizons reference and mapping.

Calibration of data

Synthetic seismograms were generated for acoustic impedance and compared with seismic derived impedance and it was observed that a good correlation of the order of 70% is available for the present study which is considered as suitable for such study.

Choice of seismic attribute

Now it has become common practice to process 3-D seismic data as partial stack to extract the AVO information.

But there are cases such as 3-D seismic data of Mumbai High where only full stack data is available and only acoustic inversion is possible .For viewing the effect AVO or elastic impedance(EI) , an attempt has been made in this paper with the help of N11-5 logs where S wave has been recorded .The EI is similar to AI response though the absolute number is lower because of the property of decrease in EI with increasing angle of incidence .Even the position's ratio value can be computed from seismic data deriving EI at 90° angle stack with the help of formula as below:-

$$EI(\theta) = V_p^{(1+\tan 2\theta)} V_s^{(-8K\sin 2\theta)} \rho^{(1-4K\sin 2\theta)}$$

$$EI(0^0) = AI$$

$EI(90^0) = (V_p/V_s)^2$,if $K = 0.25$, In case $(V_p/V_s)^2$ or K is not 0.25 ,then also EI (90^0) will be proportional to $(V_p/V_s)^2$ and this can be transformed into Poisson's ratio. In case of well N11-5, it has been observed that K is approximately 0.25. But due to limitation of seismic data such as band width variation and sensitivity of seismic to residual moveout ,computation of Poission ,ratio is not advisable. EI at 30° is compromisable .and hence EI(30) has been taken for analysis. Five attributes namely instantaneous absolute amplitude, amplitude weighted cosine phase, acoustic impedance, trace integrate and frequency attribute were selected from the attribute analysis list as shown in figure 6 for the refinement of correlation and reduction in prediction and validation errors as shown in **figures 3 and 4**. It is observed from **figure 5** that 2 to 3 well are showing spurious value and affecting the results. Neural network is not able to improve correlation in this particular case case.

Conversion of seismic to acoustic to Elastic

Trace based post-stack inversion i.e. sparse spike in-

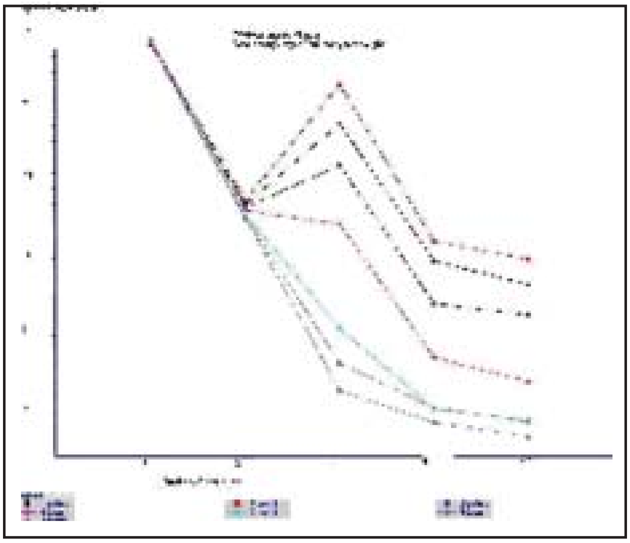


Fig. 3: Operator length test

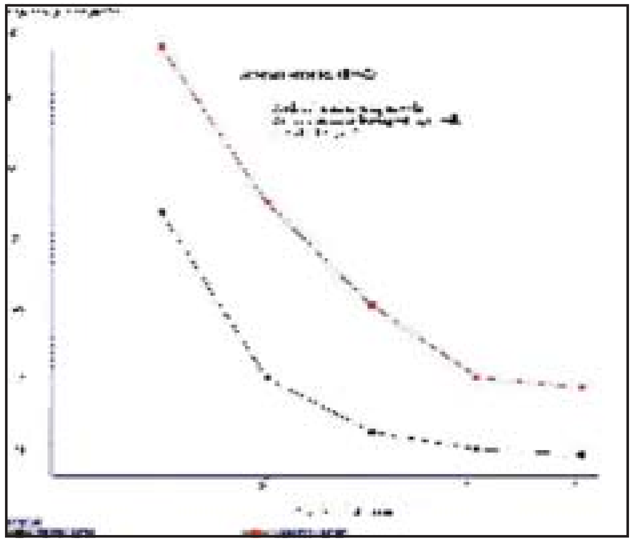


Fig. 4: Multiattribute Analysis with prediction (black curve) and Validation error (red)

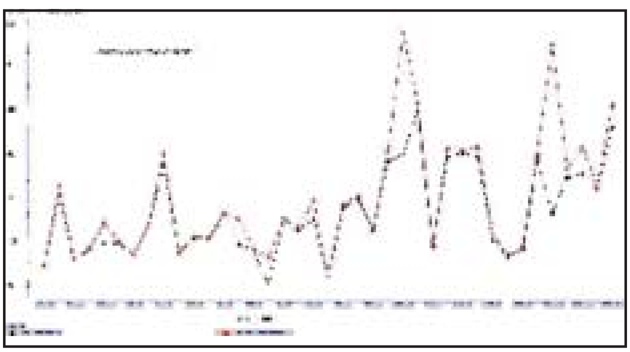


Fig. 5: Prediction (black) and validation error (red)

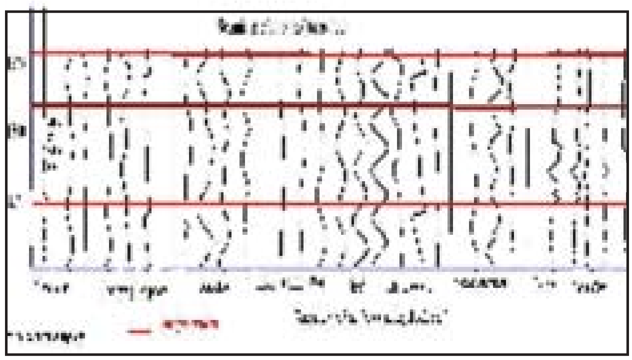


Fig. 6 : Seismic trace and list of attributes test for wells (analysis window in red color)

version technique was applied to derive acoustic impedance or pseudo-sonic log. The low frequency data below 8 Hz and high frequency above 80 Hz, not recorded during acquisition, was obtained from sonic log, VSP data and stacking velocity information and overlapped with acoustic impedance to obtain compaction trend. The help of multiattribute analysis (multi regression correlation) was taken for computing the acoustic impedance and decrease the average prediction error from 52 (with single attribute) to 35 (with multiattributes). The relation between elastic impedance (derived from above formula) and acoustic impedance at the well position was used to establish relationship then the 3-D seismic volume was converted into EI volume. Cross section extracted from the volume is shown in **figure 7**.

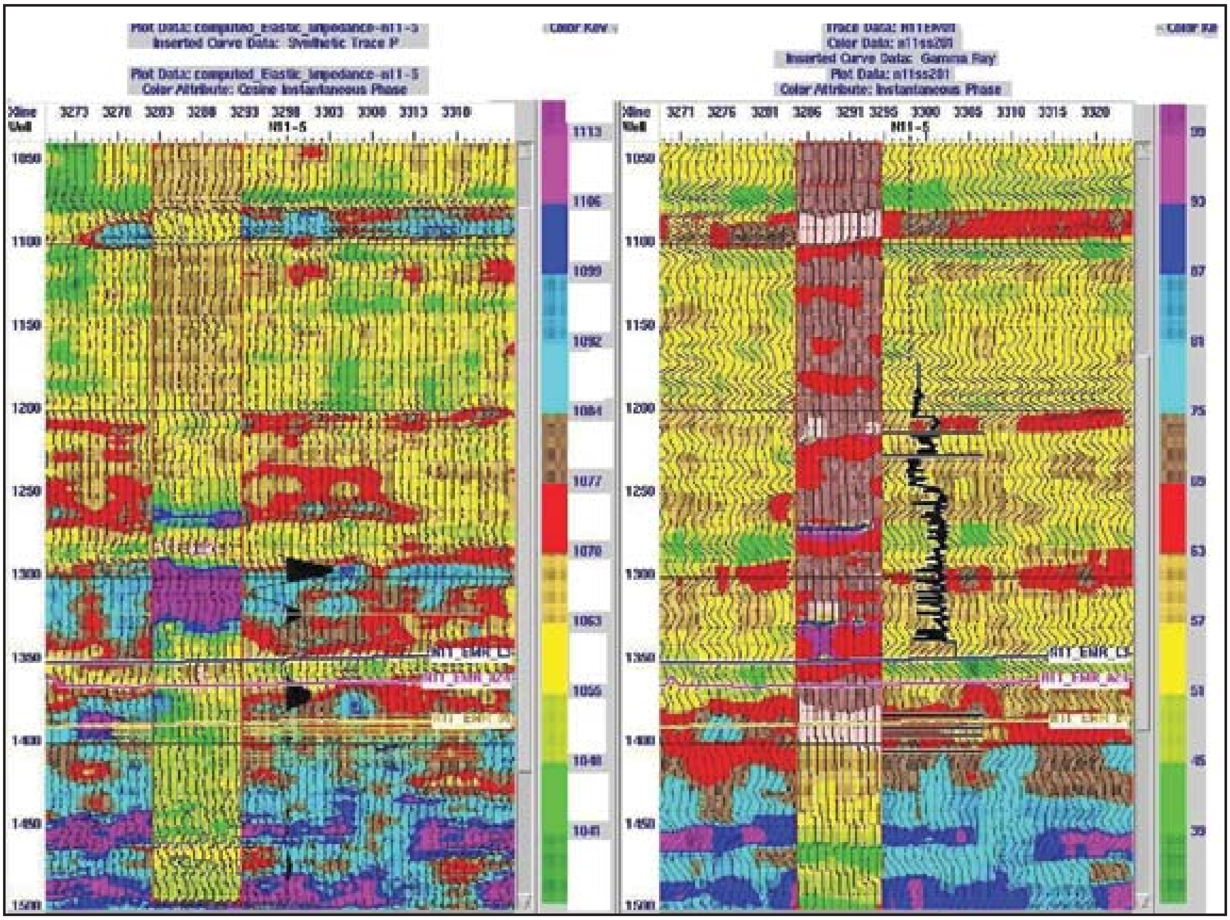


Fig.7 : Acoustic and Elastic impedance cross section

Further scope of study

Recently ,Whitecombe (2001) formulated the attribute called GI (a projection of EI) and showed that cross plot of AI and GI can be used to differentiate fluid and lithology .GI is number of normalized EI. Again EI (normalized) ,Rob Simm calculed AVO impedance (AVOI) by equation simply as:-

(AI*m + c) - EI (normalized)

Where m is slope, c is intercept and EI (normalized) is EI of sediments filled with brine water. The first term (AI*m + c) can be obtained from the regression line of the cross plot of AI and EI as shown in figure 9 and 10. The second term EI (normalized) i.e. EI of brine water filled sediments can be obtained from log using formula. The separation of facies cluster as shown in figure becomes more prominent in AI and AVOI plot. In generalized term, EI is also called AVO Impedance in those cases.

At present this type of analysis it is out of the scope of this paper but it can be extended to find out the AVO impedance and GI with the newly processed data for PSTM and PSDM.

Observation and discussion of results

Figure 8 and **9**.shows the EI log from well BH-1 with Gamma ray and resistivity logs showing comparison with (Vp/Vs) and Poisson ratio .The optimum value of K or Vp/Vs was used as 0.2 for EI computation. EI at 90° angle is almost identical to the $(Vp/Vs)^2$ curve .EI curve thus provide smooth transition between AI and $(Vp/Vs)^2$ function .Corresponding angle stack could be constructed and inverted for any desired angle stack .But it will be increasingly unreliable at higher angle .Therefore EI should be constructed optimally at 30°.

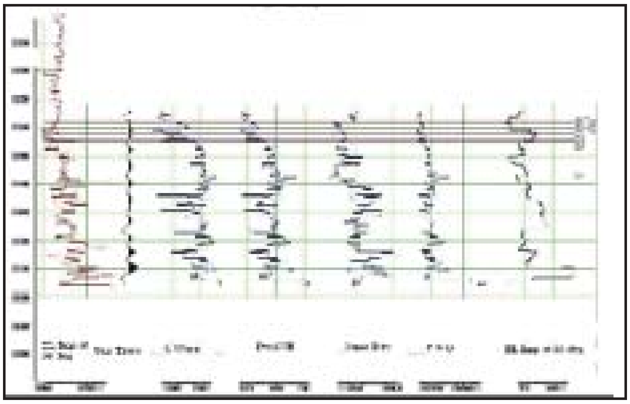


Fig. 8: Target trace at well BH-1

From the **figure 10** and **11** of cross plot of AI and EI ,it is evident that trend of various facies is similar (diagonally from bottom left to top right but it is seen that there is an different trend in cluster of shale ,brine sediments and sediment filled with oil /gas.

Comparative diagram as shown in **figure 6** indicates that $EI(0^0)$ shows more frequency contents and variations laterally and vertically even within same layer whereas AI is not able to show it.

Figure no. 12 indicate that the EI (30) extracted at reservoir level. Red and blue color shows the reservoir facies filled with gas. Yellow color indicates oil / water filled sediments and green color indicate shale. An increase in shale volume in carbonate rock has also affected the EI and

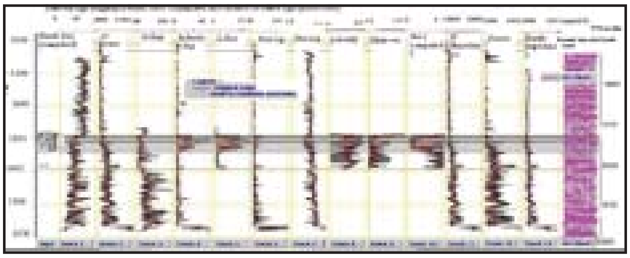


Fig. 9:Target trace with computed logs near well N11-5

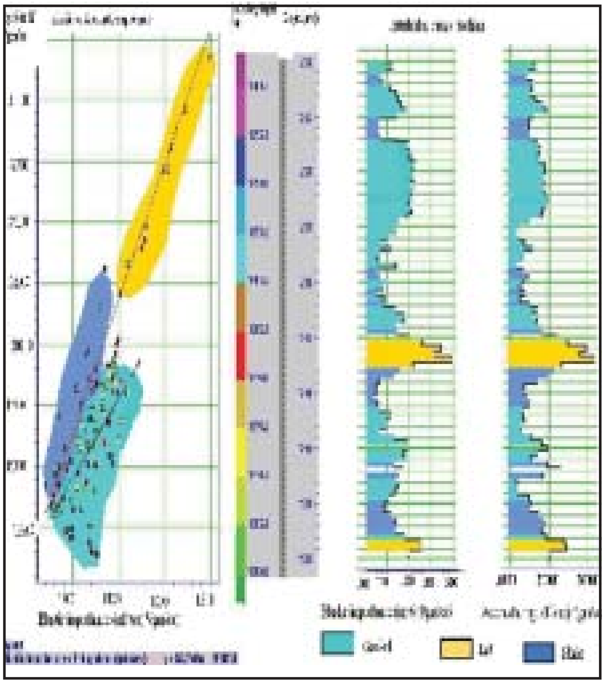


Fig. 10: Cross plot of Acoustic vs Elastic Impedance

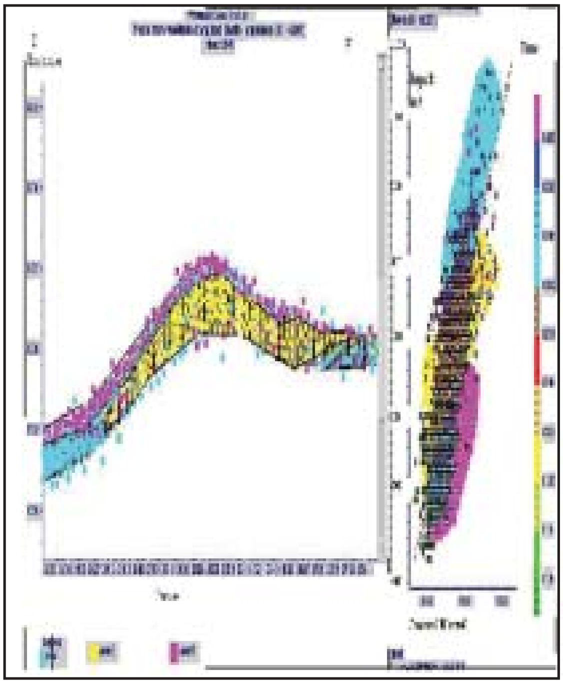


Fig. 11: Cross section passing through gas cap area and cross plot

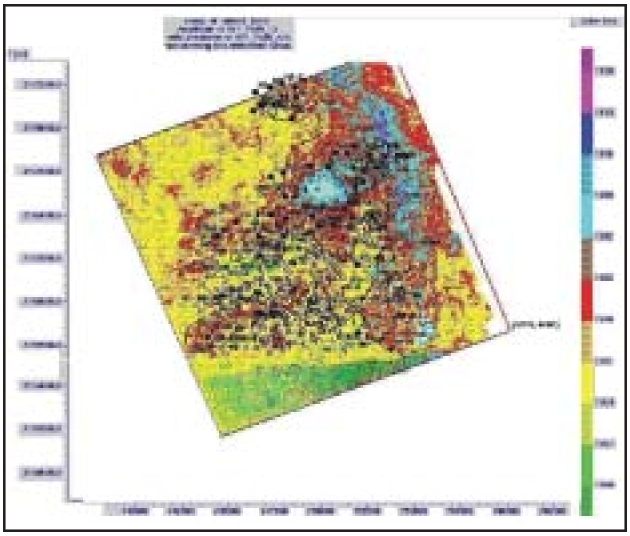


Fig. 12: Elastic Impedance slice at reservoir Level showing gas cap area

put yellow color at some places. At few points, high pressure porosity zone , abrupt change in saturation and fault zone have affected the response of EI. **Other use of Elastic Impedance**

The main benefit of EI (30^0) is that AVO affect can be visualized without availability of angle stack 3-D seismic data and it can be better understood by geologist and reservoir engineer for demarcation of fluid and lithology and analysis of geohazards such as high pressure zone.

It can be easily converted into rock physics and fluid analysis as EI is more sensitive to fluid saturation as it has taken S wave into account during computation of EI.

Limitation of the EI

It is more sensitive to noise and much depends on data quality but not as LMR attributes sensitive to data quality. It becomes difficult in differentiating fluid and lithology at low porosity below 15% using elastic attributes.

Conclusion

The EI is similar to AI response though the absolute number is lower because of the property of decrease in EI with increasing angle of incidence .It is a developing technology and it allow first order AVO effect to be incorporated into seismic using no sophisticated approach and expertise.

Difference of EI with time lapse seismic survey can provide better visualization in comparison to acoustic impedance as EI is more sensitive to fluid.

Such type of study may not be useful with noisy data where porosity pressure and saturation of liquid change abruptly.

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