Paper ID : **2004570**

Transcending Conventional Reservoir Characterization: A Geostatistical Approach in Understanding EP-IV and Chhatral Pay Horizons of Vadatal-Nadiad Area

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Abstract

In the Tarapur-Cambay tectonic block of Cambay basin, among the ten exploratory locations of Vadatal and three exploratory locations in Nadiad field drilled in recent years, three wells from Vadatal and one well from Nadiad flowed hydrocarbon in commercial quantity. Understanding the reservoir facie, its distribution and delineation of pools in case of such strati-structural plays with complex laminated subtle reservoirs, as met in this part of the basin-margin area, is a real challenge.

Reservoir characterization is a complex process to identify reservoir properties by establishing interdisciplinary relationships from pore to basin scale. It is critical to know the vertical and lateral distribution of the reservoir properties, which is a combination of depositional and diagenetic effects, within a reservoir rock in order to achieve the maximum efficiency in reservoir management for hydrocarbon production.

Facies modeling plays a significant role in understanding stratigraphic or strati-structural traps. For the study area two-staged Facies classification and analysis have been carried out. Electro-facies have been generated via Geostatistical Multivariate Cluster Analysis from the basic log inputs. Integrating with Core/Sidewall-core and Borehole Image data, converted the Electro-facies to Litho-facies in model wells and the classification had been propagated across the area. On the basis of Electro/Lithofacies distribution, key wells for Petrophysical reevaluation had been selected and the acquired log data had been processed with uniform Petrophysical model throughout the field.

In the next stage an independent Reservoir Facies model has been built with Inputs derived from dynamic Acoustic measurements, especially from Dipole Sonic Shear / Wave Sonic logs as well as from output results of Petrophysical evaluation via Clustering. Classification had been propagated to the key wells and studied the Reservoir Facies distribution vis-à-vis the production testing results.

Good correlation is seen between the signatures of Lithofacies and Reservoir facies against the potential reservoir as well as the non-reservoir sections. Moreover, Reservoir facies distribution had indicated the diminished effect of litho-variation on facies definition shifting the emphasis on hydrocarbon potential.

Up-scaling this integrated Reservoir facies model in association with Seismic facies may aid to inter-well property simulation and attribute propagation. The whole gamut of strategizing further exploration to field exploitation, from completion to production, may get a way forward from this novel facies definition and classification.

Introduction

Vadatal and Nadiad fields are situated in the Cambay–Tarapur block of the Cambay Basin and lie between Vatrak and Mahisagar rivers. In this tectonic block, the main hydrocarbon pays are EP-IV (Equivalent to Sertha member of Kalol formation) and Chhatral Eocene sands whereas sands within Olpad and fractured trap occasionally are hydrocarbon bearing. Total ten exploratory locations in the field Vadatal and three in the field Nadiad have so far been drilled in the study area which led to one discovery well in Nadiad (Chhatral & YCS pays) and three oil discoveries in Vadatal (EP-IV & Chhatral). After initial literature survey and data collection, Chaklasi field had also been included within the ambit of the study. Tectonic map of the Study area and the Location map of Vadatal field along with Nadiad and Chaklasi wells have been given in Fig.–1A&B.

Study Approach and Methodology

The present study aims to undertake comprehensive integration of available Log and Core data in the wells of Vadatal (VDTL) / Nadiad (NDAD) / Chaklasi (CKLS) area to understand the complex strati-structural entrapments for characterizing the EP-IV and Chhatral reservoirs across the field vis-à-vis production results.

Facies modeling is an important component of geostatistical reservoir characterization (1) (2). In case of complex and heterogeneous strati-structural traps it becomes far more crucial.

Two-tier Facies analysis has been carried out in the study area viz. Electro-facies/ Litho-facies and Reservoir facies along with the Petrophysical evaluations of key wells. The workflow diagrams have been shown in Fig. 2A&B for Lithofacies and Reservoir facies respectively.

Electro-facies classification: Electro-facies have been generated via Geo-statistical Multivariate Cluster Analysis from the basic log inputs (excluding resistivity measurements). Integrating with Core/Sidewall-core and Borehole Image data, converted the Electro-facies to Litho-facies in model wells and the classification had been propagated across the area. (3)

Petrophysical model building and log data evaluation: Taking into consideration the direct Geological evidences, sedimentology, bulk mineralogy as well as XRD studies of available cores and various log-derived cross-plots a uniform Petrophysical model had been built. Quartz, Kaolinite, Chlorite, Siderite, Silt (which also includes the composite heavy minerals), Coal and Carbonaceous Shale had been taken for multi-mineral probabilistic volumetric estimation. Minor occurrence of Kaolinite-Smectite association has also been incorporated for the shallower wells of Chaklasi/Nadiad (Chhatral) area along with the basic model.

Model validation: The model was finally validated by comparing model-derived effective porosity (processed result) with NMR 3ms porosity (i.e. NMR Total-NMR Clay bound porosity) and with Core-derived porosities at the total porosity level. Few sample processed outputs have been shown alongside the derived Litho-Facies columns (Fig. 3).

Reservoir facies classification: Besides electro-facies / litho-facies generation, a second tier of facies definition incorporating the Acoustic properties and Reservoir properties has been attempted. Reservoir facies classes had been grouped via unsupervised Clustering on representative wells of EP-IV & Chhatral sections. These Reservoir facies or property clusters; resulting from inputs like Acoustic Impedance (AI), VP/VS ratio, Poisson's ratio (PR), Effective porosity (PIGN) & Clay volume fraction (VCL); may in turn be integrated with Seismic facies in future for well-calibrated property simulation or attribute propagation.(4)(5)(6)(7)

Total 11 wells (VDTL-A, B, C, D, E & F; NDAD-X & Y and CKLS-U, V & W) had been taken into consideration for Reservoir facies generation. Representative wells that are hydrocarbon bearing /producing from EP-IV (i.e. VDTL-A, VDTL-D, CKLS-U & CKLS-W) and Chhatral pays (viz. VDTL-C, VDTL-D, CKLS-V & NDAD-X) had been selected for model building.

Statistical Cluster Analysis had been carried out with the above mentioned inputs and 2 sets of 5 Reservoir facies (independent of each other) for EP-IV and Chhatral formation was generated.

Good correlation is seen between the signatures of these two independent sets of facies against the potential reservoir as well as the non-reservoir sections.

Discussion of Results

EP-IV Reservoir facies: Better Reservoir facies are characterized by relatively low PR, VP/VS, AI, Vclay and comparatively high Effective Porosity (PIGN). Mean values for different facies cluster nodes for EP-IV are tabulated below. Facies 2 appears to have the best reservoir property (maxm. porosity & minm. clay

Cluster	#	Cluster	AI		PR		VPVS		PIGN		VCL	
#	Points	Spread	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
1	166	0.9975	7.7222	0.7814	0.29044	0.02183	1.8426	0.06443	0.14845	0.04168	0.34669	0.06106
2	176	0.7885	6.7003	0.5333	0.31999	0.014	1.9496	0.05813	0.20298	0.03096	0.30374	0.07947
3	102	1.193	7.4167	0.9115	0.32571	0.02555	1.9806	0.08874	0.05469	0.03975	0.65802	0.1086
4	203	1.069	6.9698	1.029	0.34724	0.01583	2.0753	0.08979	0.1245	0.0451	0.40787	0.07969
5	102	1.6	3.4958	0.944	0.39031	0.02132	2.3864	0.2109	0.00098	0.00532	0.17537	0.1819

Good Reservoir Facie (#2)

content) followed by reservoir Facies 1 (high AI caused by the Sideritic siltstone/Sst. presence). Facies 5 is mostly found to be corresponding with the coal (least AI and highest VP/VS as well as PR) whereas Facies 3 and 4 seem to cluster against shale/highly argillaceous and carbonaceous shaly layers respectively.

The EP-IV layer, tested and produced hydrocarbon in VDTL-A, VDTL-D, CKLS-U and CKLS-W, conspicuously show presence of Reservoir facies 2 (at times in association with Res. facie 1) against the producing layers of shaly sand/argillaceous siltstone. It indicates the diminished effect of litho-variation on facies definition shifting the emphasis on hydrocarbon potential.(Fig. 5B)

In cases of poorly developed EP-IV sections of other wells corresponding to silty shale, carbonaceous shales and coals, the rest three Reservoir facies i.e. facies 3, 4 & 5 are prevalent.

Facies associations across the area was then correlated and studied for understanding the strati-structural distribution pattern of prospective reservoir units (Fig. 4).

Chhatral Reservoir facies: Litho units of Chhatral consist of thin alternations of fine grained Siltstone and argillaceous Siltstone/Silty shale/Shale. Log responses in these thin bed reservoirs in most occasions fail to resolve the laminations.

Due to the thin laminated silty/shaly nature of the formation across the fields, individual properties many times appear overlapping but the aggregate facies clusters are still identifiable via statistical analysis.

Cluster	#	Cluster	AI		PR		VPVS		PIGN		VCL	
#	Points	Spread	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.
1	109	1.714	7.8446	0.8071	0.27197	0.05082	1.8026	0.08519	0.12175	0.04303	0.40749	0.05604
2	344	1.148	7.3427	0.4177	0.32081	0.01247	1.9503	0.05189	0.1155	0.0294	0.47415	0.0627
3	257	1.242	7.1975	0.532	0.32047	0.01215	1.9487	0.04824	0.14376	0.03724	0.33517	0.05832
4	193	0.8581	6.0863	0.36	0.34885	0.00838	2.0776	0.04537	0.18865	0.02678	0.43748	0.03815
5	217	0.8227	5.9278	0.2607	0.34849	0.00829	2.0756	0.0431	0.22669	0.02334	0.33905	0.04335

Good reservoir Facies

Reservoir facies 3, 4 and 5 appears to have the best Effective Porosity range with least Acoustic (P-wave) Impedance. Remaining are of poorer Reservoir grade.

The Reservoir facies model of Chhatral built on the producing wells' (i.e. VDTL-C, VDTL-D, CKLS-V & NDAD-X) reservoir properties, shows a clear gradation of reservoir quality from Reservoir facie 5 to Reservoir facie 1 (Fig.5A.).

Comparative facies plots in light of production results have also been studied for validation of results. (8)(9)

Conclusions:

- Good parity is seen between the two independent set of facies generated, i.e., Lithofacies and Reservoir facies, against the potential reservoir as well as the non-reservoir sections.
- Potential producing Reservoir facies have been identified using geo-statistical cluster analysis for Chhatral and EP-IV sections and validated with testing results. This will help in identifying the tentative prospective area in the complex basin margin fields.
- The distribution of Reservoir facies indicates the diminished effect of litho-variation on facies definition shifting the emphasis on hydrocarbon potential.
- Up-scaled Reservoir facies model may in turn be associated with Seismic facies for inter-well property simulation and attribute propagation to have a calibrated, quantitative representation of rock fluid properties across the area.

Acknowledgement

The authors thank ONGC management for providing facilities to carry out this study and permission to publish this work.

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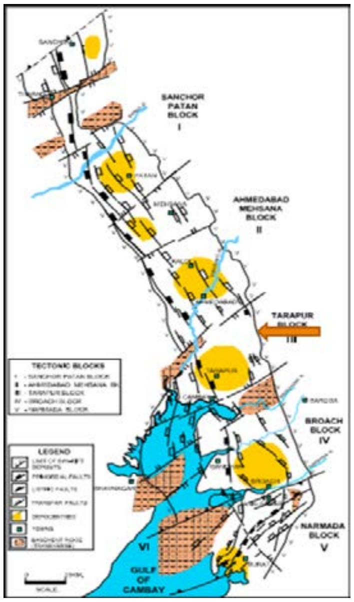
Figures

Fig. 1A & B (Study area & Locations)



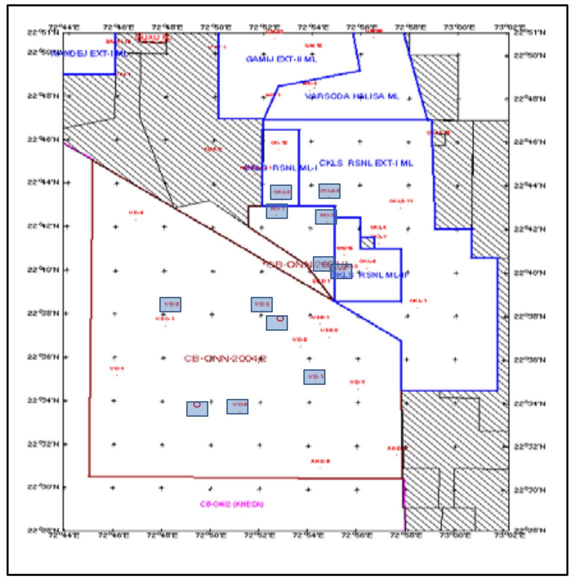
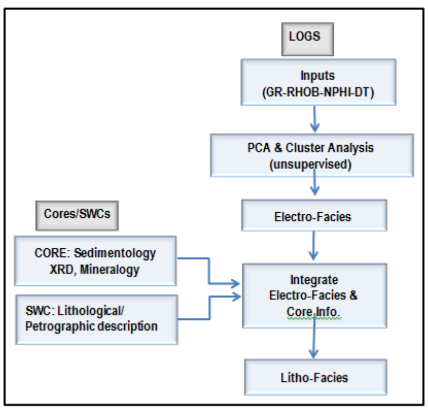


Fig. 2A & B (Flow diagram for Lithofacies & Reservoir Facies generation)



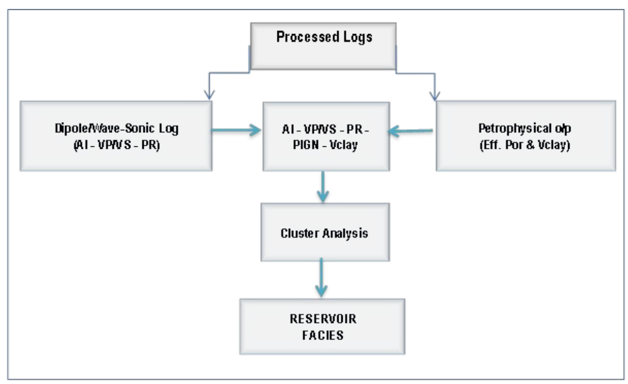


Fig 3. Example from Processed EP-IV & Chhatral sections (VDTL-C)
Along with Litho-facies distribution

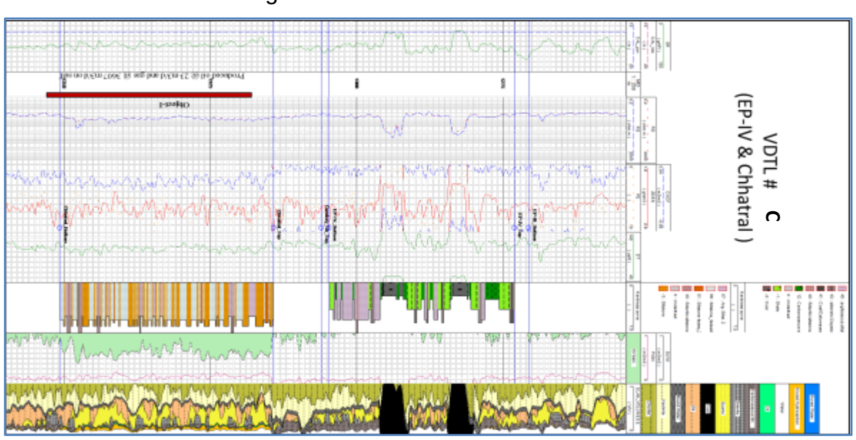


Fig. 4 Facies Correlation (EP-IV & Chhatral)

(Flattened at Kalol top; CKLS-U/NDAD-X/VDTL-C/VDTL-E & VDTL-D)

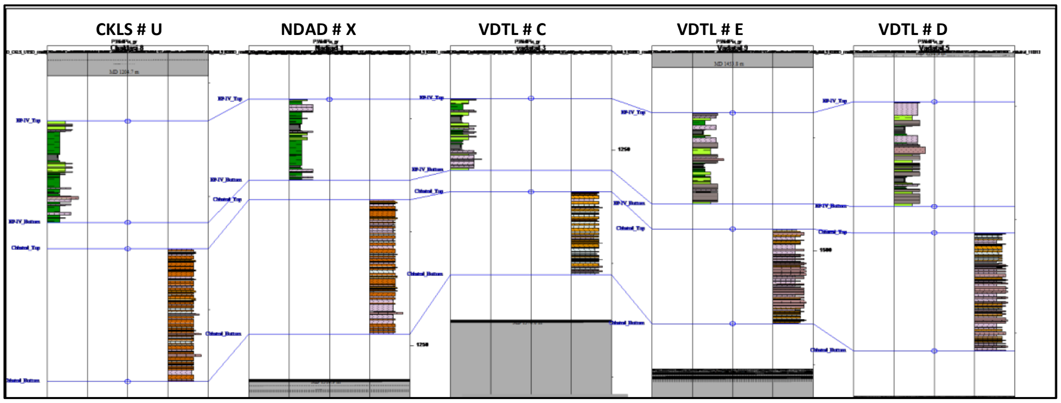


Fig. 5A Litho-facies & Reservoir-facies Comparison: Chhatral Pay

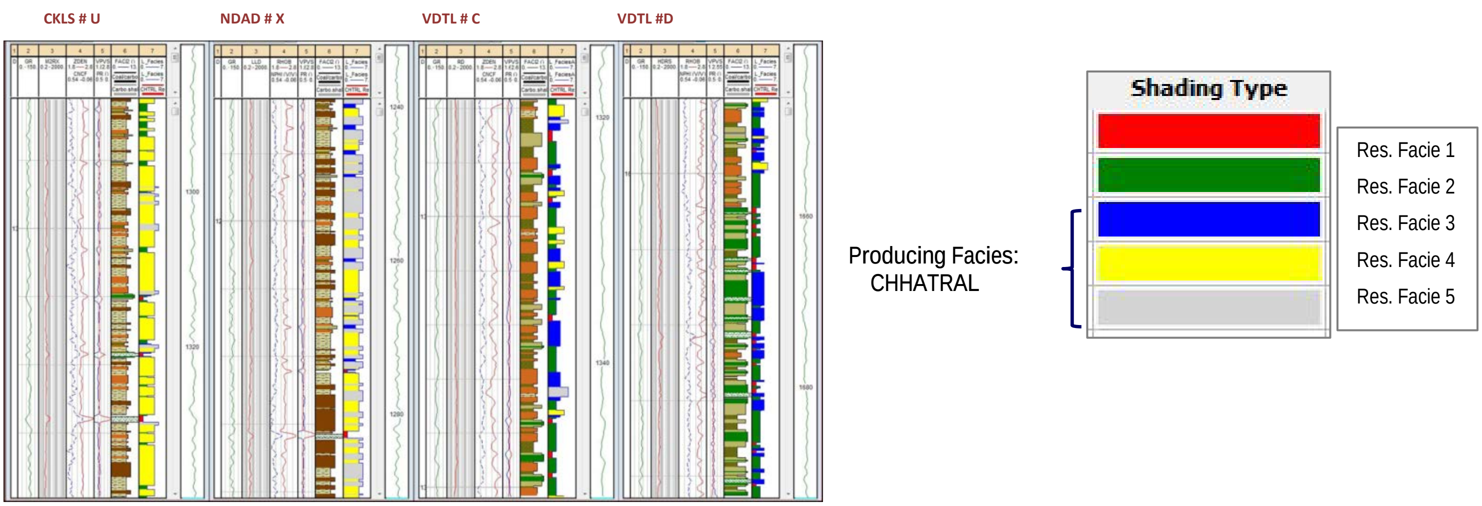


Fig. 5B: Litho-facies & Reservoir-facies Comparison: EP-IV Pay