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Application Of Seismic Inversion In Integrated Characterization of Carbonate Reservoirs: A Case Study From Mumbai High, India

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ABSTRACT : 3D seismic inversion has been qualitatively and quantitatively used in the reservoir characterization of the South-Eastern part of North Mumbai High field. The inverted impedance volume has been integrated with geological, petrophysical and production data of existing wells to bring out detailed reservoir heterogeneity in a multi–layered, diagenetically complex, producing carbonate reservoir of Mumbai High. Qualitative and quantitative integration of layer-wise acoustic impedance with production data, core data, seismic facies and porosity has come out with improved reservoir predictions. The acoustic impedance has shown a fairly good correlation (Correlation coefficient above 65%) with effective porosity and has been integrated using collocated co-kriging option resulting in generation of layer-wise porosity maps with reduced inter-well uncertainty. Subsequent drilling of wells has validated the results.

INTRODUCTION

Seismic inversion is being successfully used in the industry now-a-days, as a tool for stratigraphic interpretation, reservoir characterization and time – lapse seismic studies. The output of the seismic inversion can be P-wave and S-wave velocities, Poisson's Ratio or Acoustic impedance. The out-put of seismic inversion in any form, is the representative of the geology, which is the study of distribution of rocks properties rather than rock boundaries. An acoustic impedance volume is more directly related to reservoir properties and permits reservoir properties to be interpolated between wells on a layer-by-layer basis using calibrations at well locations. Though results of seismic inversion are non-unique in nature because of its dependence on more than one geologic and petrophysical variables, it can yield detailed information on distribution of lithology, porosity and fluid contents of the reservoir if it is analyzed thoroughly along with other attributes. Its ability to precise mapping of limits of reservoir can not be denied.

This paper, through a case study illustrates how qualitative and quantitative integration of acoustic impedance (which is the result of post stack 3D seismic inversion) with geological, petrophysical and production data can bring out improved reservoir description in a complex, multi-layered producing carbonate reservoir , like Mumbai High.

The study is a part of ongoing G&G study for re-modeling of Mumbai High. The present study covers 150 Square Kilometer area in South-Eastern part of North Mumbai High oil field (Fig.1) where detailed and integrated study for reservoir characterization was felt necessary for proper positioning of locations in a proposed production platform and also for planning of high tech horizontal wells as a part of redevelopment program of Mumbai High North.

BACK GROUND & STUDY AREA

Mumbai High is the main offshore field of India and is producing hydrocarbons since 1975. Its main producing layer L-III containing more than 90% of in place oil reserves of the field is a multi-layered carbonate and shale alternations of Early Miocene age with 10 different carbonate layers and with

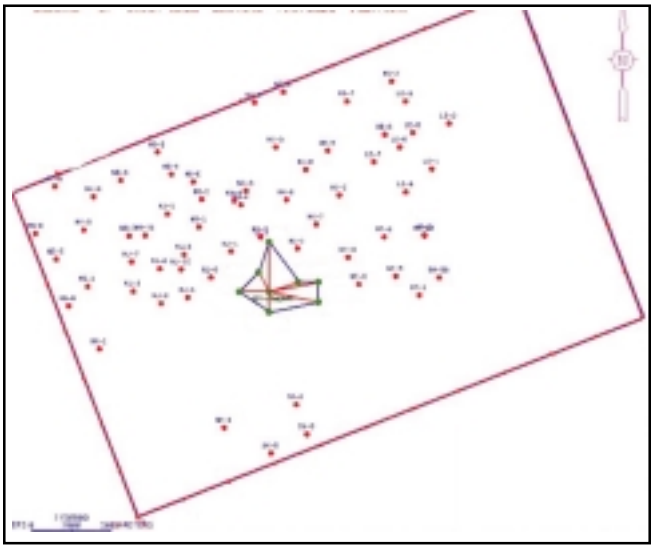

Figure 1: Map showing study area

very high degree of structural and petrophysical heterogeneity. The reservoir characterization processes in the past were primarily based on well data with limited and sparse 2D seismic data. In 1997 - 98 the whole Mumbai High field was covered by close grid 3D seismic (OBC) survey. Since then efforts have been made to integrate seismic data mainly for a field scale structural description. With the redevelopment plan of Mumbai High envisaging drilling of high cost horizontal, multilateral and long drift side-track wells; the existing geological model of the reservoir needed further refinement and detailing for accurate prognosis and placement of these targets. As a result an integrated G & G study was taken up in the area. Seismic inversion was a part of the integrated study and played an important role in refinement of the model.

The present study covers approximately 150 Square Kilometer area around the new platform N- 11, in the south-eastern part of the North Mumbai High field (Fig. 1). The area is covered by close grid 3D seismic (OBC) data with 350 In-lines and 1200 Cross-lines. 73 wells are drilled in the area. Except a few exploratory and vertical development wells, most of the wells are directional development wells from production and injection platforms.

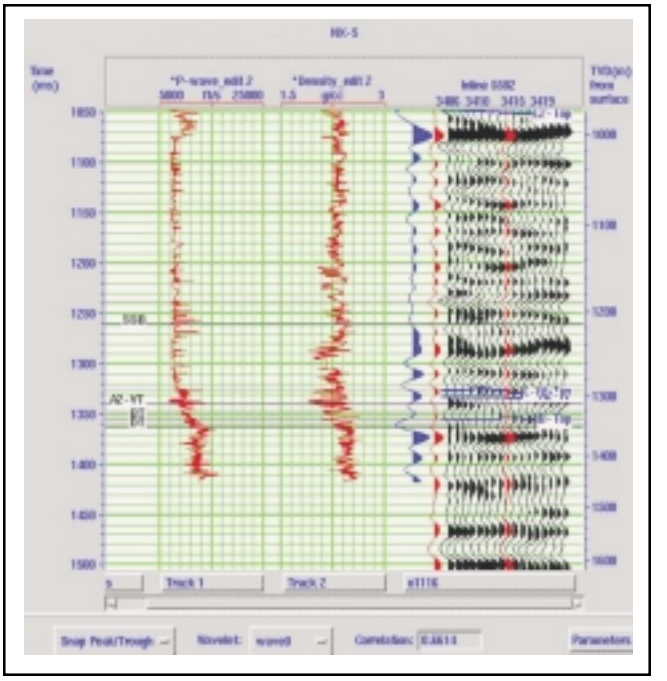

Figure 2: Calibration of seismic data with well logs & generation of synthetic trace. Cross- Correlation is 66%.

METHODOLOGY

Seismic Inversion

Post stack 3D seismic (OBC) volume with vertical sampling interval of 2 ms and processed for time migration and zero phase data was used for the purpose of inversion. The frequency content at reservoir level is approximately 60 Hz. Basic procedure of seismic inversion was reported for the first time by Lavergne(1975) and subsequently by Lindseth (1979). Due to computational efficiency, one dimensional convolutional model of seismic trace has widely been used in most of the post stack inversion methods. We carried out model based inversion using Generalized Linear Inversion (GLI) algorithm. It is assumed that the wavelet in the seismic data is known. For each trace, a synthetic seismogram is calculated using the initial guess impedance and the known wavelet. That impedance is then modified gradually until the resulting synthetic trace matches the real trace within some tolerance level. For the purpose of initial model and for low frequency impedance trend, five vertical wells having sonic as well as density logs were used. The synthetic traces obtained from logs of these wells were correlated with the seismic trace at the well location. One such correlation is shown in Fig. 2. Interpreted horizons L-II (Middle Miocene), L-III Top (Early Miocene), A2-IV (Early Miocene) and IL-III (Early Miocene) which is very close to B-Top were used as constraints. The final out put was inverted volume of acoustic impedance.

INTEGRATION & ANALYSIS

Acoustic impedance data was integrated with production data, well porosity & seismic facies and analyzed for L-III reservoir. The acoustic impedance values observed at L-III level were categorized and color coded in six zones.

Impedance values m/sec*gm/cc	Category	Color code
6000 to 6450	Very Low	Green
6450 to 6900	Low	Red
6900 to 7350	Medium	Yellow
7350 to 7800	High	Aqua-marine
7800 to 8250	Very High	Blue
Above 8250	V.V. High	Maroon

For layer-wise analysis, the acoustic impedance values were averaged (vertically) for the following four layers (within L-III reservoir) and acoustic impedance maps for these layers were generated (Fig. 4, 5, 6 & 7).

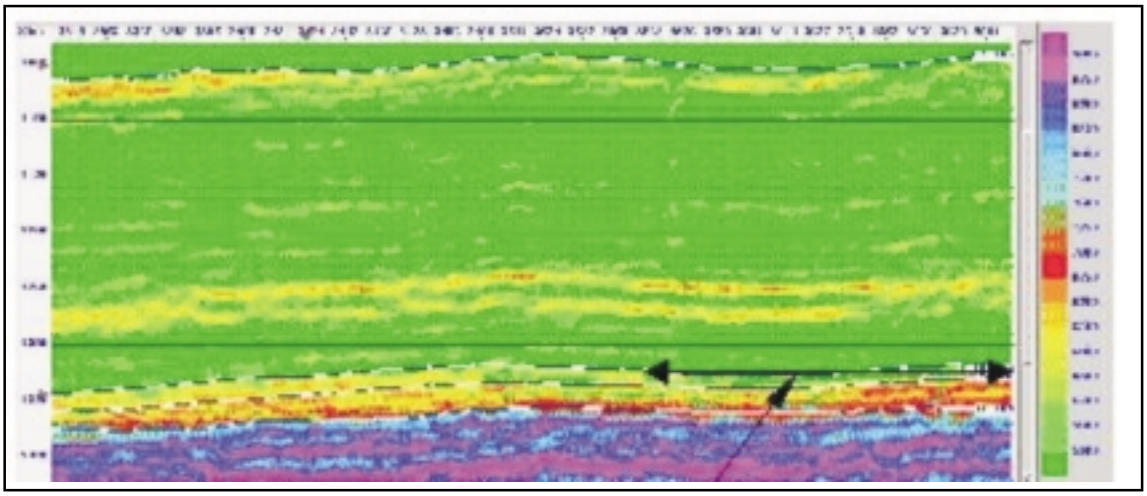

Figure 3: Vertical cross section of impedance volume along an In-line. lateral and vertical extent of gas cap can be observed clearly.

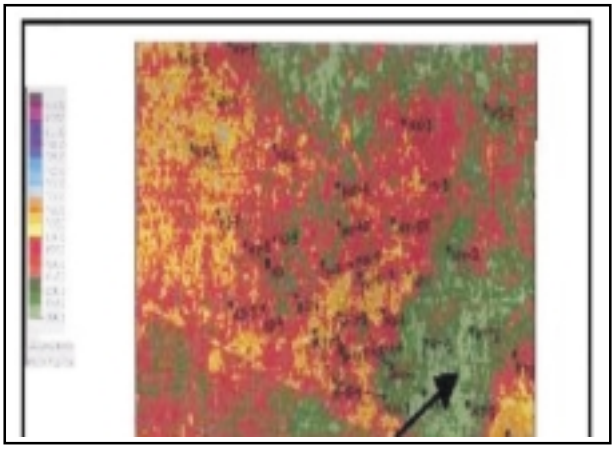

Figure 4: Average acoustic impedable at A_2-IV to A_2-VI Layers. Very low AI at 'G' defines the gas cap area.

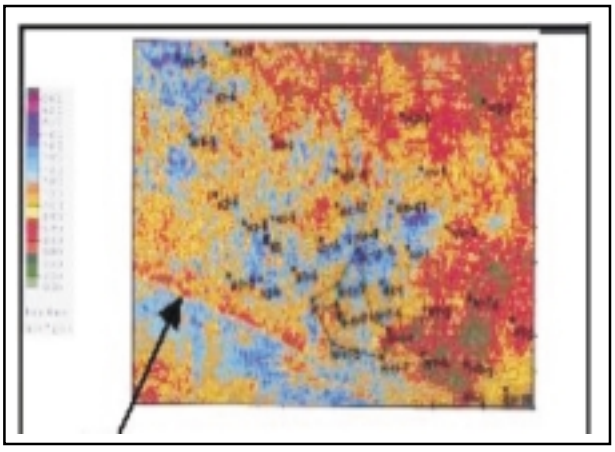

Figure 5: Average acoustic impedable at Layer A_2-VII. "F" shows a fault, the northern limit of permeability barrier.

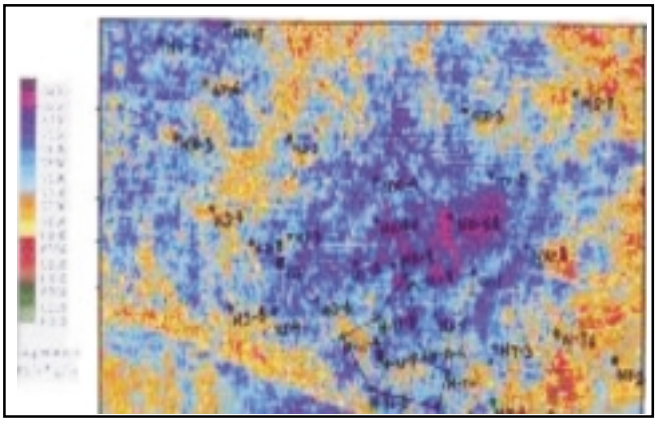

Figure 6: Average acoustic impedance at "B" Layer.

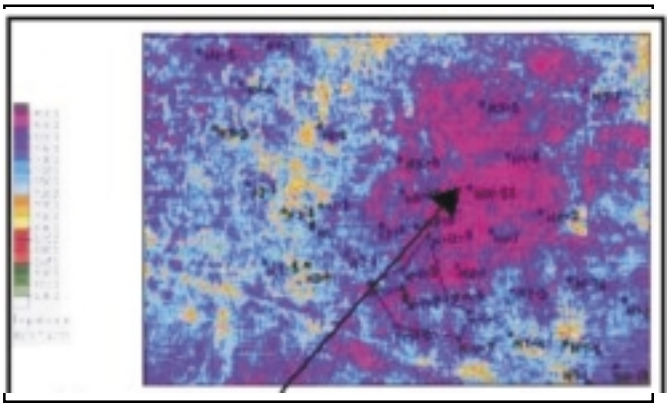

Figure 7: Acoustic impedance at "C" Layer. Very high AI in Central-Eastern part indicates deterioration in reservoir quality.

- Average impedance map for A2-IV to A2-VI Layers
- Average impedance map for A2-VII Layer
- Average impedance map for B Layer and
- Average impedance map for C Layer

Qualitative Integration

Through interactive multi-color map display on dual work station screen, a visual comparison between the acoustic impedance maps and petrophysical property (porosity, shale volume, fluid saturation, etc.) maps were made which were further validated by dynamic production data. Layer-wise correlation of reservoir properties of different wells with acoustic impedance values was carried out and range of impedance values at different layers were fixed for certain quality of reservoir (Table: 1, 2 & 3). Accordingly, the gas caplimit in upper reservoir (A2-IV+V+VI) and its disappearance in the lower layers below A2-VII were brought out with clarity (Fig.3 & 4). The reservoir quality deterioration in lower most layer (C Layer) in the eastern and central part of the area was clearly observed through very high values of acoustic impedance (Fig.7). All these observations are supported by production performance of the wells. The inferences drawn were used in conjunction with structural interpretation and seismic facies analysis for repositioning of a few platform locations.

Quantitative Integration of Acoustic impedance and porosity – Collocated Co-kriging Alternative

Acoustic impedance and effective porosity (from most of the wells) in this area when cross plotted, showed good correlation with correlation coefficient between 0.6 to 0.7(Fig. 8.a) and therefore integrated geostatistically using

Table1: Summary of IMPEDANCE values in Layer close to A2-VII

Impedance Range m/s *gm/cc	Wells	Porosity%	Pore Fluid	Proposed Locations	Remarks
7800-8250	-	-	-	-	
7350-7800	NX-1,7,9	17%	Oil	N-11-2,4	
6900-7350	NX-5	18%	Oil	N-11,3,5, 6,7	
6450-6900	NT-2,3,4, NJ-2 NX-2, 3,4,4Z,6	15-20%	OIL	N-11-1	
6000-6450	NT-1,5,6	16-20%	OIL	-	

Table 2 : Summary of IMPEDANCE values in Layer close to B

Impedance Range m/s *gm/cc	Wells	Porosity%	Pore Fluid	Proposed Locations	Remarks
7800-8250	NX-1,4Z,9	13-15%	Oil		
	NJ-1Z		Oil		
	NV-5,7		Oil		
7350-7800	NT-1,3	13-15%	Oil	N-11-1,	
	Nx-2,3,4,7		Oil	2,3,5,7	
	NJ-2,6,8,9		Oil		
6900-7350	NT-2,4,5,6,	13-16%	Oil	N-11-4,6	
	NJ-2,7		Oil		
6450-6900	-	-	-	-	

Table 3 : Summary of IMPEDANCE values in Layer close to c

Impedance Range m/s *gm/cc	Wells	Porosity%	Pore Fluid	Proposed Locations	Remarks
7800-8250	NT-6	14%	Oil	N-11-2, 3,4,5,6,7	
	NX-1,2,3,4,	14-18%	Oil		
	5,7,9	-do-	Oil		
	NJ-1Z,6	11-13%	Oil		
	NV-5,7	9&145	Oil		
7350-7800	NT-1,2,3,4	13-18%	Oil	N-11-1	
	NJ-7,8,9		Oil		
6900-7350	NT-5,	10-%	Oil	-	
	NJ-2,8	17-18%	Oil		
6450-6900	-	-	-	-	

Collocated Co-kriging resulting in preparation of porosity map with impedance as a constraint. Full co-kringing was not considered to be necessary. Only the normal score acoustic impedance data closest or collocated with the node being estimated was retained. A cross co-variance between normal scores of porosity and impedance was estimated using Markov-type model.

$$C12(h) = P12(0)*C1(h)$$

Where C1(h) is the co-variance of the normal score transformed porosity data, C12(h) is the cross co-variance of porosity and acoustic impedance normal score transform, P12 is the correlation coefficient of porosity and impedance normal score transform. The direct semi-variograms and cross semi-variogram of the variables, porosity and impedance, were calculated (Fig. 8 b, c & d). Using all these variogram functions, co-kriged the impedance values to all grid nodes to generate

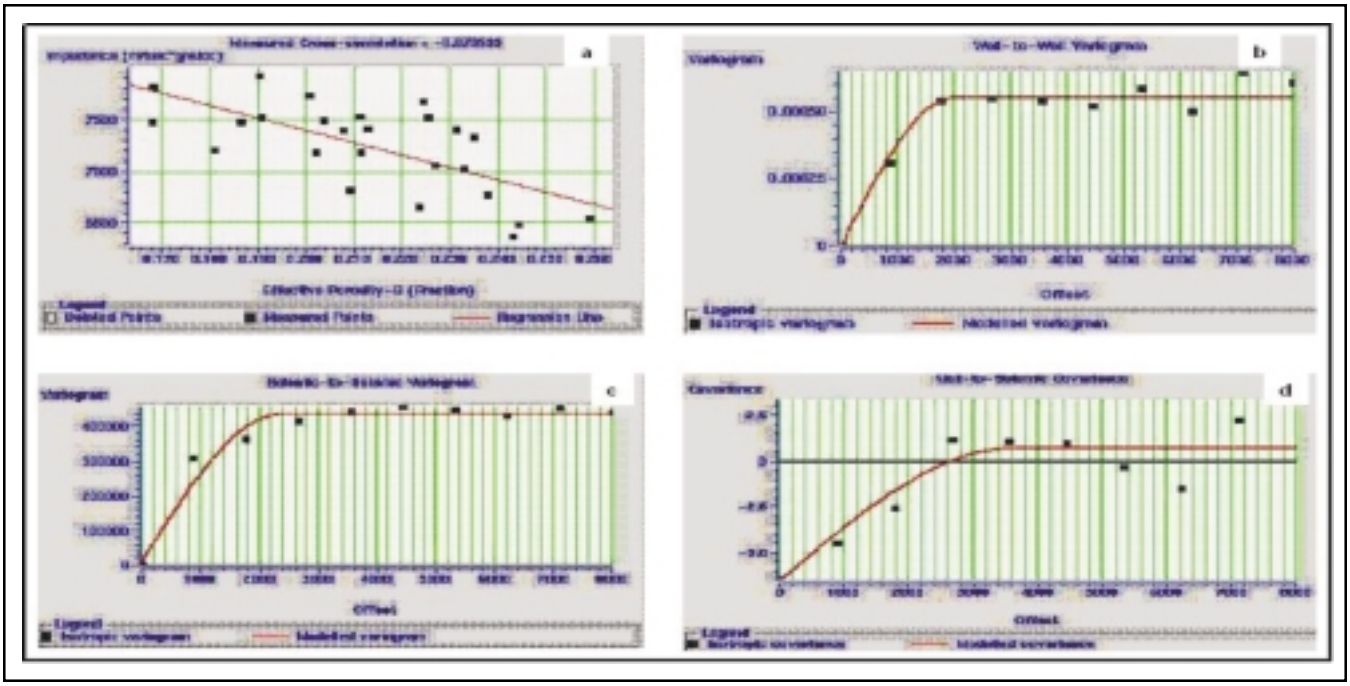

Figure 8: (a) Cross correlation between well porosity and acoustic impedance, (b) Variogram of porosity from wells, (c) Variogram of acoustic impedance, (d) Covariance of porosity and acoustic impedance

final porosity map (Fig. 9). Comparison of Fig.9 & Fig.10 indicates less uncertainty in co-kriged porosity distribution than porosity distribution from well data only.

RESULTS & CONCLUSION

Layer-wise analysis of the impedance maps qualitatively & quantitatively, integrating with petrophysical data, production data in conjunction with seismic facies and structural interpretation was used in firming up the locations and to recommend shifting of a few locations. The interpreted vertical and lateral extent of the gas cap limit and correlation of layer-wise fluid content of existing wells with acoustic impedance values were used to recommend layer wise completion strategy in infill wells. The boundary of the permeability barrier could be established with accuracy, on the basis of which a few locations were shifted northward. Subsequent drilling of a well with shifted location has validated the results.

Though the seismic inversion results are composite response of lithology, porosity, fluid saturation, pressure and temperature of the reservoir rock, leading to non uniqueness in nature; its study integrating with different attributes and well data and using geostatistical techniques can bring out qualitative and quantitative petrophysical heterogeneities within complex carbonate reservoirs. Geostatistics can be used

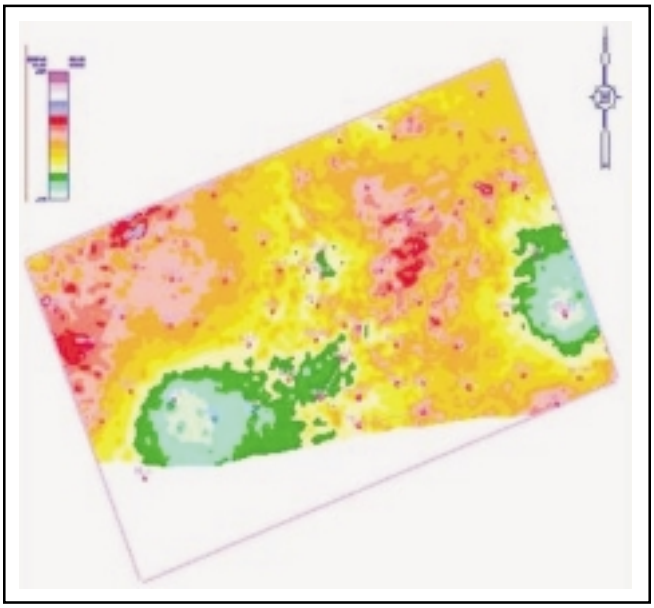

Figure 9: Porosity distribution after integration of acoustic impedance with well porosity using collocated co-kriging.

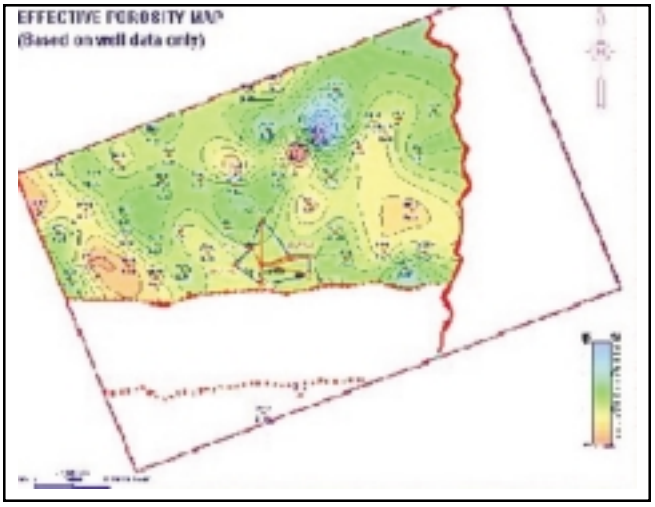

Figure 10: Effective porosity distribution map using well data

as an effective tool to integrate acoustic impedance as soft data to constrain reservoir properties. In case of large field with spacial variations in lithology, facies setting, petrophysical properties and fluid distribution, inversion analysis should be restricted to small sectors rather than full field scale.

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REFERENCES

Lavergne M., 1975, Pseudo diagraphies de vitessen offshore profound, Geophys. Prosp., V-23, 695-714.

Lindseth R. O., Synthetic sonic logs- a process for stratigraphic interpretation, Geophys., V-44, 3-26.