Understanding of Daman Sands through Reservoir Characterization for Effective Exploration and Exploitation Strategy in Western Part of Tapti Daman Sector of Saurashtra Offshore

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Keywords

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Summary

Saurashtra Offshore is situated in the northern part of the western continental margin of India. It lies at the juncture of commercially proven Mumbai Offshore basin and emerging Kutch Offshore basin. Sands of Daman Formation are the principal contributor to the commercial production of Saurashtra Offshore.

An attempt has been made to explore the Daman sands of Saurashtra Offshore using various methods of reservoir characterization. These methods includes analysis of amplitude anomalies, petrophysical properties derived by pre & post-stack inversion and AVO studies using partial angle stack seismic data. These studies improved the understanding of hydrocarbon-bearing Daman sands and help to establish strati-structural and stratigraphic traps.

Reservoir characterization studies have resulted in hydrocarbon discoveries in exploratory and appraisal wells with an accretion of more than 30 BCM of gas. Also, the subsurface positions of development locations have been firmed up and FDP is being submitted.

Introduction

The Mumbai offshore basin, a passive margin basin on the continental shelf of western India continues into the on-land Cambay basin towards the northeast. On the north, it is bounded by the Saurashtra Peninsula and on the east by the Indian craton.

The Saurashtra offshore lies to the north of commercially proven Mumbai Offshore and south of highly prospective Kutch Basin. Saurashtra offshore covers an area of about 25,000sq.km.(Figure 1)

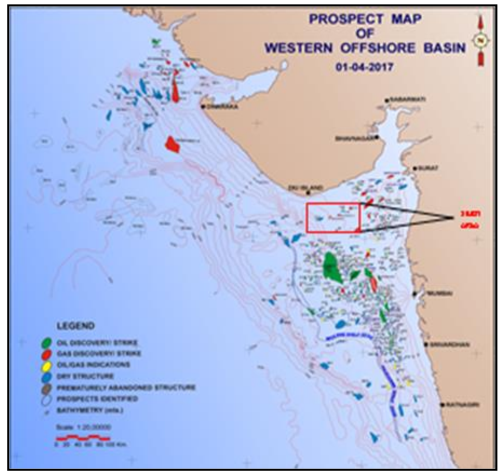

Figure 1: Prospect Map of Western Offshore Basin

The study area lies to the east of Diu Arch in the Saurashtra Offshore consisting of three parts: one NELP block i.e Area-1 and two PML blocks namely Area -2 and Area-3 (Figure 2).

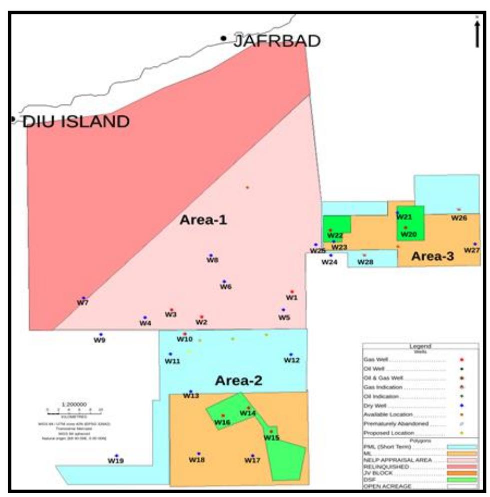

Figure 2: Location Map of Study Area

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Tectonic setting and Structural framework:

The study area lies on the continental shelf, situated on the rising flank of the Saurashtra homocline. Diu Arch is an NNW-SSE trending, basement high is present towards the northwest of the study area. The Diu depression and Daman Low lie to the south and southeast of the study area.

This area underwent rifting followed by passive margin sedimentation. The structural style is dominantly controlled by basement faults with inversion tectonics playing a major role in modifying the pre-existing structural style (Figure 3).

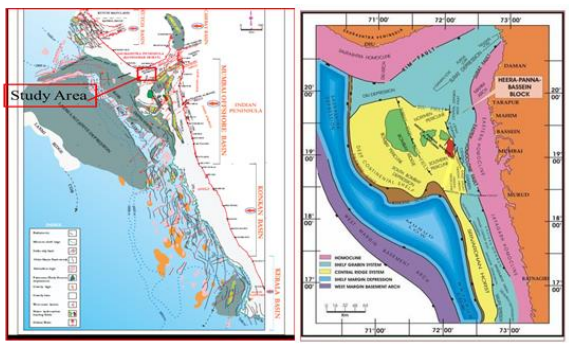

Figure 3: Structural elements of Saurashtra offshore Basin

Extensional stresses active during the rift phase created several horst-graben features along with the Dharwarian trend i.e., NNW-SSE trend. Diu arch, Dahanu structure, Saurashtra low, Surat depression, Daman low and Navasari lows have various inversion structures formed due to transpressional and transtensional forces of strike-slip movements.

Stratigraphy and Depositional Environment

So far only Cenozoic rocks have been drilled in Saurashtra Offshore. However, Mesozoic, as well as Cenozoic rocks, are observed in the Saurashtra peninsula. Upper Jurassic sedimentary sequence exposed in the northeastern part of the Saurashtra peninsula is overlain by multiple flows of Deccan Trap (Merh, 1995). The Cenozoic sequence consisting of Tertiary and Quaternary sediments overlies the Deccan Traps.
The Paleocene early and late rift sediments deposited over the technical basement are mainly fanglomerates, fluvial and lacustrine deposits. These are overlain by limestone and shale deposited during Late Paleocene - Early Eocene marine transgression. The Middle Eocene Diu and Belapur Formations are composed of clastics and carbonates respectively.

The Early Oligocene Mahuva Formation consists of siltstone and grey shales in the lower part which progressively change to shales and limestone alternations in the upper part of Mahuva Formation. Sediment supply drastically increased during Late Oligocene due to inversion tectonics and westerly tilt of the basin and this led to the deposition of Daman sands. These sands are deltaic, tidal channels and point bar deposits of regressive phase and they are the most prolific reservoirs in the area.
Neogene witnessed the deposition of Mahim, Tapti and Chinchini Formations. The stratigraphy of the basin is shown in Figure 4.

AGE		Seismic Horizon	FORMATION	LITHOLOGY
Recent				
Pliestocene				
Pliocene	Late		Chinchini	Dominantly Clay/ Claystone, though coarser clastics are expected towards the northwestern part.
	Early			
Miocene	Late	H_1A		
	Mid	H_1C	Tapti/ Bandra	Dominantly shale with Siltstone bands in to the northeast and Limestone bands developing to the southwest.
	Early	H_3CGG	Mahim	Shale with few Siltstone.
Oligocene	Late		Daman/ Alibag	Dominantly shale with sandstone beds with few thin coal layers towards the east and limestone beds towards the west.
	Early	H_3G	Mahuva	Dominantly shale with limestone beds.
Eocene	Late	H_3B		
	Mid		Diu	Shale, siltyshales.
			Belapur	Calcareous shales
	Early	H_4		
Paleocene	Late		Jafarabad/ Panna	Shale and limestone (wackestone) towards Diu arch and sandstone with lignitic coals towards Tapti-Daman area.
	Early	H_5		
Cretaceous	Late		Deccan Trap	Basalt, weathered basalts.

Figure 4: Stratigraphy of Saurashtra Offshore Basin

Analysis of integrated G &G data:

In the present study, all the available G&G data has been integrated. The seismic, well logs and laboratory data integration has yielded a well-constrained facies model for Daman pay sands namely Sand-1 and Sand-2. The structural mapping for various pays of the study area has been carried out in PSTM 3D volume. The depth conversion has been attempted using velocities of single seismic campaign constrained by well picks from 15 wells spread over the area.

Log correlation of 4 wells W20, W1, W2 and W9 along the dip direction was carried out. Clean shale corresponding to maximum flooding surfaces was correlated in all the 4 wells. The sandstones and limestones genetically related to each other were correlated with the sequence stratigraphic approach. Progradation of sands from North-East to South-West direction has been brought out. Water bearing sands and gas-bearing sands genetically related to each other has been identified (Figure 5). Between clean sandstones and clean shales, there is an abundant presence of shaly sandstones, silty sandstone, silty shales, and siltstone. The differentiation of these lithologies has been demonstrated in the logs. However, the impact of the lithological variations on seismic data has a great bearing on understanding their petrophysical relation in one dimension and lateral changes in two dimensions.

Time structure and isochronopach maps of Daman and Mahuva Formations gives evidence of basinal inversion with the shift of depocentre (Figure 6).
Spectral Decomposition (tuning cube analysis) of composite sand packs has been attempted to bring out the Daman pay sand depositional geometry & distribution pattern.

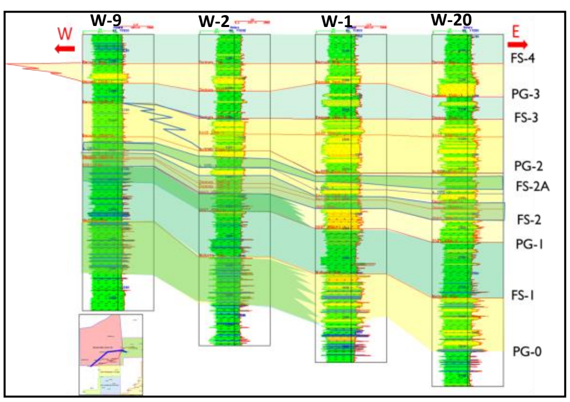

Figure 5: Log correlation along dip direction with sequence stratigraphic approach

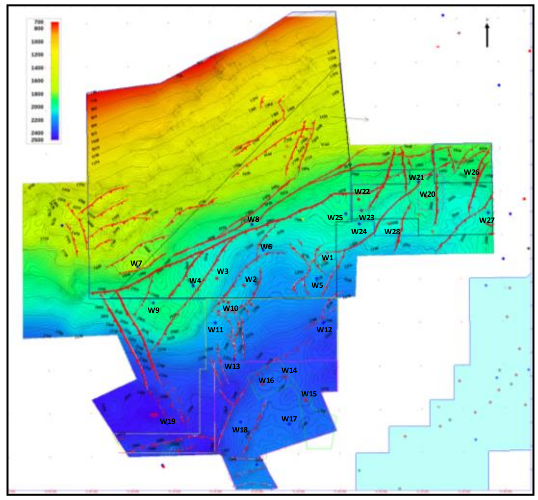

Figure 6: Time-Structure Map at Daman Top

Seismic data shows a high amplitude anomaly. The amplitude anomaly in the upper part of Daman Formation was explored in some of the wells. These anomalies proved to be hydrocarbon bearing thick channel sands (Figure 7)

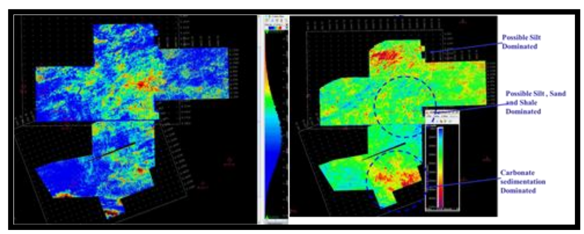

Figure 7: Seismic Amplitude Anomaly

Reservoir Charecterization

1. AVO Analysis

Based on angle stacks or PSTM/PSDM gathers, several AVO attributes were derieved from the seismic data. Some examples of the extracted attributes are intercept v/s gradient (Figure 8). Seismic amplitude anomaly in upper part of Daman Formation in an adjoing area also shows presence of similar channel sands.

Understanding of Daman Sands through Reservoir Characterization

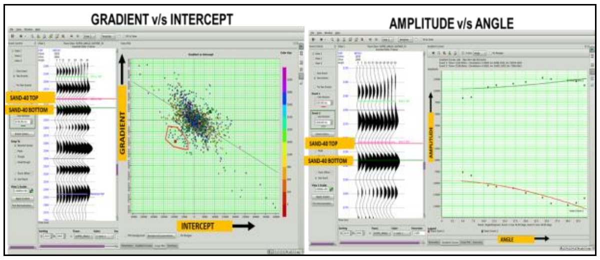

Figure 8: AVO Analysis

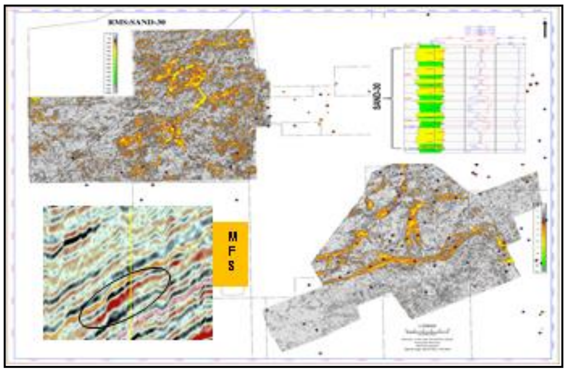

Figure 9: RMS amplitude of Sand-2

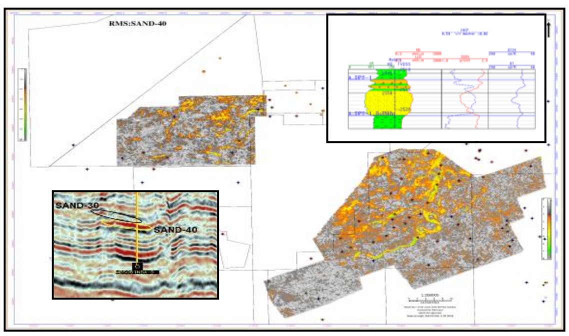

Figure 10: RMS amplitude of Sand-1

These channel sands were validated by AVO analysis. AVO analysis suggests that these anomalies are Class-III anomalies and indicate presence of hydrocarbon. (Figure 9 & 10)

2. Post Stack Inversion

Cross plots of GR and impedance against silty shale and shaly sand have high impedance value in gas-bearing well W2 (Figure 11). The relation of these silty shales to clean sands and clean shales generate different amplitude depending on the relative impedance.

The impedance of silty shales and shaly sands is high which make it difficult to differentiate between water-bearing sands and silty shales. This association of lithology however does not have an impact on seismic amplitude.

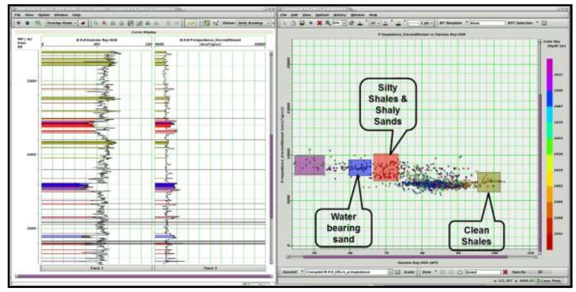

Figure 11: Impedance against Water bearing sands, Silty Shales & Shaly Sands of Lower Daman Section

Cross plots of GR and Impedance against gas bearing Sand-1 and Sand-2 in well W2 show a difference of 1000 units in their impedance values. Due to deeper burial processess, the Sand-1 is more compacted and as result of which the pore pressure is observed to be hydrostatic + 10%. The higher impedance values (7000-8000) for sand-1 corroborates Sclater and Christie decompaction algorithm which says the porosity decreases with depth as a result of normal compaction trend compared to observed lower impedance values (5900-6900) and hydrostatic pressure for shallower Sand-2 (Figure 12). The interesting fact is that the flow rates and FTHP of deeper Sand-1 are higher than that of shallower Sand-2 which is the manifestation of connected vertical burrows increasing the permeability as observed in petrographic analysis of cores from other wells.

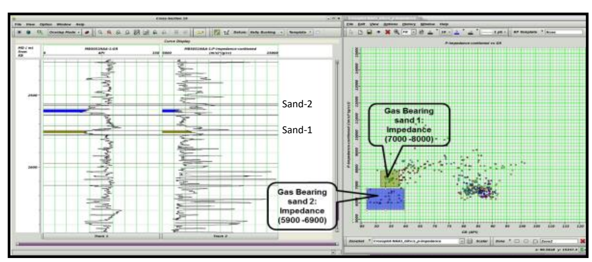

Figure 12: Impedance against two gas bearing sands in same well

3. Pre-Stack Inversion

Pre-stack seismic inversion incorporating Rock Physics Modeling (RPM) of seven wells was carried out to review the existing exploration model. Well to seismic correlation of angle dependent statistical wavelets with low frequency (Trend) model of P-impedance, S-impedance, density volume and interpreted horizons were the inputs for Pre-stack inversion. Result of inversion volume show reasonable match with actual well logs (filtered to seismic band) confirming the validity of the inversion outputs (Figure.13).

Inverted P-impedance horizon slice was extracted within -10 ms to +15 ms from Sand-1 horizon and based on the results the development locations were optimized.

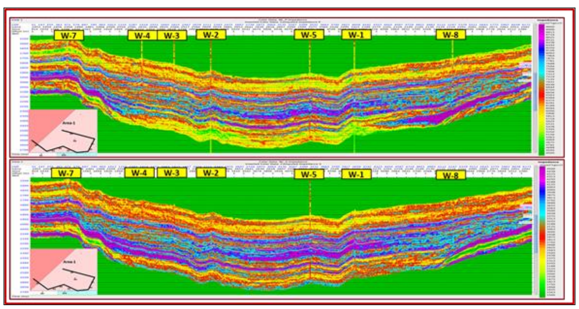

Figure 13: Inversion generated along RC line connecting all the seven wells with P-impedance and S-impedance logs

Based on the cross plot of P-impedance v/s Vp/Vs (colored with saturation), the most probable hydrocarbon polygon has been brought out for Daman Formation. The captured polygon clearly shows the pay zone related to Sand-1 and Sand-2 sands of the well W2 (Figure 14).

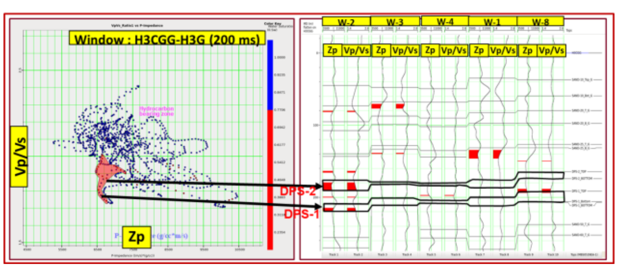

Figure 14: Crossplot of Modelled P-impedance vs Modelled Vp/Vs coloured with saturation logs shows the hydrocarbon bearing zone at Well W-2

One combined volume was generated by populating the captured points considering the optimal range of two parameters:- P-impedance and Vp/Vs. An RC line passing through all the wells from the combined volume clearly depicts the distinction in values at hydrocarbon and non-hydrocarbon bearing wells (Figure 15).

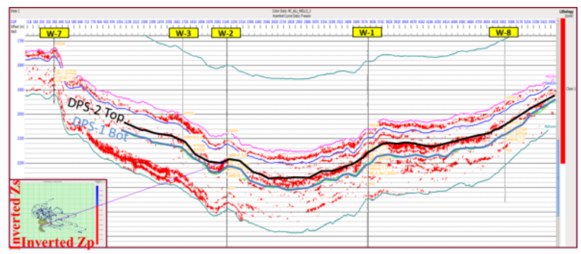

Figure15: Display highlighting the hydrocarbon polygon on Inverted P-impedance and Inverted Vp/Vs sections along the wells

Window-based slices corresponding to pay sands Sand-1 and Sand-2 are extracted with a normalized scale to indicate the extent of geo body around the well W2. Combining P-impedance and Vp/ Vs and using the proper color template (0-0.3 colored as green, representing the low probability of gas sands: 0.3-1.0 colored as yellow, representing high probable gas sands), the probable distribution of gas-bearing Sand-1 sand has been brought out (Figure16). This attribute depicts maximum gas-bearing sand development around the discovery well W2.

Similarly, combining P-impedance and Vp/ Vs using proper color template (0-0.7 colored as green representing low probability of gas sands: 0.7-1.0 colored as yellow representing high probable gas sands), the probable distribution of gas bearing Sand-2 sand has been brought out (Figure17). This attribute clearly brought out maximum gas bearing sand development around discovery well W2.

Based on P-Impedance and Vp/ Vs attribute for Sand-1and Sand-2 sands, de-risking and prioritization of ten development wells has been carried out

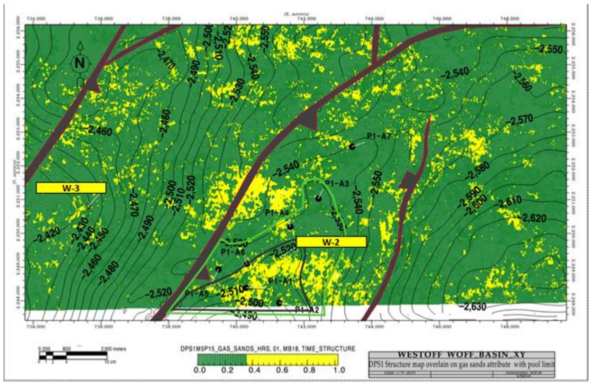

Figure 16 : Structure Map of Sand-1 superimposed on combined Zp and Vp/Vs attribute slice showing probable distribution of gas sands

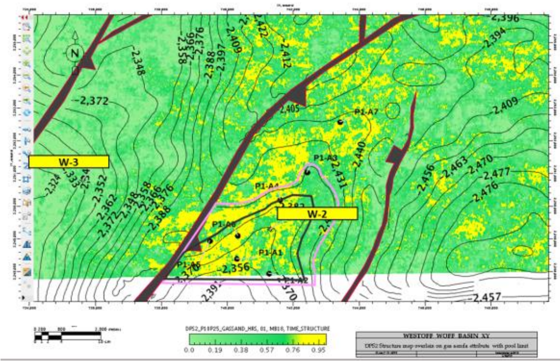

Figure.17: Structure Map of Sand-2 superimposed on combined Zp and Vp/Vs attribute slice showing probable distribution of gas sands.

Phase wise development (Geological Uncertainty):

As the northern culmination is at a larger distance from exploratory well, geological uncertainty is greater compared to southern culmination. So, It may require further appraisal/delineation through additional inputs. In view of minimizing geological risk and uncertainty in the absence of well data in the northern area of block, phase wise development for block has been envisaged to understand the extent, facies and productivity of the block. Therefore, remaining development of block is phased accordingly.

Conclusions

1) The Daman pay sands are deposited in a tidal channel complexes during regressive phase of sea level and shows significant thickness variation throughout the area. Log motifs of major pay sands are dominantly fining upward with some minor variations. Better and thicker sand bodies are gradually thinning out towards west and east.

2) Combined P-Impedance and Vp/Vs attribute for Sand-1and Sand-2 reveals good development of gas bearing sands at around W2 well. Development of good hydrocarbon facies is also observed towards the north of well W3 for Sand-1. This strati-structural prospect may be taken up in future explorations as upside potential.

3) Based on P-Impedance and Vp/ Vs attribute for Sand-1and Sand-2 sands, de-risking and prioritization of ten development wells has been carried out.

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