5th Conference & Exposition on Petroleum Geophysics, Hyderabad-2004, India PP 678-684

Seismic Guided Reservoir Characterization: Its Pitfalls and Moveouts

A.K.Nagar[1], A.K.Manchanda[1], Mahesh Chandra[1], R.Mahadevan[2] & Pramod Kumar[3]

[1]*GEOPIC, ONGC, Dehradun*

[2]*NELP Group, ONGC, Chennai*

[3]*Well Log Interpretation Devision, ONGC, Baroda*

ABSTRACT : Anisotropy is an inherent property of all the reservoirs. Reservoir characterization is essentially the modeling of this anisotropism in space and time. A robust modeling of reservoir anisotropism is essential, as anisotropism plays a crucial role in reservoir dynamics. A comprehensive reservoir characterization is a resultant of structured integration of seismics, log and core data. Nevertheless, the integration of these inputs poses a severe scale problem, as they exist at entirely different scales. Some reservoirs, particularly the ones having dual porosity system, may have patches of super-voids, where hard data cannot be acquired; but these patches of petrological chaos can be picked up and modeled by seismics. The propagation of rock properties becomes deviable in many cases, either because of poor spread of observation points or due to 'not so proper' selection and sequencing of techniques used. The present paper addresses all the pitfalls, observed in seismic guided reservoir characterization and designing of moveouts from them. The process of designing moveouts is presented in the form of a case study of a complex, carbonate reservoir. The complexity encountered is due to failure of conventional Chillinger's model, highly localized positions of observation points and the development of very conspicuous karst topography. The study illustrates identification of problems, their genesis and designing of a case specific, suitable and structured process of reservoir characterization by using a sequence of very simple techniques.

INTRODUCTION

Reservoir characterization is fragmenting the reservoir into intrinsically homogeneous 'cells', which collectively may form highly heterogeneous cluster/clusters. Heterogeneity of the reservoir rocks is inducted at a very early part of rock genesis. The onset of heterogeneity at micro scale starts from distortion of atomic space lattice of the rock constituting mineral/ minerals. On larger scale, it is manifested by the arrangements of the minerals in space and time, forming the rock texture. These heterogeneities play a crucial role in reservoir dynamics[12].

Without proper understanding of the extent and amount of heterogeneity of the reservoir, it is not possible to prepare a robust model of it. Thus for multiple purposes like preparing a development plan of the reservoir, implementation of EOR/IOR and even for a small workover job, e.g. perforation/well completion, there is no bypass or substitute of reservoir characterization.

State of the art technology in reservoir characterization seamlessly interlaces almost all disciplines of science, which can be applied on earth. This approach treats high density but low-resolution 3D/4D seismic data as soft data and other low density; but high-resolution geodata (e.g. core, log, fluid and well data) as hard data. The most of the top end seismic guided reservoir characterization software are backed up by advanced mathematics, like genetic algorithms, artificial intelligence and neural networks[9] etc. Logically this approach should yield very robust earth image; but many times, during model validation by using reservoir engineering and numerical reservoir simulation techniques, results are flabbergasting. These unexpected fiascos are outcome of certain pitfalls, some of them are due to inherent chaos of natural system and others are due to 'not so proper' selection and sequencing of techniques.

The pitfalls observed in using seismic guided reservoir characterization techniques can be broadly assigned to following problems:

- *The scale problem.*
- *The extension of the variability of rock properties in space.*
- *Candidature of technique/techniques to be used in relational statistics vs. reservoir architecture.*
- *Chaotic conditions imposed by telogenetic/ paragenetic changes in rock-fluid system.*

Since the very nature and origin of these pitfalls are quite complex and diverse, the search for their solutions demands revisiting the basics, fragmenting the problems into their basic ingredients, solving them individually and again composing the results together in suitable and structured sequence. The details of these problems and possible solutions, followed by a complex case study with sequence of simple solutions are presented in the proceeding paragraphs.

CONCEPT

In spite of rigorous research in last few decades; the wave response of earth is still not clearly understood. The relation of one particular seismic attribute with a particular reservoir property, observed in one reservoir may not be applicable for other reservoir, even qualitatively. This has forced us to remain largely in the domain of case specific solutions. Adoption of a synergic approach using the strengths of other relevant disciplines in a structured style can make a significant difference. This approach, taxonomically defined as Comprehensive Reservoir Characterization, needs precise identification and cause of origin of the problems related with reservoir imaging and strength/weakness analysis of possible moveouts. The present work is a conglomerated attempt for the same.

The scale problem

In comprehensive reservoir characterization, inputs are core, log and seismic data, representing the micro, meso and megascopic scales respectively. The translation from microscopic to mesoscopic and mesoscopic to megascopic scales is possible with some loss of fidelity and resolution of information at each step. However, it is not possible to translate microscopic data straight to megascopic scale without large errors[6].

The problem of extending the rock properties in space

In currently used techniques of seismic guided reservoir characterization[6,9,15], heterogeneity in space and time is often modeled by variography, i.e. x-plot of half of variance of data (γ) vs. the distance from observation points (lag). As a starter, variograms (fig. 1) of hard and soft data are prepared. For combining the variograms of both the types of data, a co-variogram (fig. 2) is prepared.

Either in variogram or in co-variogram, variability of the system can be modeled within a certain distance, from points of observation (range), exceeding which the variogram stops showing change in variance with increasing distance, i.e. the value of γ becomes static (sill). In other words, the variography based seismo-statistical simulation is valid within the extrapolation radii equal to value of *range* only.

Candidature of technique/techniques to be used in relational statistics vs. reservoir architecture

Recent developments in seismic technology have been effusive. They have shifted seismic analysis from time domain to depth domain, altering seismic into a better companion of hard data, which belong to depth domain.

Most of commercial software available for seismic guided reservoir characterization claim 'total solution' i.e. seismics to numerical simulation. There are easy provisions of extracting numerous seismic attributes. As the wave response of earth also contains the signatures of the rock-fluid system of the reservoir, the heterogeneity of reservoir properties can be deciphered by studying these attributes.

The conventional approach of relating seismic attributes to petrophysical properties is multiple regression. In this approach one rock property is defined as function of multiple seismic attributes with their individual weights. In almost all seismic interpretation software, two types of multiple regression methods are provided i.e. linear and non-linear regressions. However, in many cases this approach does not work. If a set of seismic attributes is grossly non-linear and one or more than one seismic attributes are having

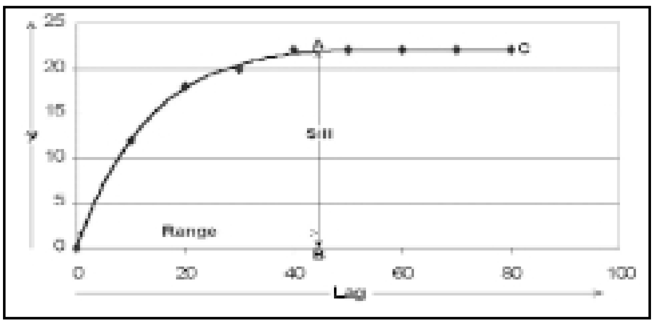

Figure 1: A Typical Variogram

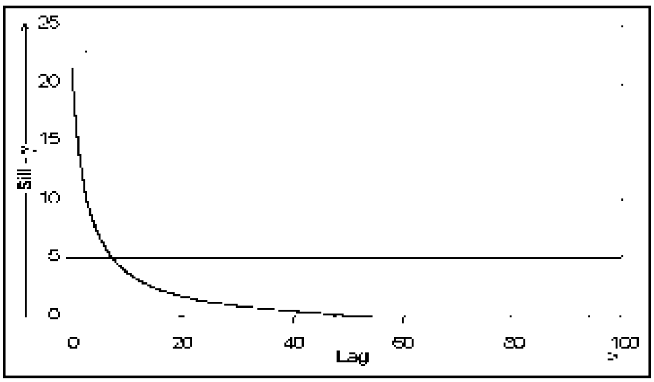

Figure 2 : A Typical Co-Variogram

linear relationships with the rock property under consideration, during the application of non-linear equation, linear attributes will introduce noise in the resultant relational equation. This phenomenon is more profound when a set of linear attributes contains one or more than one non-linear attributes and the set is subjected to multiple linear regression.

This problem of suitable handling of typology of attributes can be solved in three ways. One choice is adopting bivariate relational statistics with ranking, using x as one seismic attribute and y as the rock property. The ranking of these multiple relations can guide in picking the most significant and theoretically explainable relation of a particular seismic attribute and the rock property under consideration[5]. Bivariate statistics also provides information of typology of the system, so as a second choice, we can also prepare sets of pure and significant linear and/or non-linear attributes for suitable type of multiple regression. The third choice is to go for, relatively new, non-parametric multiple regression equation, which has got the ability to handle a mixture of linear and non-linear parameters.

Further, regression techniques can only be applied to continuous type of systems and cannot handle random or stochastic systems[13]. Thus, in terms of reservoir architecture, regression can only be applied to layer cake type of reservoirs[14] and is not suitable for brickwork or labyrinth types. On the other hand, if an equation, meant for stochastic system[3,10,11,15], is applied on continuous system, it diminishes the actual smoothness/continuity to some extent.

Almost all algorithms used[7] in the process of reservoir characterization are iterative in nature and the process of reservoir characterization itself is multi-step. Thus the whole process requires a careful sequencing of operations and removal of error at every step. This prevents the cumulative error from growing beyond the limits of maximum removable error allowed ($\pm$ Standard Deviation).

In general, the most of the ‘user friendly’ seismic interpretation software do not provide the crucial and complete information regarding typology of the attribute-rock property relation, amount of error and standard deviation in step-wise manner. Testing of multiple realizations is done by elimination techniques. As the next step, the resultant matrix is handed over to A.I. (artificial intelligence) or N.N. (neural network) module[9]. At this stage also, in most of the cases, it is not possible to determine whether the software is under-trained or over-trained (the most common condition). Viewing these limitations, it is surprising to find almost 100% match between actual and simulated property! In such conditions, it is difficult to know whether an extremely good and error free simulation is achieved or it is a case of ‘forced fitting’. In such conditions, the solution is to put these realizations under sensitivity analysis in the middle stage of numerical reservoir simulation and trim down the most suitable. Of course it will mean a bit too late and a big ‘U turn’ in the course of study.

Chaotic conditions imposed by teleogenetic/ paragenetic changes in rock-fluid system

Many a times, from the end part of rock genesis till present, the reservoir rock undergoes severe alterations in patches. It is more pronounced in carbonate reservoirs having dual porosity system. In such reservoirs, the secondary porosity may be in form of patches of vugs, cavities and even caves (karst topography). It is this conspicuous absence of reservoir rock, which has huge storage capacity and permeability. Thus, hard data of these patches cannot be obtained. However, such patches of super-voids are often picked up in 3D seismic volume. Imperatively, due to the presence of these super-voids, any modeling process evolving through core and log analyses will show patches of anomalies, when applied on 3D seismic attribute cube. These anomalous patches may be representing zones of high voidage. It can be easily confirmed by ERD (Enhanced Reservoir Description) technique[1,2], performance analysis or numerical simulation. It is implicit that in the course of reservoir characterization, conditioning of simulated images should not be applied on seismic guided image as the final step. The final step must contain unconditional and conditioned rock property visualizations. Subtraction of these two visualizations (residual) will give zones of anomalies, that is what is desired, though mathematically it is error (chaos or random noise) map[13]. In this way, it is a unique use of 3D seismics to extract a reservoir property, which cannot be sensed even by micro and mesoscopic techniques.

CASE STUDY

As an illustrative explanation of the concept, one offshore, layer-cake, carbonate reservoir from west of Mumbai (Maharashtra, India) has been selected. 3D seismic survey, covering the reservoir is available. The seismic indicates presence of well-developed karst structures in reservoir zone. It also shows that at many places the roof portions of solution caves are collapsed. The extent of the reservoir is huge; but the wells are clustered in highly confined localized patches (fig. 5). Sufficient core data is available; but due to dual porosity system and prominent lateral variation of reservoir properties, conventional core lab derived K-ϕ based Chillinger's model[4] cannot be used for modeling of permeability. The reservoir is operating under active bottom water drive. The reservoir is posing almost all the problems described for seismic guided reservoir characterization and is a suitable candidate for illustration of designing moveouts of the problems.

Petrophysical Studies

The conventional core lab derived K-ϕ based Chillinger's model exhibited a widely scattered cloud, making it unfit for modeling of permeability. Build-up permeability values also showed a large variation. Visualizing these problems, Enhanced Reservoir Description (ERD) technique of Amaefule[1,2] was adopted with some modifications required to address the present sets of problems. The concept of ERD carries that micro-properties, like porosity, permeability, capillarism, wettability, Sw_{irr} and indirectly the Cation Exchange Capacity (CEC) and V_{shale} are mere manifestations of a coarser rock property, the rock fabric (geometric parameters of pore cavities, pore necks, inter-pore channels & rock texture). There is no theoretical support for relating porosity with permeability, as practiced in Chillinger's model. However, both are related with the rock fabric, which is represented by a single term FZI (Flow Zone Index).

Flow unit modeling

In ERD technique, FZI is determined on the basis of depth matched core data. Flow Unit Model of the reservoir (fig. 3) revealed a gradational change in the petrophysical properties. This observation is also supported by log responses

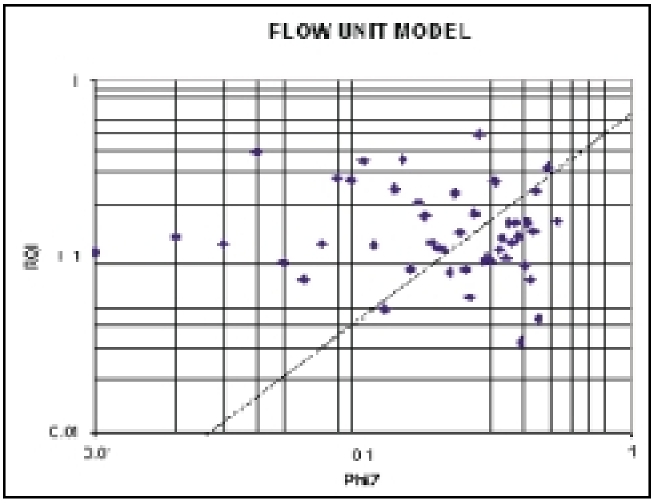

Figure 3: Flow Unit Model

of the wells. The Flow Unit Model also illustrates that the reservoir is composed of one main flow unit with Flow Zone Index of about 0.7. There is dimensional variation rather than the component variation in pore fabric, which results into virtual heterogeneity of FZI as depicted by the performance of the producers of this reservoir.

Upscaling

After the preparation of Flow Unit Model, relational bivariate statistics was solved between FZI_{core} and all the above scribed finer rock properties. Amaefule's approach recommends that FZI_{core} should be linked with all available wireline parameters against the cored section. The coefficients thus obtained, should be used to determine FZI (FZI_{log}) at all logged but uncored sections of the wells of the field. In the present case, for the illustration of easiest possible solution, bivariate relational statistics, coupled with rank correlation was used. The values of GR, SP, different resistivity logs, bulk density, ϕn and Δt logs were correlated with FZI_{core}. After rank correlation of these bivariate analyses, linear regression equation between ϕn and FZI_{core} was selected for splicing core data (FZI_{core}) on logs (fig. 4).

In this way, core analysis of micro-scale is spliced on logs (meso-scale). Once FZI_{log} is determined at all well positions, it was upscaled to flow unit level.

Since the flow unit model and the wireline characteristics have suggested that the changes in petrophysical properties are gradual in vertical direction and the reservoir consists of a single flow unit, downscaling of seismic has not been attempted. The core data was upscaled to log level first and then it was upscaled to seismic level, with a series of unconditional simulation of the data, which has been conditioned with observed values as and when warranted.

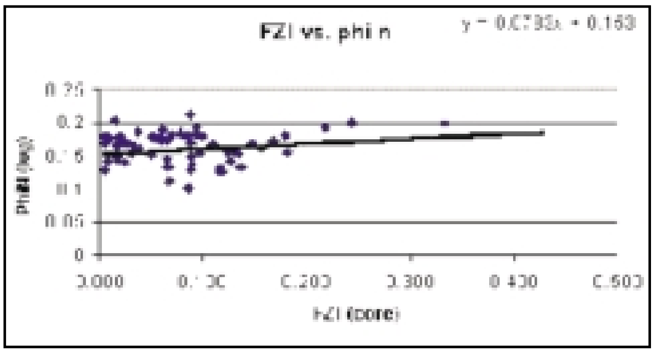

Figure 4 : Relating core driven FZI with the log.

The variability of rock properties in space

Conventionally, this set of upscaled FZI should then be extended away from the well positions by using suitable geostatistical technique. As the wells in the field are clustered into confined patches in the vast field area (fig. 5), orthodox geostatistical property distribution techniques, e.g. use of variography, was found unsuitable. In present case, inter-platform distance was much beyond the *range* of horizontal variogram.

3D seismic volume inherently contains high density and wide coverage, with heterogeneity of the reservoir obscured in it[8]. This makes seismic field a very powerful medium for data propagation, as well as for extracting the ‘petrological chaos’ (high permeability zones), which could not be picked up by cores and logs. With this perspective, anisotropy of seismic volume itself was used as propagation medium and a much suitable replacement of variography. This was accomplished by correlating FZI_{log}, conditioned and upscaled to seismic scale ($FZI_{seismic}$), with various seismic attributes (average absolute amplitude, frequency and acoustic impedance). The attributes were extracted from the window covering pay zone of the reservoir. The same window was also used for upscaling FZI_{log} to $FZI_{seismic}$. After ranking, the relational equation between average absolute amplitude and $FZI_{seismic}$ (fig. 6) was found to be the most suitable for converting this attribute volume into FZI map (fig. 7). This map represents the process of translation of microscopic scale

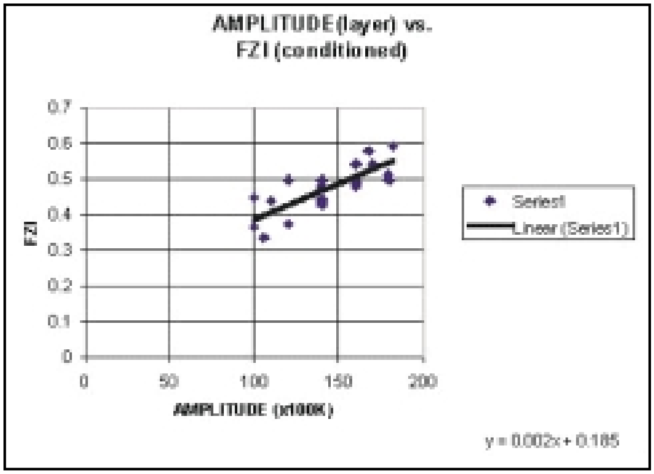

Figure 6 : Relating conditioned $FZI_{seismic}$ with amplitude.

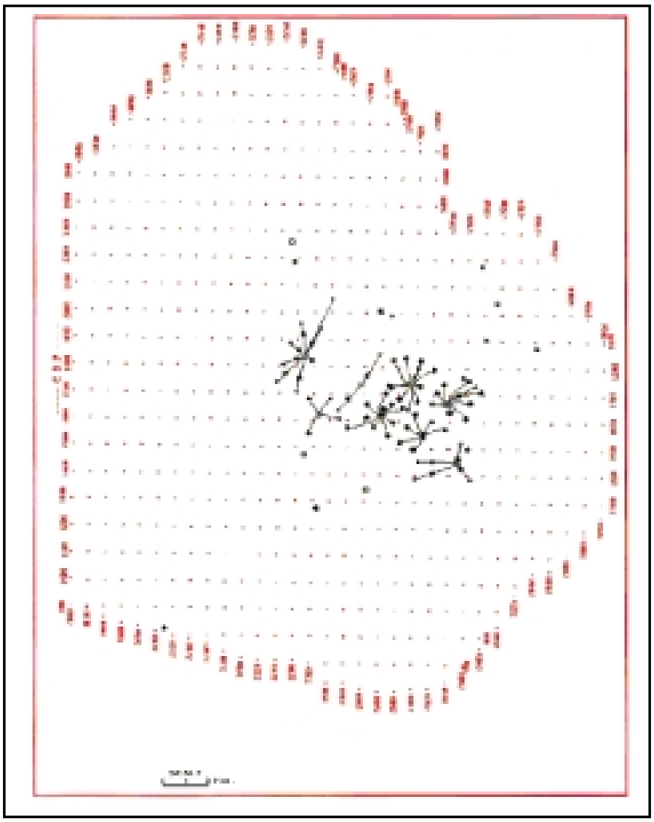

Figure 5 : Well Location Map of The Study Area

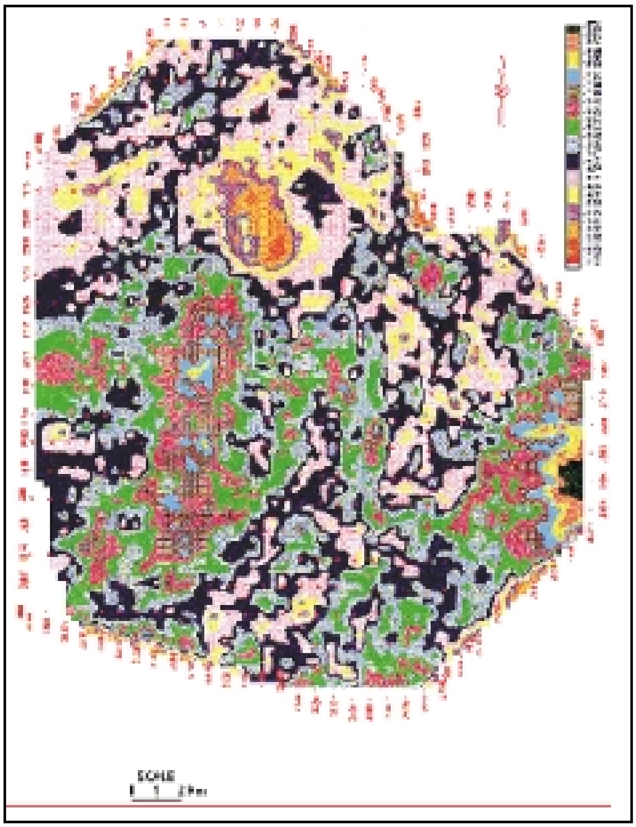

Figure 7 : Conditioned FZI Map

core data to megascopic seismic scale through mesoscopic scale of logs.

At this stage, once the volume of the rock fabric is generated, all the finer rock properties like porosity, permeability, Sw_{irr}, capillary pressure behaviour, etc., can easily be generated. As an illustration of some of the outputs of the case study, conditioned porosity map and permeability template are presented as fig. 8 and fig. 9 respectively.

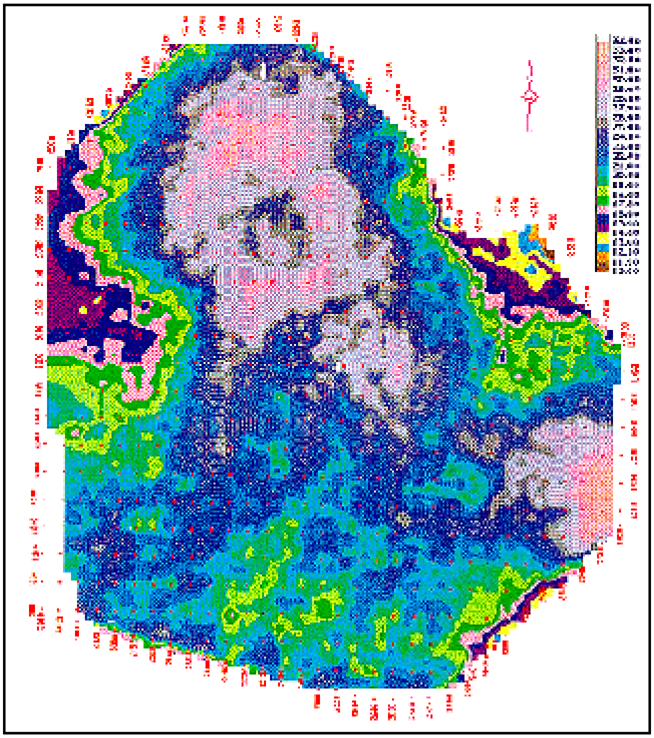

Figure 8 : Conditioned Porosity Map.

CONCLUSION

- All reservoirs are inherently anisotropic in nature.
- Every reservoir performs as an individual entity and the process design for reservoir characterization has to be case specific.
- Seismic guided reservoir characterization has certain pitfalls.
- Input data for reservoir characterization is at different scales. A well-defined and sequential upscaling is essential for translation of data from micro to meso and to megascopic scales.
- Selection of data propagation technique should be based on typology of reservoir and spread of observation points.

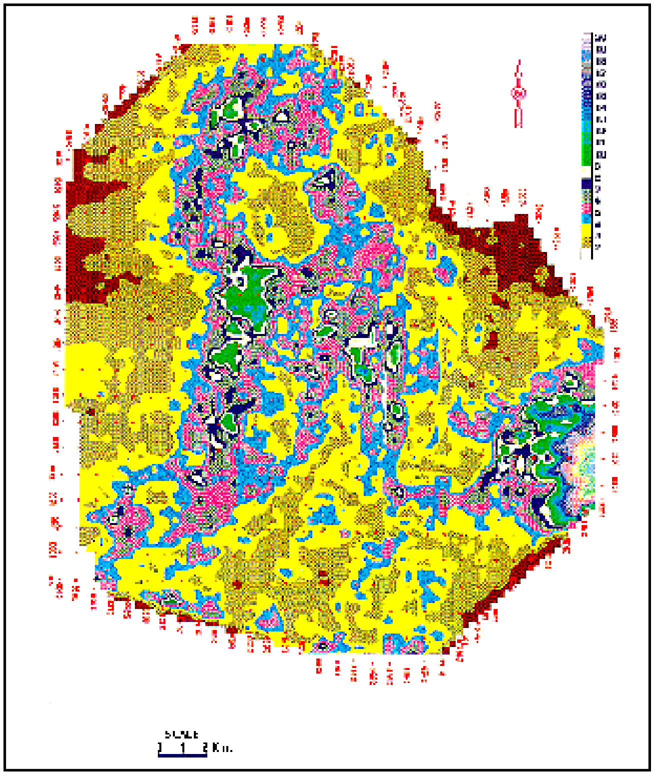

Figure 9 : Permeability Template.

- Anisotropy of seismic volume can be used for propagation of data as a brilliant substitute of variography.
- Petrological status and reservoir architecture of the reservoir are the most crucial controlling factors in the selection of technique and designing of the characterization process.
- Even complex cases can be efficiently addressed by fragmenting the problems into their basic ingredients. These can then be solved individually and recomposed in suitably structured sequences.
- 3D seismic volume inherently contains the information of gross heterogeneity of the reservoir, which is sometimes missing in hard data due to certain petrological chaos.
- Analysis of the strengths and limitations of seismic, core and log data indicates that their structured integration can lead to a robust and comprehensive reservoir characterization.

ACKNOWLEDGEMENT

The authors find an opportunity to thank GGM (GEOPIC) for providing the facility to carry out this work.

Seismic backup of very high value during the case study by Dr. R.J.Singh, the then SG(surface), ONGC; is gratefully acknowledged.Thanks are due to ONGC management for granting permission to publish this work.

REFERENCES:

Amaefule J.O., Altunbay M., Tiab D., Kersey D.G., Keelan D.K.(1993) "Enhanced Reservoir Description: Using Core and Log Data To Identify Hydraulic (Flow) Units and predict Permeability In uncored Intervals/Wells." *Presented in 68th Annual SPE Conference and Exhibition, Houston, Oct 3-6, SPE paper no. 26436*.

Amaefule J.O. (1995) " A Flow unit Approach On Integrated Reservoirs" *World Expro 1995*, pp 25-31.

Brattvold, Holden, L., R.B., Svanes, T. and Tyler, K.(1995) "STORM: Integrated 3D stochastic Reservoir Modeling Tool for Geologists and Reservoir Engineers", *Computer Applications*, June, pp58-67.

Chillingar G.V. (1964) "Relationship Between Porosity, permeability and Grain Size Distribution of Sands and Sandstones" in LMJU Van Straaten (ed.) - *Deltaic and Shallow marine Deposits*, Elsevier, Amsterdam.

Cynthia, T.K.(1997) "Potential Risks When Using Seismic Attributes as Predictors of Reservoir Properties", *Leading Edge*, March, pp247-251.

Deutsh,C.V., Srinivasan, S., Mo,Y.(1996) "Geostatistical Reservoir Modeling Accounting for Precision and Scale of Seismic Data" *SPE paper 36497*. presented at *Ann. Tech. Conf. And Exhib.* Denver, pp 9-16.

Deutsh,C.V., Journel, A.G.(1997) "GSLIB: Geostatistical Software Library and User's Guide", 2nd edn. Oxford Univ. Press, NY.

Doyen, P.M.(1988) "Porosity from Seismic Data: A Geostatistical Approach", *Geophysics, 53, 10, October,* , pp. 1263-1275.

Hampson, D.P., Schuelke, J.S., Quirein, J.A.(2001) "Use of Multiattribute Transforms to Predict Log Properties", *Geophysics*, *66*, 1, January-February, pp 220-236

Heldersen, H.H., Demsleth, R. (1990) "Stochastic Modeling", *JPT, 42*, (4), pp 404-412.

Hewett, T.A. and Behrens, R.A. (1988) "Conditional Simulation of Reservoir Heterogeneity With Fractals",*SPE paper no. 18326*, presented *63rd Ann. Tech. Conf. and Exhib. SPE*, Houston, TX,Oct., pp 645-660.

Hewett, T.A. (1986) "Fractal Distributions of Reservoir Heterogeneity and Their Influence on Fluid Transport", *SPE paper no. 15386*, presented at *61st Ann. Tech. Conf. and Exhib. Of SPE, New Orleans*, LA, Oct., pp 1-17.

Nagar, A.K., Srivastav, M., Josyulu, B.S., Chandra, M.(2002) "Design of Seismic Guided Lithological Discriminator in Multi-Lithological Setup", *Proceedings of 4th Conf. & Expo. On Petroleum Geoph., Mumbai, India*, pp 492-497.

Webber, K.J. and VanGenus, L.C.(1990) "Framework for Constructing Clastic Reservoir Simulation Models" *JPT*, pp1248 and 1296.

Zhu, H. and Journel, A.G.(1993) "Formatting and Integrating Soft Data: Stochastic Imaging via The Markov-Bayes Algorithm" Soarres (ed.), *Proceedings of 4th International Geostatistical Congress, Kluwer*, Dordrecht, pp 1-12.